CHAPTER 9.

Oak Savanna Restoration in Central Iowa: Assessing Indicators of Forest Health for Ecological Monitoring

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INTRODUCTION

Savanna ecosystems were once a dominant feature of the Midwestern Corn Belt Plains ecoregion, occurring within the dynamic boundary between prairies to the west and forests to the east, and maintained in the landscape by complex interactions between fire, climate, topography, and human activities (Anderson 1998). Characterized by their continuous understory layer and widely scattered overstory trees, primarily oak species, Midwestern savannas are today extremely rare, largely converted to agricultural or transitioned to woodlands following changes to disturbance regime. Today, less than 1 percent of the original extent of savanna vegetation remains (Nuzzo 1986), mostly in a highly degraded state due to fire suppression, overgrazing, habitat fragmentation, and subsequent woody encroachment and invasion by non-savanna understory and overstory species (Anderson 1998, Gobster and others 2000).

The health of Midwestern oak savannas is of regional concern due to low rates of oak regeneration and increasing domination of the understory by shade tolerant species, both of which alter the quality, composition, structure, and ecological functions of these forested systems. Restoring native oak savanna ecosystems generally involves overstory thinning and reintroduction of fire (McCarty 1998). However, little is known about the impacts of such restoration activities on biotic and abiotic ecosystem attributes and on achieving restoration goals, and about the extent to which standard monitoring protocols, e.g., those established by the Forest Inventory and Analysis Program of the Forest Service, U.S. Department of Agriculture, are sensitive to these changes. Long-term monitoring and evaluation is necessary to better understand current forest conditions and the effects of restoration treatments to guide future management decisions.

Our research involved a replicated landscape scale experiment to restore oak savanna ecosystems at a site in central Iowa that had been encroached by shade tolerant species and transitioned into woodland vegetation. The restoration process included mechanical removal of encroaching vegetation and prescribed fire. The overall goal of our research was to complement monitoring of the health of oak savanna ecosystems by the Forest Health Montioring (FHM) Program of the Forest Service; the goal was to achieve our monitoring through the collection of process-level ecosystem indicators of restored and degraded savannas to identify sensitive indicators for long-term monitoring. The planned objectives of our project included:

- Objective 1: Assess the effects of savanna restoration on stand structure, growth, and productivity of remnant savanna oak trees.
- Objective 2: Determine patterns and success of oak seedling recruitment in response to restoration treatments.

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- Objective 3: Document the response of the understory herbaceous layer to restoration treatments, particularly in terms of species composition and diversity.
- Objective 4: Assess the effects of restoration treatments on biophysical variables (e.g., light, soil moisture, and soil properties).
- Objective 5: Establish FHM Detection Monitoring plots at the savanna restoration site for comparison with process-based data.

METHODS, RESULTS, AND DISCUSSION

Site Description and Study Design

The study was conducted on eight white oak (*Quercus alba*) savanna remnants near Saylorville Lake in Des Moines, IA, ranging in size from 1.5 to 3.3 ha. Following several decades of fire suppression, these sites were encroached by non-savanna tree species (e.g., *Fraxinus americana*, *Ulmus* sp., *Ostrya virginiana*), leading to canopy gap closure. Encroaching woody vegetation was removed by mechanical treatment in 2002–04 from four randomly selected remnants. One transect was established along the length of each study site (100–200 m) for sampling of vegetation (Asbjornsen and others 2005, Brudvig and Asbjornsen 2007, Karnitz and Asbjornsen 2006). Concurrently, four FIA phase 2 plots were established at each site. Phase 2 plots were arranged linearly, to coincide with sampling transects and to fit within savanna site boundaries. FIA-based data are detailed in objective 5.

Objective 1

Assess the effects of savanna restoration on stand structure and growth and productivity of remnant savanna oak trees.

Methods—Along each 100–200 m transect, we conducted annual vegetation surveys from 2002 to 2006. We recorded species and diameter at breast height (d.b.h.) for trees and species of all samplings and shrubs. Percent cover by understory vegetation, leaf litter, bare ground, and down woody material was also recorded (Brudvig and Asbjornsen 2007). In brief, along each transect we sampled trees in contiguous 10x10-m plots, saplings in contiguous 10x4-m plots, shrubs in 3-m^2 circular plots located every 10 m along the transects and understory data in 1x1-m plots located every 10 m along the transects. Full sampling details are described in Brudvig and Asbjornsen (2007). To assess the growth response of the remnant savanna trees, tree cores were extracted using an increment borer from large oak trees growing in restored and encroached sites in 2009. The cores were assessed for width and year, and results from the sites compared to assess change in annual mean increment growth and change in basal area across sites (Brudvig and others 2011). We used analyses of variance (ANOVA) to determine the impacts of the removal treatment on stand structure and overstory tree response. We ran a separate ANOVA for each response variable, e.g., tree density, sapling density, etc., using site-level means in our analysis and restoration treatment as the independent variable (n=4/treatment).

