EFFECT OF RESERVE TREES ON REGENERATION IN CENTRAL WISCONSIN OAK SITES

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Abstract.—Anecdotally, higher retention levels after harvest are believed to have a negative impact on oak (*Quercus*) regeneration accumulation. For this study, harvests with four retention levels of 0, 15, 30, and 45 percent were established to determine the impact of overstory retention on the success of oak regeneration after harvest. Previous research has shown that an increase in reserve trees can increase the accumulation of the intermediate shade-tolerant oak and of other species with similar shade tolerance and reduce the abundance of more intolerant species such as aspen. Seven to eight years after harvest, the regeneration levels in all plots met the requirements for adequate stocking based on standards set by the Wisconsin Department of Natural Resources. There were no significant differences in oak regeneration between retention levels. At this stage of regeneration, oak can apparently persist under higher retention levels, but further study will be necessary to determine recruitment into the canopy.

INTRODUCTION

Oaks growing on dry, nutrient-poor sites are an important cover type in central Wisconsin. The stands are generally composed of northern pin (*Quercus ellipsoidalis* E.J. Hill) and black oak (*Q. velutina* Lam.) with variable representation of white, jack, and red pine (*Pinus strobus* L., *P. banksiana* Lamb., and *P. resinosa* Aiton), red maple (*Acer rubrum* L.), aspen (*Populus tremuloides* Michx.), and bur and white oak (*Q. macrocarpa* Michx. and *Q. alba* L.). Coppice and overstory removal has been a generally accepted practice for scrub oak regeneration in Wisconsin and can be successful on these poor quality sites where oak has a strong competitive advantage (Arend and Scholz 1969).

Because the prescription, suggested in the past by the Wisconsin Department of Natural Resources, for the lowest quality of these stands has been a pulpwood rotation at 45-70 years old, the overstory trees are small and the number of stems per acre is high. Oak sprouting has been important on similar sites (Lynch and Bassett 1987). On these dry sites, sprout origin regeneration would have an important competitive advantage over the seedling regeneration of more mesic site species (e.g., red maple). In addition to the stump sprouts, oak seedlings with their tap root development (Chadwell and Buckley 2003) and adaptations to drought (Abrams 1990) can compete successfully on dry, nutrient-poor oak sites.

Even though coppice or overstory removal can be a viable harvest method for oak on dry, nutrient-poor sites, the aesthetics of partial harvests often better meets other landowner goals. Johnson (1992) demonstrated that the height of the tallest oak stem per 5.5-m^2 plot was greater as the overstory density declined; however, differences between overstory species and habitat type increased the density of oak seedling regeneration. Because oak is generally favored by disturbance in the areas of North America where fire played a significant role (Dey and Fan 2009), and because oak regeneration tends to accumulate on dry, nutrient-poor sites (Johnson et al. 2002), these scrub oak sites present a competitively favorable environment for oak

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regeneration. Higher levels of overstory retention can, however, decrease the growth rate of the oak seedlings and make them more susceptible to herbivory (Russell et al. 2001) and mortality from other environmental factors (Buckley et al. 1998). Because higher levels of overstory retention might reduce the competitive advantage of oak compared to other more shade-tolerant species (Abrams 1992), determining the level of overstory retention at which regeneration, especially oak regeneration, is compromised would be useful to managers. The objective of this study is to determine the impact of the level of overstory retention on density, aggregate height, and stocking of oak seedlings.

METHODS

Study Sites

Five dry, nutrient-poor oak sites were selected in central Wisconsin for this study. Three sites were selected in Greenwood Wildlife Area, henceforth referred to as Greenwood West (GWW), East (GWE), and South (GWS); one in the Emmons Creek Fisheries Area (EC); and one in the Henry C. Kurtz Memorial Forest (KMF). All sites but EC were harvested during the winter of 2007-2008, EC was harvested in the winter of 2008-2009. The overstory was predominantly northern pin/black oak and white/bur oak with occasional white pine, red pine, black cherry (*Prunus serotina* Ehrh), and red maple. The average ages of the stands and site index (SI) (50 years SI; data based on 10 cores taken from the trees remaining after harvest) were: EC 82 years (SI 51; size 27 acres), KMF 72 years (SI 47; size 18 acres), GWW 89 years (SI 53; size 17 acres), GWE 56 years (SI 65; size 33 acres) and GWS 68 years (SI 48; size 19 acres). Occasional individual trees (especially white and bur oaks) were significantly older. Initial basal area (mean ± se) was 143 ± 3, 101 ± 4, 150 ± 5, 153 ± 3, and 150 ± 3 square feet per acre for EC, KMF, GWW, GWE, and GWS, respectively. The soils were all quite sandy and of glacial origin. KMF was in an outwash sand plain; GWW, GWE, and GWS were in morainal sands formed by glacial deposits that are a matrix of moraine and pitted outwash; and EC was in morainal sands that were partially resculpted by meltwater and postglacial erosion with some exposed till. They consisted of Plainfield and Plainfield/Kranski (mixed, mesic Typic Udipsamments), Richford (mixed, superactive, mesic Arenic Hapludalf), Brems and Meehan (mixed, mesic Aquic Udipsamments), and Coloma (mixed, mesic Lamellic Udisamments).

