REGENERATION DEVELOPMENT 3 YEARS AFTER THINNING AND FERTILIZATION IN AN EAST TEXAS BOTTOMLAND HARDWOOD STAND (TO MANAGE OR TO REGENERATE: CAN WE DO BOTH?)

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Abstract—Silviculture textbooks state that intermediate treatments, such as thinning, are prescribed to regulate the growing space for the benefit of existing trees and not to create enough growing space to initiate new trees of desirable species. If new, desirable regeneration develops, then it is considered a by-product of the intermediate treatment and is not to be managed, else the operation is a reproduction. In bottomland hardwood management where oaks (*Quercus* spp.) are the primary species being managed, new oak reproduction often initiates following a thinning operation, especially if the operation coincides with an exceptionally good acorn crop. Given past difficulties in regenerating bottomland oaks, an opportunity exists to promote the development of this reproduction during future thinning operations where growth and development of desired overstory crop trees is still the primary objective. Results following 3 years of crown thinning and low thinning, along with a fertilization treatment, showed few differences in the density and development of oak reproduction compared to unthinned plots, but an oak regeneration pool is developing. We believe the lack of differences reflect the young nature of the stand, i.e., it is just entering acorn production age. Future thinnings should enhance the establishment and development of oak reproduction despite the concurrent development of future midstory canopy species such as American hornbeam (*Carpinus caroliniana* Walt.) and deciduous holly (*Ilex decidua* Walt.).

INTRODUCTION

The first decision a forest resource manager faces when initiating a management program for an existing bottomland hardwood stand, after determining the management objectives, is whether to continue managing the existing stand or begin steps to secure regeneration. A decision model, HARDWOOD, was recently developed to help forest resource managers with this initial decision (Belli and others 1993). The model takes into account aspects of each tree in designated inventory plots including tree class, species, crown class, butt log grade, vigor, and merchantable length (Manuel and others 1993). If the decision is to manage the existing stand, then the forester has options regarding intermediate treatments, such as release or thinning, depending on management objectives and current stand structure (Meadows 1996). If the decision is to regenerate the existing stand, then the forester must determine if adequate natural regeneration exists (Belli and others 1999, Hart and others 1995, Johnson 1980), determine the steps needed to secure adequate advance regeneration if inadequate regeneration exists (Clatterbuck and Meadows 1993), or utilize artificial regeneration (Gardiner and others 2002).

This initial decision, to manage or to regenerate the existing hardwood stand, reflects traditional silviculture (Daniel and others 1979, Nyland 2002, Smith and others 1997). When managing an existing stand, reproduction that initiates and develops following an intermediate treatment is simply an artifact of the disturbance and is ignored, else the operation is considered a regeneration cutting instead of an intermediate treatment. Continued development of this reproduction, especially if shade-intolerant to moderately tolerant species, is considered an inefficient use of growing space for overstory tree growth and development, i.e., a poor marking and/or logging operation. The dichotomy, to manage or to regenerate, works well with species that are relatively easy to regenerate such as loblolly pine (*Pinus taeda* L.). For species that are more difficult to regenerate, such as the oaks (*Quercus* spp.) (Loftis and McGee 1993), a gray area may exist in this dichotomy where intermediate treatments that focus on residual tree growth and development may also be used to initiate and/or promote the development of desirable advance reproduction. The objective of the research project described in this paper is to follow the establishment and development of reproduction following thinning and fertilization in a bottomland hardwood stand. Three-year post-treatment results are reported.