Results and discussion—The savanna restoration treatment resulted in the reestablishment of the savanna structure comprised of overstory oak trees at relatively low density, reducing canopy cover from 84 to 89 percent to 8 to 52 percent, while stem densities for smaller size classes (<40 cm) were also reduced. Nevertheless, the understory was dominated by advanced regeneration of shade tolerant tree species, suggesting that encroached savannas represent an alternative stable state. Thus, in addition to understory removal, management interventions including prescribed fire will likely be needed to establish the understory herbaceous layer (Brudvig and Asbjornsen 2007). The dendrochronology assessment of growth response revealed that basal area of overstory oak trees increased by 59 percent following removal of encroaching vegetation. These results suggest that encroaching trees compete directly with savanna trees for key resources thereby reducing growth rates, but that even after long periods of suppressed growth, these savanna oaks have the potential to respond to release from competition through accelerated growth (Brudvig and others 2011).

Conclusion—Removal of encroaching vegetation from degraded savanna ecosystems is an effective approach for restoring savanna overstory structure and promoting growth of mature savanna oak trees. However, restoration of the understory herbaceous structure and composition will require additional restoration interventions such as prescribed fire. Without such interventions, these savannas will likely transition back to the alternative stable woodland state consisting of intercanopy gaps filled with non-savanna woody vegetation.

Objective 2

Determine patterns and success of oak seedling recruitment in response to restoration treatments.

Methods—Along each transect, we annually surveyed from 2002 to 2006 all saplings within 4-m wide belts, all shrubs within 3-m^2 plots every 10 m along the transect, and all seedlings in 1-m^2 plots every 10 m along the transect (Brudvig and Asbjornsen 2007). In addition, 10 "canopy" and 10 "canopy-gap" plots were established within each of the 8 study sites, but outside the main 100–200-m sampling transects. All canopy and canopy-gap plots were annually surveyed from 2002 to 2006 for *Q. alba* seedlings in the year before and for 3 subsequent years after restoration, by recording height, basal diameter, and number of leaves, after the removal treatment (Brudvig and Asbjornsen 2008). Finally, we transplanted *Q. alba* seedlings every meter along transects radiating from overstory *Q. alba* trees toward inter-canopy gaps (5-6 seedlings/transect), as well as seedlings in inter-canopy gaps. For each seedling, we collected data on basal diameter, height, number of leaves, herbivory, and survival over a 2-year period (Brudvig and Asbjornsen 2009a).

Results and discussion—Following the removal treatment, seedlings of *Q. alba* exhibited a gradual increase in abundance over the 3-year post-treatment measurement periods. In contrast, seedlings of other species (e.g., *Ostrya virginiana, Fagus americana, Ulmus americana, Prunus serotina, U. rubra*) did not vary in abundance after 3 years. We also observed a recruitment pulse in shrub density 2 years and sapling density 3 years after removal of encroaching vegetation, primary attributed to vigorous stump sprouting. Thus, regeneration is dominated by encroaching species shortly after removal treatments, providing evidence for the existence of an alternative woodland stable state resulting from the savanna encroachment process (Brudvig and Asbjornsen 2007). However, *Q. alba* seedlings growing in canopy and canopy-gap locations exhibited clear differences, with canopy-gap seedlings displaying greater survival, as well as increases in height, basal diameter, and number of leaves relative to canopy (control) sites. These findings suggest that removal of woody encroachment can have positive impact on promoting regeneration of *Q. alba*, a critical component of ensuring the recruitment of young oaks into the canopy over longer time scales (Brudvig and Asbjornsen 2008). Growth and survival of transplanted seedlings increased with distance from overstory trees and were greatest in the gap areas of restored sites (Brudvig and Asbjornsen, 2009a).

Conclusion—Removal of encroaching vegetation from degraded savannas leads to rapid growth response in understory shade-tolerant (non-savanna species) shrubs and saplings, while at the same time creating gap environments that are more favorable to the establishment and growth of desirable *Q. alba* seedlings. Further work with prescribed fire and/or grazing may elucidate to what extent tree-herbaceous understory dynamics may be restored through restoration interventions in Midwestern oak savannas.

Objective 3

Document the response of the understory herbaceous layer to restoration treatments, particularly in terms of species composition and diversity.

Methods—We annually surveyed understory species composition and abundance in 1-m^2 plots located every 10 m along each transect from 2002 to 2006 (Brudvig 2010). With these data, we calculated species richness (number of species), Simpson's diversity, and species evenness using standard protocols (Magurran 2004) at the local (1x1m) and site (sum of 1x1-m plots/site) scales. We subsequently calculated beta richness and Simpson's diversity as the difference between site and local scale values (Brudvig 2010).

