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Notes and Discussion

Oak Regeneration Before and After Initial Restoration Efforts in a Tall Grass Oak Savanna

Conference Paper

Abstract.—Unsuccessful oak (*Quercus* spp.) regeneration could result in losses of the rarer portions of the midwestern North American oak savanna region, including the tall grass oak savannas. We undertook this study to understand the effects of restoration on promoting growth of naturally occurring *Q. alba* seedlings in a degraded tall grass oak savanna in Iowa, USA. Initial restoration efforts, which involved mechanical removal of encroaching overstory trees, promoted positive increases in height and basal diameter of *Q. alba* seedlings in canopy gaps. Conversely, seedlings growing under *Q. alba* tree canopies in restoration areas and seedlings in control areas failed to display height and diameter increases. As seedlings were most abundant beneath *Q. alba* canopy trees, this created a dichotomy whereby seedling source (beneath canopies) and proper conditions for growth (in canopy gaps) were not one in the same. Although this restoration is still in its early stages, these results suggest that *Q. alba* regeneration may be successfully promoted at this site.

Introduction

Throughout North America, failed oak (*Quercus* spp.) regeneration has resulted in major changes in community structure (Loftis and McGee, 1993; Russell and Fowler, 1999; Abrams, 2003). Certainly this is a concern, especially in rare or degraded *Quercus* ecosystems. One such ecosystem of particular concern is tall grass oak savanna which currently occupies only 0.02% of its presettlement range (Nuzzo, 1986). Historically, tall grass oak savanna formed the transition zone between the tall grass prairie and the central hardwoods regions of North America and is a fire maintained ecosystem characterized by scattered open-grown trees of various *Quercus* species and a dense herbaceous understory (Anderson, 1998). Following settlement, agricultural conversion led to rapid destruction of tall grass oak savannas and most remaining remnants are severely degraded by livestock grazing and/or fire suppression and subsequent encroachment by shade tolerant/fire intolerant tree species (Cottam, 1949; Anderson, 1998). Due to this recent decline and degradation, tall grass oak savanna is of particular interest for restoration efforts, many of which have used a combination of mechanical removal of encroaching trees and prescribed fire to open the overstory (Packard, 1993; McCarty, 1998).

In this paper we present a study conducted in an area of degraded tall grass oak savanna in Iowa, USA. This site has undergone a dramatic overstory species composition change since Euro-American settlement (Asbjornsen *et al.*, submitted). Analysis of Government Land Office (GLO) surveys conducted at the time of settlement in Iowa, 1845–1850, indicated that the most abundant overstory trees in the area were *Quercus alba* (28% of trees), followed by *Q. macrocarpa* (20%) and *Q. velutina* (12%). In contrast, a 2002 vegetation survey revealed *Q. alba* and *Q. velutina* to be relatively infrequent at this study site, each representing 4.3% of the trees sampled (trees were defined as having diameter at breast height (DBH) $\geq$ 15.0 cm). Six species of trees were more abundant in this survey, which was dominated by *Carya ovata* (16%) and *Gleditsia triacanthos* (15%). *Quercus macrocarpa* was absent from this survey, which also revealed *Q. alba* saplings (defined as height $>$ 150 cm and DBH $<$ 15.0 cm) to be rare, representing only 1% of saplings sampled.

Savanna restoration efforts can shift stand structure toward historic (*i.e.,* presettlement) conditions by mechanical removal of encroaching trees, but the continued existence of these ecosystems lies in part in successful regeneration of *Quercus* trees from seedlings. It has been suggested that overstory regeneration has not occurred for some time in at least one degraded midwestern oak savanna (Russell and Fowler, 1999) and oak ecosystems in general (Abrams, 2003). Failed regeneration coupled with the eventual senescence of overstory trees will result in the wholesale loss of these ecosystems. In order to prevent this, it is important to understand the effects of specific savanna restoration treatments on promoting *Quercus* regeneration.

We undertook this study to assess the effectiveness of canopy tree removal (*i.e.,* "thinning"), as part of a tall grass oak savanna restoration, as a means of promoting *Quercus alba* seedling survival and growth.