MATERIALS AND METHODS

Study Site

The study was conducted on the Shawnee Creek floodplain, a minor bottom (Hodges 1997), in Angelina County, east-central Texas. The climate is characterized as long, hot summers and cool, fairly short winters (Dolezel 1988). The average annual temperature is 67 °F with a monthly average high ranging from 48 °F in January to 83 °F in July. Precipitation occurs throughout the year, averaging 41 inches per year with a monthly average of 2.5 inches in August to 4.3 inches in May. Prolonged droughts are rare (Dolezel 1988). Flooding occurs annually for brief periods. Soils are of the Pophers series (fine-silty, siliceous, acid, thermic Aeric Fluvaquents). Site index, base age 50 years, was estimated to be 90 to 95 for cherrybark oak (*Q. pagoda* Raf.), water oak (*Q. nigra* L.), and willow oak (*Q. phellos* L.) using the Baker/Broadfoot soil-site evaluation method

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(Baker and Broadfoot 1979). The study site was originally planted to loblolly pine around 1970 following mechanical site preparation (shearing). Herbicides were not used. Pine survival was poor due to flooding and the site reverted to an even-aged bottomland oak stand (see table 1 for initial stand characteristics). Stand age at the time of study installation was about 30 years.

Treatments and Study Design

Three levels of thinning and two levels of fertilization were applied in this study. Thinning consisted of no thinning (control), low thinning, and crown thinning. Low thinning consisted of removing all trees from the intermediate and suppressed crown classes [see Meadows and others (2001) for a description of hardwood crown classes]. No trees in the dominant and codominant crown classes were removed. Crown thinning consisted of removing trees in the codominant and dominant crown classes. No trees in the intermediate and suppressed crown classes were removed. A tree class system was developed [see Meadows (1996) for a description of tree classes] to select leave trees (crop trees) in each thinning treatment. In short, crop trees were of desired species (red oaks when possible), possessed healthy crowns, either contained or had the potential to develop a grade 1 butt log, had few to no epicormic branches on the butt log, and were disease free. Crop trees were released on at least two of four possible sides in the upper canopy in the crown thinning treatment. Marking was conducted in February 1999 with thinning conducted the following month. Due to wet soil conditions, trees were chainsaw felled and left in place.

Fertilization consisted of no fertilization (control) and 200 pounds of nitrogen per 50 pounds of phosphorus per acre applied as di-ammonium phosphate. The fertilization treatment was based on standard fertilization practices in intensive loblolly pine silviculture in the Atlantic Coastal Plain region (Jokela and Stearns-Smith 1993, North Carolina State Forest Nutrition Cooperative 2000). The fertilizer was applied to designated plots in June 1999, later than planned due to early spring flooding on the study site. Application was accomplished using hand-held spreaders. Treatments were randomly assigned to one-half acre rectangular plots with a designated one-quarter acre interior measurement plot. Six plots, 1 for each thinning and fertilizer combination, were utilized in each of 4 blocks in a randomized complete block design (24 total plots).

Measurements

Prior to treatment, all trees ≥ 3.6 inches d.b.h. (4-inch diameter class) were identified by species and had their d.b.h. measured (diameter at breast height, 4.5 feet above the ground) and crown class assessed. Two 0.01-acre circular regeneration plots were systematically installed in each plot. All stems in the regeneration plots were tallied by species into the following height classes: (1) < 1 foot tall, (2) 1 foot to 3 feet tall, (3) > 3 feet tall but less than 1 inch d.b.h. (using d.b.h. classes such that the one-inch class was 0.6 to 1.5 inches d.b.h.), and (4) 1 inch to 3 inches d.b.h. Additional measurements for all oak stems ≥ 1 foot tall included actual height [in centimeters (cms)]. Distance and azimuth from plot center were recorded for these seedlings for future measurements. All measurements were conducted during the early dormant season for each of the 3 years after treatment.

Analyses

Regeneration subplots were combined in each plot and scaled to per acre values. Analysis-of-variance was used to determine if differences in seedling density and height existed. Density values were transformed using the log transformation before analyses (untransformed data are shown in all tables and figures). Seedling heights were analyzed using initial seedling height as a co-variate. Duncan's Multiple Range Test was used to detect differences between treatments ($p \leq 0.10$). Metric height measurements were converted to English units in all tables.