Experimental Design

The experimental design of this study was a balanced randomized complete block analysis of variance with five blocks (harvest units), each with three replicates of each of four randomly assigned treatments (0, 15, 30, and 45 percent retention levels [RLs]). An alpha level of 0.10 was used to reduce the risk of type II error.

Field Methods

On each harvest unit, three replicates of the four treatments were randomly assigned to one of the twelve 0.5-acre square plots. The initial corner of the first plot was located using a random number of feet from the stand boundary, and additional plots were located based on that plot. Because these stand boundaries were irregular, plot locations were designed to fit within the boundaries of the stand. Distance between plots was roughly 60 feet, although the size and shape of the harvest unit varied. The matrix between the plots was completely harvested; all trees were removed down to a 2-inch diameter at breast height (d.b.h.). Within the plot, an approximately 33-foot buffer inside the plot was not sampled (to avoid the effect of the edge). During 2015, subplots were located at 20-foot spacings along four paced transects that were approximately 27 feet apart. Although corners of plots were initially monumented, logging damage and vandalism (many of the corner posts were stolen from two harvest units) required that these corners be relocated using GPS with its associated inaccuracies. These subplots should not be construed to be identical to the preharvest subplots, because they represent only the plot as a whole. Although this is not ideal, the data for each subplot were aggregated and the level of replication was at the level of plot (the plot was the level to which the treatment was applied). This provided 240 subplots per harvest unit, for a total of 1200 subplots. For each subplot, a round 1/735-acre regeneration subplot was established. A tally of all advanced tree regeneration by species was recorded in 2-foot height classes (0-2, 2-4, 4-6, 6-8, 8-10, and 10+ feet). Because site visit observations indicated that both wind damage and mortality had occurred since harvest, spherical densitometer measurements were taken on an additional site visit on subplots that approximated every other regeneration subplot (retaining the approximately 33-foot buffer from the plot edge). These were not taken on the original site visit because the extent of damage was not expected prior to sampling.

Data Analysis

Data were analyzed using Minitab 15.1.1.0 (Minitab, Inc., State College, PA). Analyses were performed with $\alpha = 0.10$, as the consequences of a type II error are greater than the consequences of type I error. The model for this design is:

$$\gamma = \mu + \beta_i + \tau_j + (\beta\tau)_{ij} + e_{ijk}$$

Where

γ = Aggregate height for plot l, in treatment j found in block i,

μ = Mean aggregate height across all treatments,

β_i = Block (site) effect for treatment i,

i = GWW, GWE, GWS, EC, KMF,

τ_j = Treatment effect for treatment j,

j = 0, 15, 30, or 45 percent RL,

$(\beta\tau)_{ij}$ = Error term associated with the interaction between block i and treatment j,

e_{ijk} = Error term, and

k = 1, 2, … 12 (replicate subplot).

Analysis was completed individually for aggregate height per acre (based on Fei et al. 2006) and number of seedlings per acre for oak seedlings and total tree seedlings.

Because some crown cover was lost between logging and measurement in 2015 (from wind damage and mortality), a general linear model with Block as a random factor and canopy closure (spherical densitometer) as main factors were used to determine if current canopy closure better predicted regeneration conditions.

Modified procedures from Jacobs and Wray (1992) were used to determine an oak stocking value. In our modification of this procedure, a 1-foot size class seedling was assigned a stocking value of 3, a 3-foot seedling was a 15, and a 5-foot or taller seedling was assigned a 30. A plot with a total stocking value of 30 or higher was determined to be stocked. An analysis of variance was completed by treatment level to determine if there were any significant differences.