This is important because the pretreatment scarcity of *Q. alba* saplings suggests that a bottleneck exists between the seedling and sapling stages of development. Our study had two parts. In the first part, we determined the current but prerestoration distribution and abundance of *Q. alba* seedlings at our study site. We hypothesized that *Q. alba* seedlings would be most numerous below mature *Q. alba* trees, as predator satiation during mast years can result in unmoved acorns (Schnurr *et al.*, 2002). The second part of the study examined the effectiveness of thinning treatments at promoting seedling survival and growth one year after these treatments were performed. We hypothesized that seedling growth would be greatest in canopy gaps because light has been shown to be crucial to seedling recruitment in oak forests (Cho and Boerner, 1991; Orwig and Abrams, 1995; Collins and Battaglia, 2002) and oak savannas (Rebertus and Burns, 1997). We also hypothesized that mortality might be greater in these areas due to stresses imposed upon the seedlings by the restoration process coupled with the new canopy environment.

METHODS

STUDY SITE

Site description.—The study was conducted at an upland site along the southwest edge of Saylorville Lake (NAD 83 zone 15; UTM coordinates: Northing: 4,618,000, Easting: 441,000), a reservoir on the Des Moines River in central Iowa, USA. This area is characterized by east/west oriented upland ridges frequently dissected by valleys created by ephemeral streams. The predominant soils of the uplands in this area are the Hayden series (Fine-loamy, mixed, superactive, mesic Glossic Hapludalf), which developed under forest and the Lester series (Fine-loamy, mixed superactive, mesic Mollic Hapludalf), which developed under savanna communities (Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Official Soil Series Descriptions. Available URL: http://soils.usda.gov/soils/technical/classification/osd/index.html [Accessed 6 April 2004]).

STUDY DESIGN

During September 2002 four treatment areas were established within the Saylorville Lake study site. Treatment areas, which ranged in size from 2.1 to 3.3 ha, were roughly rectangular and oriented east/west on ridge tops. Canopy cover, measured during July 2002, was ~84% at all four areas (Asbjornsen *et al.*, submitted). Two treatment areas were assigned control status and were left in the original state. Of the two remaining areas, one was assigned a light thinning treatment and one a heavy thinning treatment. Light thinning involved mechanical removal of all non-*Quercus* and non-*Carya* species trees, which reduced canopy cover to ~45%. Selection of *Carya* was based on various historical documents which describe these species as important tree components of some tall grass oak savannas (*see* Muir, 1913). Heavy thinning involved mechanical removal of all non-*Quercus* species trees, which reduced canopy cover to ~15%. Mechanically removed trees were cut by chain saws and burned in off-site slash piles by hand crews. There were no herbicide applications made. Thinning treatments were performed during the winter of 2002–2003. The values for postthinning canopy cover fell within the range of published definitions of tall grass oak savannas (10–50%: Curtis, 1959; 10–30%: Packard, 1993).

Within each of the four treatment areas, up to 20 *Quercus alba*, 20 *Q. velutina* and 20 *Q. rubra* canopy trees were randomly selected from the pool of trees in the area. If 20 trees for a particular species were not present in an area, all the available trees for that species were included. This resulted in a total of 66 *Q. alba*, 29 *Q. velutina* and 61 *Q. rubra* canopy trees. For each tree, the canopy was vertically projected onto the ground and the distance measured from the base of the trunk to the edge of the projection, in each of the four cardinal directions. The mean of the four canopy measurements was then used as a radius to create a circular plot under each tree, with the trunk as the center of the circle (hereafter referred to as "canopy plots"; Fig. 1). Radii ranged from 0.8 m to 9.0 m. An additional "canopy gap plot" was established at a distance of three canopy radii in a random direction from each study tree (Fig. 1), provided that this did not result in any part of a non-oak plot occurring under another *Quercus* spp. tree. These plots were circular and had the same radius as their respective canopy plot, so as to provide equal sampling area for canopy and canopy gap plots. Canopy gap plots in thinned areas became true "canopy gaps" after the thinning treatments occurred, whereas those in control areas were still in the shade of non-*Quercus* spp. trees.