Results and discussion—Following the removal treatment, understory species richness and Simpson's diversity increased at local and site scales. Species evenness and beta diversity and richness (indicators of spatial turnover) were unaffected. These changes were due to increased richness and cover of graminoids and woody species following encroachment removal. Restoration promoted savanna indicator species, as well as non-savanna species, including exotic species, at local and site scales.

Conclusion—Restoration by woody encroachment removal resulted in establishment and proliferation of savanna and non-savanna understory species. Future work might investigate the long-term effects of reintroduction of characteristic savanna understory species (not colonizing naturally following restoration) and prescribed understory fire on richness and cover of woody, exotic, and other non-savanna understory species.

Objective 4

Assess the effects of restoration treatments on biophysical variables, e.g., light, soil moisture, soil properties.

Methods—At each site, we randomly selected five large, open-grown *Q. alba* trees, and established a randomly oriented transect radiating from the bole to 1.5 times the distance to the canopy edge. Along each transect, we established five to six 1x1-m "understory" plots. Similarly, 5-6 "gap" plots were established at three times the distance to the canopy edge. Between July 2004 and August 2006, we sampled the plots for vegetation, light (hemispherical photography), soil physical (texture) and chemical (pH, percent organic matter, concentrations of nitrate N, total P, and K) properties, and soil moisture.

Results and discussion—The restoration treatment of removing encroaching vegetation significantly altered biophysical gradients relative to the control sites. Restored sites exhibited a strong relationship between light and distance from overstory trees. Restored sites also had greater variability in soil moisture due to both higher levels immediately after rain and greater drying rates. With restoration, a positive relationship occurred between understory vegetation cover and distance from overstory trees, while species richness increased with distance from overstory trees in the final year. In contrast, there was little evidence for spatial patterns of soil nutrients, and more long-term monitoring may be needed to fully understand restoration impacts on savanna soil resource patterns. Common understory species were correlated with gradients of canopy cover and soil moisture associated with restoration plots, as well as with gradients of soil texture and N associated with both restoration and control plots. These findings suggest that an important consequence of removal of encroaching vegetation is the conversion of a homogenized biophysical environment common to encroached savannas to more diverse patterns of environmental gradients typical of intact healthy savannas (Brudvig and Asbjornsen 2009b).

Conclusion—Despite decades of degradation as a result of fire suppression and understory encroachment, Midwestern oak savannas maintain high resiliency that enables them to respond positively to restoration inventions.

The reestablishment of biophysical gradients in the understory environment, particularly related to light and moisture during the initial years following removal of encroaching vegetation, is a key aspect of promoting diversity and composition of understory plant species as part of the savanna restoration process.

Objective 5

Establish FHM Detection Monitoring plots at the savanna restoration site for comparison with process-based data.

Methods—FIA phase 2 plots were surveyed in 2002 and 2004 at two control and two savanna restoration sites, and four FIA plots were surveyed in 2006 and 2008 at four control and four savanna restoration sites, (two additional FIA plots were established in 2006). In each year, woody species were recorded using standard FIA methodology for seedling, sapling, and tree size classes. We analyzed these data with repeated measures ANOVA, and these results were compared to data derived from the transect-based sampling methodology (Brudvig and Asbjornsen 2007; described above in objectives 1 and 2).

Results and discussion—FIA sampling conducted over the course of the study (2002–08) illustrated patterns of reduced sapling and overstory tree densities and increased tree seedling densities following woody encroachment removal; however, replication was too low (n=2) to resolve these differences statistically (fig. 9.1). Conversely,