RESULTS

There were losses of crown cover for each RL except the 0 percent RL. The measured current crown cover for RLs 0, 15, 30, and 45 percent were 0, 11 ± 1, 16 ± 2, and 31 ± 3 percent, respectively. This loss of trees was due to a combination of wind damage and mortality (likely caused by oak wilt, which is an expanding problem in this region, although the cause of mortality was not definitely determined for this project).

There were no significant differences between RL for any of the parameters tested: number of oak seedlings per acre (OS), total number of seedlings per acre (TS), aggregate oak seedling height per acre (OH), or aggregate total seedlings height per acre (TH) (Table 1). There were differences, however, in OH and TS between sites ($p = 0.06$ and 0.02, respectively). There was also no difference between RL for the proportion of plots that were stocked (based on calculated stocking value) (Table 2). Across all sites, regeneration was composed of 6 percent red oak, 37 percent black/northern pin oak, 37 percent white/bur oak, 6 percent red maple, 12 percent black cherry, and 2 percent other species.

Although there were no significant differences between the quantity and size of regeneration in the plots with the various overstory retention levels, there were significant changes in the number of seedlings between 2007 and 2015 (Table 3). Both OS and TS decreased (total number reduced); however, OH and TH essentially did not change, meaning that average

Table 1.—Mean values per acre in 2015 for number of oak seedlings (OS), total tree seedlings (TS), aggregate oak seedling height (OH), and aggregate total seedling height (TH) per acre. Data presented ± standard error. Sample size was 15 plots per retention level.

Retention (%)	OS (number/acre)	TS (number/acre)	OH (feet/acre)	TH (feet/acre)
0	1970 ± 244	2418 ± 244	6759 ± 1028	9622 ± 1445
15	2203 ± 295	2710 ± 296	6251 ± 778	9533 ± 1488
30	2279 ± 287	2849 ± 327	6302 ± 770	9231 ± 957
45	2624 ± 358	3477 ± 355	5575 ± 632	10217 ± 1772

Table 2.—Proportion of plots stocked with oak at a stocking value (SV) of 30 or more in 2015. Data presented ± standard error.

Retention level (%)	Proportion of plots ≥30 SV
0	0.23 ± 0.04
15	0.29 ± 0.05
30	0.26 ± 0.04
45	0.29 ± 0.04

Table 3.—Mean number of oak seedlings (OS), total tree seedlings (TS), aggregate oak seedling height (OH), and aggregate total seedling height (TH) per acre. Data presented ± standard error.

Year	OS (number/acre)	TS (number/acre)	OH (feet/acre)	TH (feet/acre)
2007	5064 ± 336	6279 ± 330	7150 ± 499	10805 ± 635
2015	2269 ± 149	2863 ± 158	6222 ± 401	9651 ± 706

Table 4.—Oak seedlings per acre by height class in each crown cover in 2015

	Height class (feet)					
Crown cover (%)	0-2	2-4	4-6	6-8	8-10	10+
0	588	620	500	191	59	12
15	943	715	350	108	56	29
30	1022	774	277	98	61	47
45	1529	799	196	59	22	20

height of seedlings was increasing. Even though we did not record deer browse levels in this project, a noteworthy number of the stems appeared to have a history of browse damage. The effective height of deer browsing is somewhat less than 6 feet during most years, but 101-262 oak seedlings per acre were taller than normal deer browsing height (Table 4). No significant difference in the number of oak seedlings per acre taller than 6 feet was found between RLs ($p = 0.11$), although there were differences between sites ($p = 0.062$).

DISCUSSION

Some loss of reserve trees is expected as the stands respond to harvest. Indeed, the addition of snags and course woody debris is one advantage of maintaining reserve trees in a harvest. Calculating annual mortality rates from the published values of Starkey and Guldin (2004) in Arkansas and Miller et al. (2006) in Appalachia, approximately 0.5 to 1.6 percent loss per year could be expected. On similar sites in Wisconsin, Mujuri and Demchik (2009) found a 5.5 percent rate of annual mortality for northern pin oak reserve trees and no measured loss for white oak. Considering these published values, the losses are not surprising. Expectations of some mortality and wind damage should be included in planning when reserve trees are retained on similar sites.