Each canopy and canopy gap plot was surveyed during September 2002 for *Quercus alba* seedlings. Seedlings were defined as woody stems of distinctly different basal origin and less than 50.0 cm height.

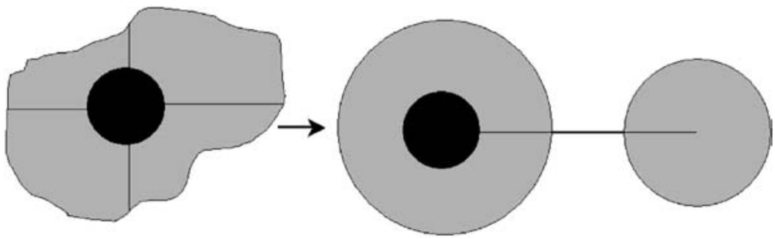

FIG. 1.—Aerial schematic diagram of canopy and canopy gap plot establishment. On the left is a canopy tree with trunk and measurements from the trunk to the edge of the canopy, in the four cardinal directions. In the center is the same tree trunk with the canopy plot, which uses the average of the four canopy measurements as its radius. On the right is the corresponding canopy gap plot of equal radius, at a distance of three canopy radii from the canopy tree trunk

All seedlings were tagged with a numbered aluminum tag attached with aluminum wire and measured for height with a tape measure and basal diameter at the root collar with a caliper. During September 2003, following the thinning treatments, all seedlings were resurveyed and measured, using the same criteria as in the original survey.

DATA ANALYSIS

In the first part of the study, which investigated pretreatment seedling distributions and densities, we combined the pretreatment data collected at the four sites. We had 6 plot types: oak and non-oak plots for *Quercus alba*, *Q. rubra* and *Q. velutina*. We analyzed this study as a one-way ANOVA, with plot type as the independent variable. The dependent variable was density (seedlings per m^2) which was transformed to the sqrt $(1 + \text{seedling count})/\text{plot area}$. This transformation was performed to account for plots that contained zero seedlings and to normalize the residuals. To test whether *Q. alba* seedlings were most abundant below mature *Q. alba* trees, we conducted independent contrasts.

For the second part of the study, we examined seedlings' responses after thinning treatments had been imposed. To determine the effects of canopy gap formation, only data from *Quercus alba* oak and non-oak plots were used for these analyses. We analyzed this study as a one-way ANOVA with plot type (oak plot, non-oak plot) as the independent variable, blocked within treatment area (control 1, control 2, light thinning, heavy thinning). Dependent variables analyzed were seedling survival, height change and basal diameter change. We calculated seedling survival as a per plot percentage, defined as: (number of seedlings that survived from 2002 to 2003)/(number of seedlings in 2002) * 100. Height and basal diameter changes were calculated as the change in height or basal diameter per surviving seedling between 2002 and 2003. To explore significant differences between treatment areas and between plot types, we conducted independent contrasts.

All statistical analyses were performed using SAS (2002, The SAS System for Windows, Version 9.00).

RESULTS

PRETREATMENT DISTRIBUTION OF QUERCUS ALBA SEEDLINGS

Our first analysis compared prethinning *Quercus alba* seedling ($n = 2115$) density in the six plot types: canopy and canopy gap plots for *Q. alba*, *Q. rubra* and *Q. velutina*. One-way ANOVA showed that plot types differed in seedling density ($F = 10.06$, $df = 5$, $P = <0.0001$; Fig. 2), with *Q. alba* seedlings more densely distributed in *Q. alba* canopy plots than other plot type (independent contrast: $t = 6.84$, $P < 0.0001$). Additionally, *Q. alba* seedling density was higher in *Q. alba* canopy plots than in *Q. alba* canopy gap plots (independent contrast: $t = 4.03$, $P < 0.0001$).

