COMPARING NATURAL AND ARTIFICIAL METHODS FOR ESTABLISHING PIN OAK ADVANCE REPRODUCTION IN BOTTOMLAND FORESTS MANAGED AS GREENTREE RESERVOIRS

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Abstract—In greentree reservoirs within the Mingo Basin in southeastern Missouri, we compared the survival and growth of underplanted pin oak (*Quercus palustris* Muenchh.) acorns, bareroot seedlings, and RPM® container seedlings in plots that were thinned with and without ground flora control. After one growing season, we found that RPM® container seedlings had the greatest survival (87 percent without ground flora control and 77 percent with) followed by bareroot seedlings (86 percent without ground flora control and 66 percent with). Survival of planted stock was similar to natural reproduction (85 percent in thinned-only plots, 60 percent where thinned with ground flora control and in untreated plots). Direct-seeded seedlings had the poorest survival (9 percent without ground flora control and 4 percent with). Diameter growth of planted stock was significantly less than that of direct-seeded or natural stock; height growth of bareroot stock was less than that of all others.

INTRODUCTION

Oak regeneration has remained an important forest management issue for decades and has proven to be particularly problematic on mesic sites (Johnson and others 2002, Loftis and McGee 1993, Lorimer 1993). On mesic sites, adequate advance reproduction is critical for regenerating oaks (Johnson and others 2002, Lockhart and others 2000). However, oak advance reproduction generally does not accumulate readily in mesic sites (Hodges and Gardiner 1993, Johnson and others 2002), and oak seedlings are less competitive than mesophytic species following release by harvesting (Hodges and Gardiner 1993, Johnson and others 2002, Loftis 1983).

Regenerating oaks in hydric to wet-mesic bottomland hardwood forests presents many of the same challenges as on mesic upland sites (Clatterbuck and Meadows 1993, Janzen and Hodges 1987). Bottomlands commonly have a high capacity to supply both nutrients and water, which generally favors species having exploitive establishment strategies and rapid growth rates (Hicks 1998). Much like on mesic upland sites, oak advance reproduction is critical for regenerating bottomland stands (Clatterbuck and Meadows 1993) but often is inadequate in size and number largely because of competition by mesophytic species. Oak regeneration in bottomlands is further complicated by poorly drained soils and flooding, which favor species that are more tolerant of wet conditions than are most bottomland oaks.

The continued interest in regenerating bottomland oaks and the recognition of the importance of advance reproduction has lead to many studies evaluating methods for establishing oak advance reproduction in bottomland forests (Gardiner and Hodges 1998; Janzen and Hodges 1985, 1987, Lockhart and others 2000). Most studies have focused on midstory and understory thinning with and without herbicides to control competition and to increase light levels reaching the forest floor in an effort to increase the density and size of advance reproduction (Janzen and Hodges 1985, 1987; Lockhart and others 2000). These studies have shown that increasing the sunlight reaching the forest floor increases the size and density of natural oak advance reproduction (Janzen and Hodges 1985, 1987) as well as underplanted stock (Lockhart and others 2000) for many of the southern bottomland oaks.

Oak regeneration has remained an important problem in greentree reservoirs within the Mingo Basin in southeastern Missouri. Pin oak (*Quercus palustris* Muenchh.) is the most abundant overstory species in these forests and is valued for its mast production for waterfowl and other wildlife. However, efforts to regenerate pin oaks in the Mingo Basin have failed, largely because advance reproduction is absent or inadequate. It is unclear whether this inadequate advance reproduction has resulted from the lack of light reaching the forest floor, the fall and winter flooding associated with water management in greentree reservoirs, or a combination of both. During the past few years, greentree reservoir managers in Missouri have modified water management regimes to more closely resemble the natural hydrologic cycle and also have improved drainage in greentree reservoirs to keep them drier during the growing season. Studies are needed to determine how to modify the amount of sunlight reaching the forest floor to create or enhance pin oak advance reproduction in greentree reservoirs under the improved water management regimes. Moreover, unlike other commercially important bottomland oaks, relatively little is known about how to establish pin oak advance reproduction (Smith 1993).

Our objective was to compare natural and artificial methods for establishing advance reproduction of pin oak in greentree reservoirs in the Mingo Basin. We compared the survival and growth of natural pin oak reproduction in plots where the midstory was thinned and the ground flora was or was not controlled, and in untreated (control) plots. We also compared the survival and growth of underplanted pin oak acorns, bareroot seedlings, and large container seedlings produced with the root production method (RPM®) (Dey and others 2004) in plots having these same thinning and ground flora treatments. Our goal was to determine if pin oak advance reproduction could be established within bottomland forests managed as greentree reservoirs.

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METHODS

Study Sites

This study was conducted within two greentree reservoir management pools, one in Mingo National Wildlife Refuge managed by the U.S. Fish and Wildlife Service and the other in Duck Creek Conservation Area managed by the Missouri Department of Conservation. Both study areas are located within the Mingo Basin in Stoddard County north of Puxico, MO. The Mingo Basin is the largest remaining tract of bottomland hardwood forest in the Upper Mississippi Alluvial Valley (Missouri Department of Conservation 1999).