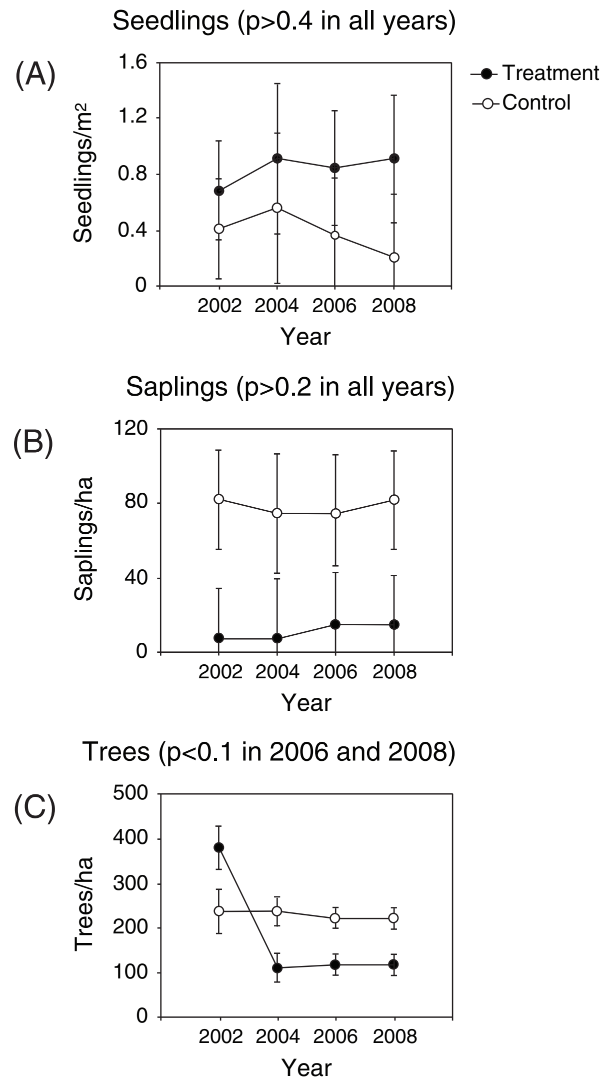

Figure 9.1—Effects of restoration (mechanical woody encroachment removal, conducted during 2002–04) on oak savanna stand structure: density of (A) woody species seedlings, (B) saplings, and (C) overstory trees. Data were collected using four Forest Inventory and Analysis phase 2 plots/site (n=2 sites/treatment). Replication was too low to statistically resolve patterns. Values are mean ±SE.

FIA sampling during 2006 and 2008, with increased replication (n=4) was able to resolve these differences: increased seedling density and reduced sapling and tree density following restoration by woody encroachment removal (fig. 9.2). In general, these FIA derived data mirrored results of data derived from transect-based sampling, though it is difficult to draw any strong conclusions regarding the sensitivity of FIA phase 2 plots to temporal change, due to low sample size. For example, with n=2 phase 2 plots sampled every other year, we were unable to resolve the sapling recruitment pulse that was evident through the transect-based data.

Conclusion—Data from FIA phase 2 plots effectively documented coarse patterns in stand structure following oak savanna restoration, e.g., major reduction in overstory density, but were ineffective at resolving finer scale changes in stand structure following restoration, e.g., temporal changes and sapling recruitment pulse. This was likely due to low replication and it is possible that these changes would have been resolved with annual sampling at full (n=4) replication. Finally, standard FIA plot layout was not useful for our study sites, as sites were not wide enough to accommodate normal phase 2 plot arrangement. As such, rearrangement of subplots to fit within our sites was necessary.

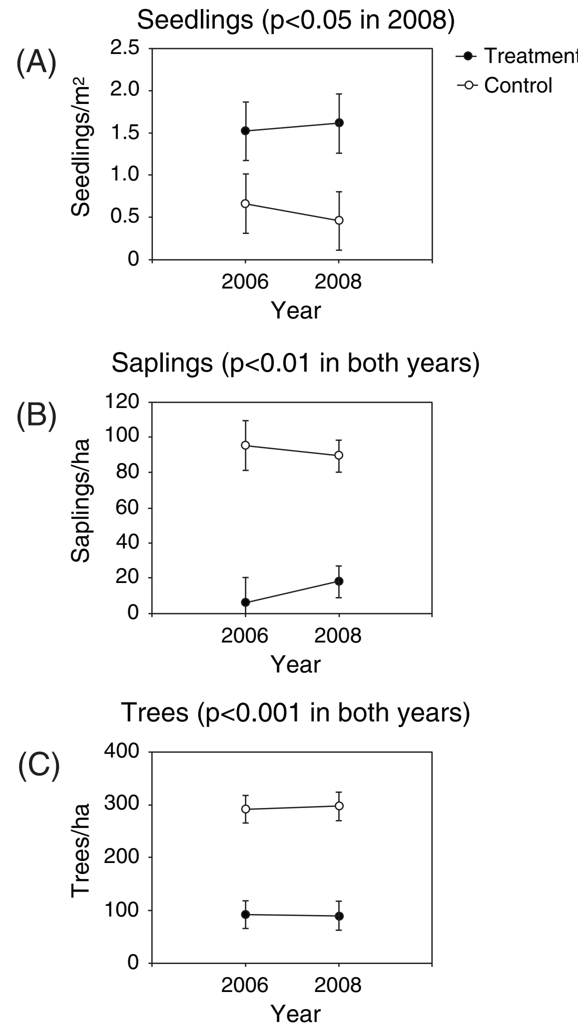

Figure 9.2—Effects of restoration (mechanical woody encroachment removal, conducted during 2002–04) on oak savanna stand structure: density of (A) woody species seedlings, (B) saplings, and (C) overstory trees. Data were collected using four Forest Inventory and Analysis phase 2 plots/site (n=4 sites/treatment). This level of replication was sufficient for resolving differences between treatment groups for all strata in 2008 (p<0.05). Values are mean ±SE.

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