Regeneration of oak on dry, nutrient-poor sites is generally simpler than on richer sites. Schlesinger et al. (1993) found that through shelterwood harvesting (i.e., low-density management) adequate regeneration will develop on lower quality sites; however, higher quality sites may require further understory treatment to remove competing species. On the lower quality sites they found no detrimental effects of using the shelterwood method. Schwartz and Demchik (2013) found both natural regeneration and stump sprouts to succeed after overstory removal (clearcut/coppice) on dry, nutrient-poor oak sites (12 years after harvest) where 41 percent of the plots had at least one oak seedling taller than 10 feet even in the presence of significant deer populations (average 39 deer per square mile during the first 5 years after harvest). Oak is much better adapted to dry, nutrient-poor sites than many of its competitors. Although fire has undoubtedly played a role in the establishment of these stands in the past, it does not appear to be necessary on these dry, nutrient-poor sites for oak to dominate the regeneration. This is likely not true as soil becomes either more mesic or more nutrient rich.

The regeneration levels of all species in all treatments were generally high and met "rule of thumb" guidelines of 1000 seedlings of desirable species per acre. Following modified protocols of Jacobs and Wray (1992), the sites were 23-29 percent stocked with oak seedlings. When examining stocking based on aggregate height according to the standards described by Steiner et al. (2008), expected oak stocking would be 41-47 percent. These results support previous studies (Weigel and Johnson 1998, Weigel and Peng 2002) that showed oak can regenerate successfully on poor quality sites. Without additional site treatments that favor oak, these stands will likely be more diverse in species composition than before harvest. Oak maintenance is a management goal on these sites specifically and across state lands in Wisconsin as a whole, but increased species diversity on these dry, nutrient-poor sites is probably desirable. Oak wilt is an expanding problem in central Wisconsin, and diversifying these stands may reduce this disease's impact and speed of transmission. Because these data are from only the 7th and 8th seasons after harvest, however, we cannot predict success beyond that timeframe.

Many authors have studied the impact of modified light levels on oak regeneration success. Shelterwood has been shown to promote the growth of regeneration, but Steiner et al. (2008) suggested that it may not increase the regeneration that is established after harvest. Preharvest regeneration or site treatments to promote regeneration are often needed if adequate advanced regeneration is not present. Without sufficient regeneration before harvest, recruitment often fails. On lower quality sites, particularly those used in the current study, oak advance regeneration is typically abundant and rotation is often at a much younger age (main product of pulpwood, not saw logs as is common on richer sites). We found an average of more than 5000 oak seedlings per acre before harvest, although most were in the smallest size class (0-2 feet tall). In addition to the often copious regeneration, the contribution of stump sprouts can be significant and their growth rates very high. Lynch and Bassett (1987) found northern pin oak to stump sprout frequently even to advanced ages. Schwartz and Demchik (2013) found average stump sprout height after 12 years to be 24 feet even under significant browse pressure.

Although there is currently no statistical difference between regeneration under different overstory RLs, this may change over time as the sites continue to develop. Because crown cover decreased over time in these stands from wind damage and mortality, this may well have increased the success of the regeneration. Because these sites were measured 7-8 years since harvest, however, that may be too soon in the regeneration phase to determine any differences. Smith et al. (1989) measured regeneration in deferment harvests 5 years post-treatment and found no significant differences from what would be expected in a clearcut. This same pattern was noted in regeneration surveys 2-5 years after a shelterwood harvest (Johnson et al. 1989). Limited differences in light levels between treatments may explain the lack of differences between treatments. A study by Atwood et al. (2009) that involved three harvest levels (clearcut, leave-tree [BA = 21 square feet per acre], and shelterwood [BA = 59-51 square feet per acre]) found no differences in light levels between the leave-tree and shelterwood levels of residual trees. Although there were differences in residual densities, these differences were not significant enough to alter the light levels that reached the forest floor. In our study, oak seedlings were still the largest part of the regeneration. The lower light levels created by higher RLs could still give oak a higher competitive advantage over more shade-intolerant species such as red maple or aspen. This would provide oak sufficient time to reach a height that is more likely to achieve dominance in the canopy, as seen in studies by Sander (1971, 1972). Overall, a longer timeframe may be necessary to determine which treatment will have a greater rate of recruitment of oak, because oak success after harvest changes through time.

SUMMARY

Retention of reserve trees can help attain some ecological and aesthetic goals. For oak on dry, nutrient-poor sites, retention of 0-45 percent crown cover results in comparable number, aggregate height, and stocking value for oak seedlings during the first 7–8 years after harvest. Whether this will continue is unknown. Some mortality and wind damage of reserve trees should be expected.

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