RESULTS AND DISCUSSION

Regeneration Density

Few differences existed in total regeneration density and oak regeneration density between treatments, even when analyzed by regeneration size class. High variability existed between regeneration plots within and between treatments. Therefore, the results and discussion below pertain to combined density across all treatments.

Pre-treatment regeneration consisted of 35 tree species with an average density of 3,297 stems per acre (spa) (table 2). Total regeneration density decreased 43 percent following the first year after treatment before increasing to about 2,100 spa the following two years. Greatest changes in density occurred in the < 1 foot tall size class (table 2). The number of seedlings < 1 foot tall decreased 54 percent 1 year after thinning and fertilization. Seedlings < 1 foot tall

Table 1—Pre-treatment trees per acre (d.b.h. ≥ 3.6 inches), d.b.h. (quadratic mean), basal area, andstocking (using Goelz 1995) for all trees and crop trees in an east Texas bottomland hardwood stand

Trees	Tree per acre	d.b.h.	Basal area per acre	Stocking
		inches	*square feet*	*percent*
All trees	311(216-432)	8.5(7.4-9.8)	123(100-150)	115(92-141)
Crop trees	45(16-84)	11.6(9.6-14.2)	33(18-48)	28(15-40)

Values in parentheses represent the maximum and minimum mean plot values.

Table 2—Regeneration density per acre for all tree species in an east Texas bottomland hardwood stand 1 year prior and 3 years following thinning and fertilization[a]

Size class	Pre-treatment 1999	1999	2000	2001
< 1 foot tall	2,800 (± 653)	1,300 (± 432)	977 (± 266)	1,225 (± 535)
1 foot - 3 feet tall	296 (± 109)	434 (± 194)	848 (± 390)	538 (± 209)
> 3 feet tall - < 1 inch d.b.h.	51 (± 37)	42 (± 30)	144 (± 65)	163 (± 112)
1 inch - 3 inches d.b.h.	150 (± 103)	88 (± 46)	219 (± 95)	173 (± 57)
Total	3,297 (± 742)	1,864 (± 618)	2,188 (± 585)	2,099 (± 678)

Values in parentheses represent 1 standard error.
[a] All thinning and fertilization treatments combined.

are relatively new seedlings, usually 1 to 2 years old (personal observation). Population fluctuations in seedlings < 1 foot tall are expected since they usually arise from bumper seed crops. Their relatively small root systems combined with low leaf areas growing in partially shaded to heavy shaded environments, especially for shade intolerant to moderately shade intolerant species, predisposes them to rapid mortality. Further, these seedlings are most likely to perish during flooding episodes, especially during the growing season.

Another reason for the decrease in the number of seedlings < 1 foot tall was continued growth into the larger size classes (table 2), especially for those seedlings that could acquire and utilize additional resources. Seedling density increased 32 percent and 65 percent from the < 1 foot tall size class to the 1 foot to 3 feet tall size class one and two growing seasons after treatment, respectively. Increases were also noted in the > 3 feet tall but < 1 inch d.b.h. and 1 inch to 3 inch d.b.h. size classes, especially after the 2000 growing season. The decrease in these latter two size classes following one growing season after treatment may be due to damage that occurred to these larger seedlings and saplings during the thinning operations. The decrease in three of the four size classes following the 2001 growing season (table 2) may also be due to growth into larger size classes. Initial seedling density for the > 3 feet tall but < 1 inch d.b.h. size class in the crown thinning-no fertilization treatment was 13 spa. This density increased to 88, 288, and 425 spa following the 1999, 2000, and 2001 growing seasons, respectively. Decreases in density among the other treatments may be due to canopy closure from the thinning and fertilization treatments.