POSTTREATMENT RESPONSES

Seedling survival.—One-way ANOVA revealed that seedling survival differed significantly over blocks, which were the treatment areas ($F = 5.49$, $df = 3$, $P = 0.0026$; Fig. 3). There was a trend for seedling

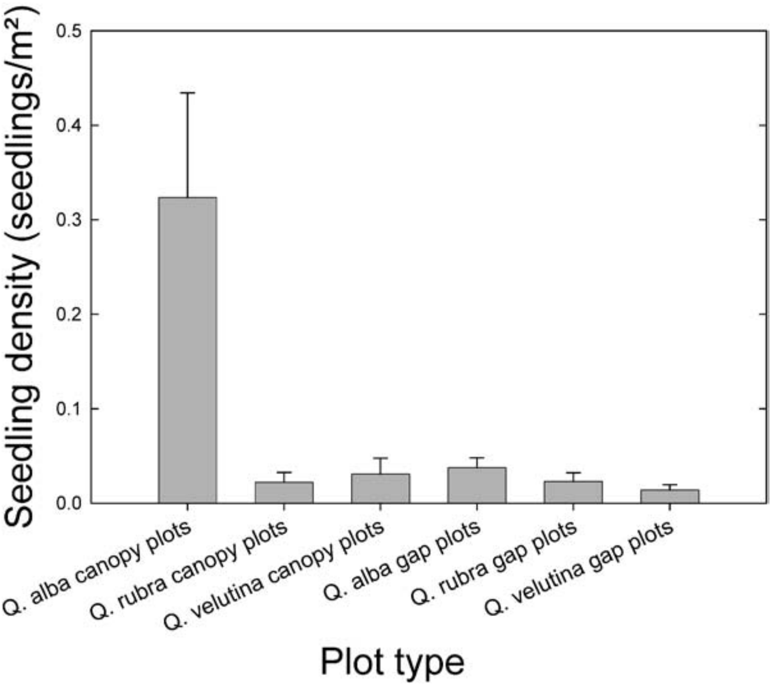

FIG. 2.—*Quercus alba* seedling density in canopy and canopy gap plots for *Q. alba*, *Q. velutina* and *Q. rubra* trees, before thinning treatments. Mean seedling density was significantly greater in plots under *Q. alba* than in all other plot types (independent contrast: $t = 6.84$, $P < 0.0001$)

survival to be greater in control areas, than in canopy thinning treatment areas (independent contrast: $t = 1.74$, $P = 0.0891$). Seedling survival did not differ between canopy and canopy gap plot types (independent contrast: $t = 1.43$, $P = 0.1600$), although survival was consistently higher in canopy gap plots, than canopy plots, within each treatment area (Fig. 3).

Seedling height and basal diameter change.—For seedlings that survived from 2002–2003 ($n = 594$), change in height differed over treatment areas ($F = 8.80$, $df = 3$, $P < 0.0001$; Fig. 4) though basal diameter did not ($F = 1.08$, $df = 3$, $P = 0.3565$; these data are not presented as a figure, as the patterns are the same as in Fig. 4). Seedling height changes were greater in thinning treatment areas than in control areas (independent contrast: $t = 4.63$, $P < 0.0001$), with this difference driven by the pronounced height increases demonstrated by seedlings in thinning treatment area canopy gap plots (Fig. 4). A similar trend was seen for basal diameter increases in thinning treatment areas' canopy gap plots, though the difference between control and treatment areas was weaker for seedling basal diameter increases (independent contrast: $t = 1.62$, $P = 0.1073$). No differences were seen between the light and heavy thinning treatments for seedling height change (independent contrast: $t = 0.63$, $P = 0.5278$) or basal diameter change (independent contrast: $t = 0.13$, $P = 0.8965$).