A majority of the initial seedling density was composed of oak species (75 percent), including white (*Q. alba* L.), overcup (*Q. lyrata* Walt.), swamp chestnut (*Q. michauxii* Nutt.), water, cherrybark, and willow oaks. Throughout the 3 year study period, greatest density within the oak regeneration size classes was seedlings < 1 foot tall (table 3). Population fluctuations were again noted in this size class. Increases in the 1 foot to 3 feet tall size class are the result of growth of oak seedlings from the < 1 foot tall size class with a nearly 100 percent increase in density from 1999 to 2001. Unfortunately, practically no increase has occurred in the 2 largest size classes, > 3 feet tall to < 1 inch d.b.h. and 1 inch to 3 inches d.b.h. Lack of growth into these size classes reflects the slow initial growth of oak seedlings following a disturbance that increases light levels reaching the seedlings (Deen and others 1993, Janzen and Hodges 1987, Lockhart and others 2000).

Of particular note is the density of other species in the larger size classes (> 3 feet tall but < 1 inch d.b.h. and 1 to 3 inches d.b.h.). American hornbeam (*Carpinus caroliniana* Walt.) and deciduous holly (*Ilex decidua* Walt.), two species

Table 3—Regeneration density per acre for oak species in an east Texas bottomland hardwood stand 1 year prior and 3 years following thinning and fertilization[a]

Size class	Pre-treatment 1999	1999	2000	2001
< 1 foot tall	2,302 (± 672)	1,098 (± 342)	823 (± 272)	1,106 (± 506)
1 foot - 3 feet tall	169 (± 79)	261 (± 137)	398 (± 210)	329 (± 155)
> 3 feet tall - < 1 inch d.b.h.	2 (± 2)	6 (± 6)	13 (± 11)	9 (± 9)
1 inch - 3 inches d.b.h.	6 (± 6)	2 (± 2)	11 (± 11)	2 (± 2)
Total	2,480 (± 743)	1,367 (± 460)	1,244 (± 437)	1,446 (± 582)

Values in parentheses represent 1 standard error.
[a] All thinning and fertilization treatments combined.

noted for their shade tolerance and midstory canopy development, along with hickories (*Carya* spp.), are prominent members of these larger reproduction size classes (table 4). American hornbeam and deciduous holly comprised 42 percent of the seedlings and saplings in the 2 largest size classes after the 2001 growing season while oaks represented 3 percent (tables 2, 3, and 4). Hickory species *C. cordiformis* (Wang.) K. Koch, *C. glabra* (Mill.) Sweet, *C. ovata* (Mill.) K. Koch represented 12 percent of these seedlings and saplings. The hickory species, when combined with American hornbeam and deciduous holly, comprised 54 percent of the total regeneration pool in the > 3 feet tall but < 1 inch d.b.h. and 1 to 3 inches d.b.h. size classes. American hornbeam, deciduous holly, and possibly the hickories, are probably of the same age as the overstory, having initiated in the early 1970s following site preparation and loblolly pine planting. Their presence represents the initial regeneration floristics that follow a major forest disturbance (Egler 1954, Oliver 1981). Their presence in the larger regeneration size classes in this 30-year-old stand also represents normal stand development in minor creek bottoms in the west Gulf Coastal Plain (Bowling and Kellison 1983, Johnson and Krinard 1988). Continued development of these species will result in a moderately dense midstory canopy. Without future silvicultural intervention, this midstory canopy will be detrimental to continued oak seedling establishment and development (Janzen and Hodges 1987, Lockhart and others 2000).

Oak Seedling Development

Eighty-two oak seedlings > 1 foot tall were initially flagged for future measurement (table 5). These seedlings were distributed across the treatments with a maximum of 18 in the low thin-fertilization treatment and a minimum of 8 in the crown thin-no fertilization treatment. Oak seedling survival was relatively poor throughout the 3 year study period, ranging from 50 percent in the low thin-no fertilization treatment to 5 percent in the crown thin-fertilization treatment. While no statistical differences were found between treatments an interesting pattern may be developing that at least allows for making hypotheses for future testing. Survival in the no thin treatment has dropped considerably over the 3 year period, averaging 15 percent by the end of the 2001 growing season. We hypothesize that these seedlings simply do not receive enough sunlight for survival, much less growth. Lockhart and others (2000) noted low survival rates of cherrybark oak seedlings in mature bottomland hardwood stands with a prominent

Table 4—Regeneration density per acre for selected species and selected size classes in an east Texas bottomland hardwood stand 1 year prior and 3 years following thinning and fertilization[a]

Size class	Pre-treatment 1999	1999	2000	2001
American hornbeam and deciduous holly				
> 3 feet tall - < 1 inch d.b.h.	36 (± 31)	7 (± 7)	65 (± 36)	63 (± 53)
1 inch - 3 inches d.b.h.	65 (± 58)	23 (± 18)	102 (± 80)	79 (± 40)
Hickory species				
> 3 feet tall - < 1 inch d.b.h.	4 (± 2)	7 (± 7)	7 (± 4)	9 (± 7)
1 inch - 3 inches d.b.h.	23 (± 13)	27 (± 17)	32 (± 14)	30 (± 20)

Values in parentheses represent 1 standard error.

[a] All thinning and fertilization treatments combined.

Table 5—Survival (percent) of oak reproduction (initial seedling height ≥ 1 foot) by treatment in an east Texas bottomland hardwood stand 3 years following thinning and fertilization. Values in parentheses represent 1 standard error

Thinning treatment	Fertilization treatment	n[a]	1999	2000	2001
No	No	14	88 (± 9)	32 (± 11)	12 (± 9)
	Yes	13	54 (± 12)	45 (± 14)	18 (± 8)
Low	No	16	71 (± 2)	58 (± 5)	50 (± 0)
	Yes	18	67 (± 14)	53 (± 7)	36 (± 11)
Crown	No	8	56 (± 17)	56 (± 17)	38 (± 19)
	Yes	13	63 (± 19)	38 (± 17)	5 (± 4)
p-value			.5493	.7916	.4012
Survival across treatments			67 (± 12)	47 (± 12)	27 (± 9)

[a] n represents the number of oak seedlings ≥ 1 foot across all replicates within a thinning and fertilization treatment combination.

midstory canopy. We also hypothesize the low oak seedling survival rate in the crown thin-fertilization treatment may reflect intense herbaceous competition. While not directly measured, it was noted that crown thin-fertilization treatments resulted in dense herbaceous, and particularly grass, cover.

Height development of these oak seedlings was generally poor (table 6). Initial seedling height was 14 inches and increased to 21 inches by the end of the 2001 growing season. No differences were found between treatments but, as with oak seedling survival, an interesting pattern may be occurring. Seedlings in the thinning treatments appear to be responding to the increased light levels compared to seedlings in the unthinned treatments. The lack of a statistical difference probably reflects the low number of sample seedlings with an associated high variability between treatments, especially for the low thin-fertilization treatment (table 6). Bottomland red oaks have been shown to respond to increases in light levels following midstory competition control (Deen and others 1993, Janzen and Hodges 1987, Lockhart and others 2000).

Height development of oak seedlings > 1 foot tall, including those that grew to this minimum height for measurement during the past 3 years, indicates that oak seedlings are responding to the treatments (table 7). Oak seedlings in the low thinned-fertilized treatment were taller than seedlings in the unthinned treatments after one growing season. This statistical difference disappeared the following 2 years, in part to an increase in the number of oak seedlings growing into the ≥ 1 foot tall size class. Increases in height development over time appear to be occurring but high variability prevents these differences from yet being statistically significant. These trends in height development, for both the original pool of oak seedlings ≥ 1 foot tall and the combined original seedlings and new seedlings that have grown into the ≥ 1 foot tall size class indicate that an oak seedling bank is developing in this mid-rotation aged bottomland oak stand.