DISCUSSION

SEEDLING DISTRIBUTION, SURVIVAL AND GROWTH

Prior to restoration efforts, *Quercus alba* seedlings were found in highest abundance beneath mature *Q. alba* trees, which is likely an artifact of seed rain in these locations. *Quercus alba* displays mast seeding, where acorns are produced heavily every few years and little or not at all in years between (Sork *et al.*, 1993). During mast years, some non-predated acorns are relocated by small mammals and birds, but

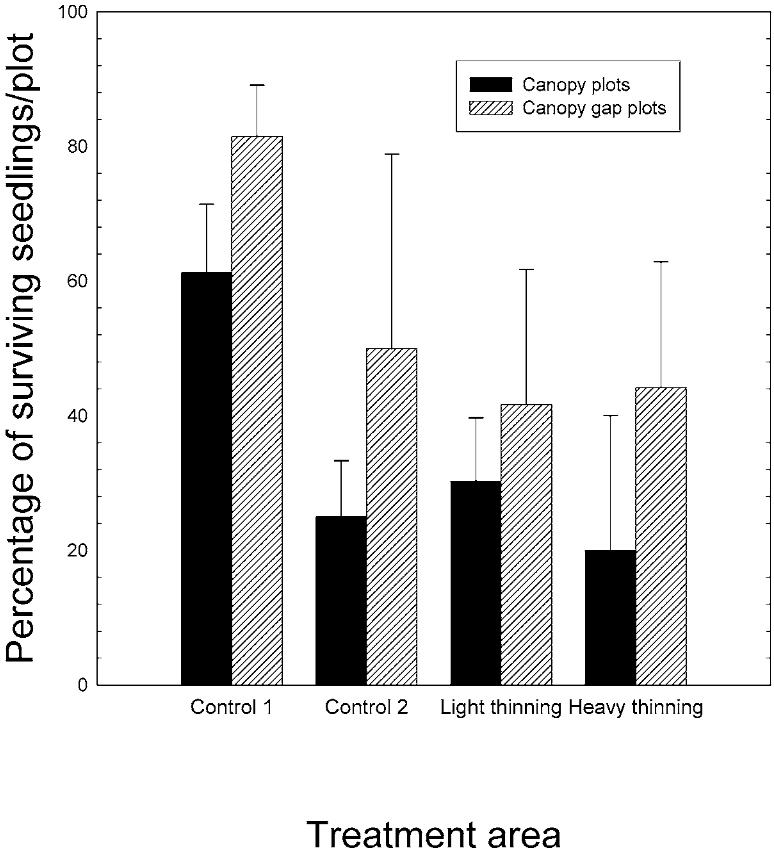

FIG. 3.—Percentage of *Quercus alba* seedlings that survived for 1 y after thinning treatments. There was a trend for seedling survival to be greater in control areas, than in canopy thinning treatment areas (independent contrast: $t = 1.74$, $P = 0.0891$)

many non-predated acorns remain where they fall, resulting in a high abundance of seedlings directly beneath the parent tree (Janzen, 1971; Bossema, 1979; Schnurr, 2002). The results of our study are consistent with this pattern of acorn distribution, but are contrary to those reported by Rebertus and Burns (1997), where *Quercus* spp. seedlings in Missouri savannas were more densely distributed in canopy gaps, compared to under *Quercus* canopies. "Seedlings" in the Rebertus and Burns (1997) study were mostly sprouts from large root systems, with the word "seedling" used more as a size class. As we measured seedlings at the root collar, we can be sure that seedlings in our study were not sprouts of larger root systems, but rather recent sprouts from acorns. This difference in seedling origin may account for the discrepancy of findings between the two studies.

As hypothesized, seedling growth was greatest in canopy gaps (canopy gap plots in thinning treatment areas; Fig. 4). It is interesting that positive growth responses were only found in true canopy gaps, as positive growth was not seen for seedlings in any other plot type. These findings of a growth response in canopy gaps are contrary to Orwig and Abrams (1995), where *Quercus alba* seedlings did not respond to experimental gap formation. However, despite the increases in height and basal diameter that surviving seedlings displayed in canopy gaps, seedling survival was marginally lower in thinning treatment areas, than in controls (Fig. 3). This sets up an interesting dichotomy, whereby restoration treatments resulted in increased *Q. alba* seedling mortality, though those seedlings that did survive in canopy gaps displayed increased growth rates.