Table 6—Height (inches) development of oak reproduction initially ≥ 1 foot tall by treatment in an east Texas bottomland hardwood stand 1 year prior and 3 years following thinning and fertilization

Thinning treatment	Fertilization treatment	Pre-treatment 1999	1999	2000	2001
No	No	13 (± <1)	12 (± 4)	14 (± 6)	14[a]
	Yes	15 (± 1)	14 (± 1)	13 (± <1)	17 (± 5)
Low	No	13 (± <1)	10 (± 2)	12 (± <1)	15 (± 1)
	Yes	16 (± 1)	21 (± 4)	28 (± 13)	31 (± 17)
Crown	No	14 (± <1)	17 (± 1)	21 (± 4)	33 (± 1)
	Yes	14 (± 1)	13 (± 2)	16 (± 5)	5a
p-value		.2566	.1387	.3822	.7679
Height across treatments		14 (± 1)	15 (± 2)	17 (± 5)	21 (± 4)

Values in parentheses represent 1 standard error.
[a] Only one treatment replication contained oak seedlings so no standard error of the mean could be calculated.

Table 7—Height (inches) development of oak reproduction initially ≥ 1 foot tall and those seedlings that grew into the ≥ 1 foot height class by treatment in an east Texas bottomland hardwood stand 3 years following thinning and fertilization

Thinning treatment	Fertilization treatment	1999	2000	2001
No	No	13 (± 1) B[a]	13 (± 2)	15 (± 1)
	Yes	14 (± 1) B	13 (± 1)	15 (± 2)
Low	No	12 (± 1) B	12 (± 1)	15 (± < 1)
	Yes	20 (± 3) A	18 (± 2)	20 (± 4)
Crown	No	17 (± 1) AB	19 (± 1)	21 (± 2)
	Yes	13 (± 2) B	17 (± 2)	19 (± 2)
p-value		.0165	.1039	.1530
Height across treatments		15 (± 4)	15 (± 4)	17 (± 5)

Pre-treatment 1999 values are the same as Table 6.
Values in parentheses represent 1 standard error.
Means followed by a different letter within a column are significantly different at p ≤.10.

CONCLUSIONS

Three years after thinning and fertilization in a 30-year-old bottomland oak stand, few differences were found in the regeneration density for all species, density of oak species, and height development of oak seedlings between treatments. The regeneration pool, especially seedlings < 1 foot tall, consisted of over 2,000 spa with about 75 percent of these stems consisting of oak species. The total regeneration pool is developing as evidenced by the increased density of the larger size classes over time, but a possible problem in this stand is the development of shade-tolerant species in the larger size classes, e.g., American hornbeam and deciduous holly. Without silvicultural intervention these midstory species, along with the hickory species, may hinder future development of the oak reproduction. The size of the oak reproduction is increasing but at a slower rate compared to the other species. Future thinnings, while needed to maintain or increase the diameter growth of desired crop trees in the overstory, should also increase light availability to developing oak reproduction.

Establishment and development of oak regeneration following intermediate stand treatments, such as thinning, may be one way to reduce current oak regeneration problems. Hodges (1987) stated "... the answer to the question of how to insure adequate oak regeneration in bottomland hardwood stands is not the development of some radically new method of cutting, but the recognition that all cutting operations in the stand, from the very first, should have as one of their objectives the creation of an environment, largely light conditions, favorable for oak regeneration." While growth and development of the residual stand is the primary objective of intermediate treatments, establishment and development of oak regeneration should be viewed as an important secondary objective. Future thinnings in the present study will promote the establishment of more oak seedlings, especially as the stand matures and acorn production increases. These thinnings will also benefit the development of advance oak reproduction, possibly negating the need for midstory competition control as currently recommended in mature bottomland oak stands. Development of an advance oak reproduction pool during intermediate treatments should give the forest resource manager more options when the decision is eventually made to regenerate the stand. These options include the development of two-aged stand structures and even the possibility of developing uneven-aged oak stand structures. This increased flexibility afforded the forest resource manager should result in greater oak sustainability in bottomland hardwood stands.

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