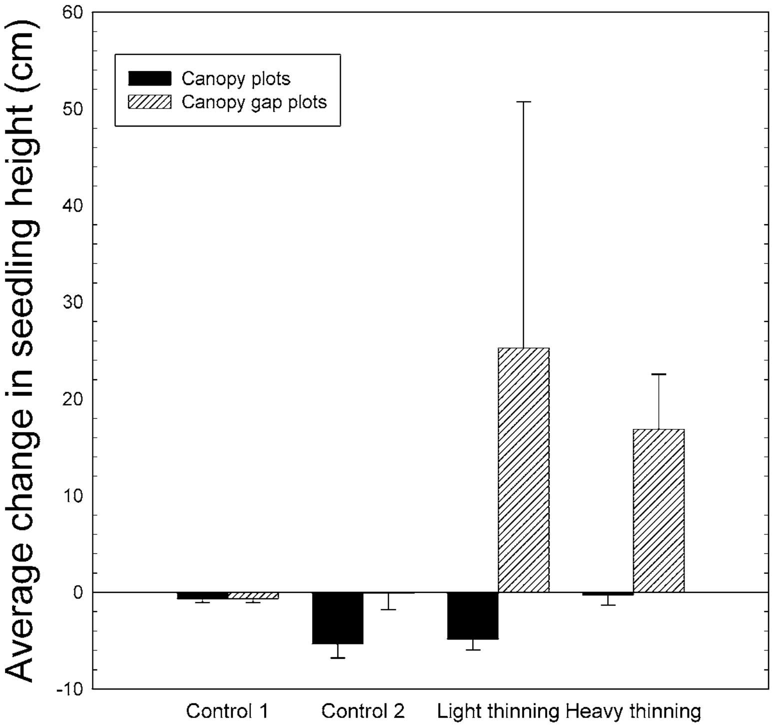

FIG. 4.—Changes in *Quercus alba* seedling heights for seedlings that survived from 2002–2003. Seedling height changes were greater in thinning treatment areas than in control areas (independent contrast: $t = 4.63$, $P < 0.0001$)

Disturbance associated with the mechanical thinning treatments may have contributed to higher seedling mortality in thinning treatment areas. Although sudden increases in light environment have been shown to be stressful on *Quercus* spp. seedlings (Ashton and Berlyn, 1994), there was a consistent trend for seedlings in canopy gap plots to display higher survival, over all treatment areas (Fig. 3).

Although the results of this study are preliminary, the interplay between canopy oak trees (seed source) and canopy gaps (proper conditions for seedling growth) in this savanna might influence the spatial arrangement of trees in this savanna system. Seedlings may grow to the sapling stage most often at the edge of existing *Quercus alba* tree canopies, where seedling abundance is high and the light environment more favorable for growth. Over time this could result in clusters of *Q. alba* trees, intermixed with areas devoid of trees. Interestingly, presettlement oak savannas were described by some early settlers as a mosaic of tree clusters and open grassland (White, 1994). The initial results of this study provide a potential mechanism for how regeneration dynamics in tall grass oak savannas could generate this spatial pattern.

IMPLICATIONS FOR RESTORATION

Canopy thinning at our site appears to be a necessary restoration step before *Quercus alba* seedlings increase significantly in size. Without canopy thinning, seedlings in our study did not grow, suggesting that seedlings may be regularly replaced by new seedling cohorts, but surviving seedlings do not persist to the sapling stage. If thinning of the overstory does indeed promote *Q. alba* seedlings into the sapling stage, this means of restoration may effectively promote persistence of *Q. alba* as a major overstory species at this site.

Although these initial results appear promising, this restoration is still in its early stages and we can not be certain that these preliminary patterns will remain the same over longer time scales. The absence of *Quercus macrocarpa* will need to be addressed at some point in this restoration and as tall grass oak savanna is a fire maintained ecosystem, prescribed fire will be integral to this restoration. Prescribed fires may likely reinforce the spatial implications of this study, since *Quercus* seedlings have shown lower survival in canopy gaps than under canopies during prescribed fires in oak savannas (Rebertus and Burns, 1997). Again, this may confirm the critical zone of the interface between *Q. alba* canopy edge and canopy gaps for facilitating regeneration and for promoting mosaic configurations in savannas.

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