The pools within these areas have been managed for waterfowl habitat and hunting for more than 50 years and are flooded nearly annually for short periods during the fall waterfowl migration and hunting season, approximately November and December. Before 1999, the pools were flooded to depths of 6 to 20 inches prior to the waterfowl hunting season and drained after the season ended. Since then, managers have varied the timing and duration of flooding to match the season's weather conditions by flooding some of the pools later for shorter durations during dry years and earlier and longer during wet years. The flood scheduling is varied by pool so that adjacent pools have slightly different regimes. This scheduling, on average, floods individual pools to shorter than average durations once every 3 years and longer than average durations once every 3 years (Missouri Department of Conservation 1999).

The two pools were selected so that we could evaluate methods for establishing advance reproduction in both healthy and declining stands. Pool eight (Mingo National Wildlife Refuge) was selected because the oaks appeared to be healthy, and there was very little observable crown dieback or mortality. Pool three (Duck Creek Conservation Area) was selected because the oaks exhibited moderate or advanced decline and had compromised mast production.

In these two pools, pin oak was the dominant species (54 percent of the basal area). Other important species included sweetgum (*Liquidambar styraciflua* L., 12 percent), overcup oak (*Q. lyrata* Walt., 10 percent), red maple (*Acer rubrum* L., 7 percent), American elm (*Ulmus americana* L., 6 percent), willow oak (*Q. phellos* L., 5 percent), green ash (*Fraxinus pennsylvanica* Marsh., 2 percent), persimmon (*Diospyros virginiana* L., 1 percent), and cherrybark oak (*Q. pagoda* Raf., 1 percent).

Design

We used a randomized complete block design with a total of six blocks, each containing nine treatment units. During the summer of 2002 in each of the two management pools, we established 3 10-acre blocks containing 9 1.1-acre treatment units that were 220 by 220 feet wide. Blocks were positioned and configured so that they were internally homogeneous in stand conditions. In the center of each of the nine experimental units, we established a circular, 0.2-acre plot and recorded the species and diameter of all trees ≥ 1.5 inches d.b.h. Within 0.2-acre plots, trees < 1.5 inch d.b.h. were inventoried in five 0.01-acre subplots.

Treatments

In each of the experimental units within each block, we randomly assigned one of nine treatments (table 1). The nine treatments included thinning in combination with each of four stock types (natural, direct seed, bareroot, RPM® container) and two ground flora control treatments (herbicide versus none), and one control (not thinned). The thinning treatment was intended to increase the amount of photosynthetically active radiation (PAR) to the oak seedlings. The different artificial stock types represented those most commonly available to forest managers in the region to provide reasonable comparisons to the alternative of relying on natural reproduction. The ground flora control treatment was to remove competing vegetation including undesirable tree species and woody vines released by the thinning treatment.

Table 1—The nine treatment combinations compared in the study[a]

		Midstory and understory thinning	
Stock	Control	With ground flora control	Without ground flora control
Natural	X	X	X
Direct seed		X	X
1-0 bareroot		X	X
RPM® container		X	X

[a] Midstory and understory thinning treatments were applied to all non-oaks as small as 0.5 inches d.b.h. Ground flora control was a foliar application of herbicide to all woody and herbaceous vegetation surrounding each tagged pin oak seedling. The control treatment was not thinned and only natural pin oak reproduction was monitored. Stock types (all pin oak) included natural seedlings ≤ 1-year old, seedlings from direct-seeded acorns, 1-0 bareroot seedlings, and one-year-old RPM® container (3 gallon) seedlings.

The thinning treatment was conducted during February 2003, to remove all non-oaks in the midstory and understory as small as 0.5 inches d.b.h. This was done by spraying 0.03 ounces of Arsenal® AC solution (20 percent concentration) into hacks made in the tree bole with a hatchet having a 1.25-inch bit. We made a single hack (plus herbicide application) per 3 inches d.b.h. approximately 4.5 feet above the ground. Except for the control, the thinning treatment was applied across the entire 1.1-acre experimental unit. We revisited all treated trees after the first growing season and re-treated those that had not died.

In April 2003, we sowed pin oak acorns within 0.2-acre plots in all experimental units designated for direct seeding. Acorns were purchased from the Missouri State Nursery in Licking, MO. These had been collected during the preceding autumn and screened for soundness, stratified, and stored according to standard nursery practices. In each 0.2-acre plot, 40 acorns were planted by hand 3 inches deep approximately 15 feet apart in concentric circles around the plot center. All planting locations were marked with a numbered wire tag.

Also in April 2003, we planted 22 bareroot pin oaks and 22 RPM® pin oak container seedlings, each in their respective designated treatment units. These were planted approximately 20 feet apart in concentric circles around the plot center within each 0.2-acre plot and marked with a numbered metal tag. In treatment units designated for natural reproduction, we marked up to 22 natural pin oak seedlings with numbered tags within 0.2-acre plots. We selected only those individuals that appeared to be 1-year-old as evidenced by the presence of the acorn attached to the base of the stem. The initial basal diameter and height of all stock other than the direct-seeded acorns was recorded immediately after tagging.

In June 2003, the ground flora control was applied to those units designated for this treatment. For the ground flora control, we applied Garlon® 3A solution (6 ounces of chemical per gallon of water) with a Solo® backpack sprayer to the foliage of all herbaceous vegetation and non-oak woody vegetation within the 0.2-acre plot. Oak seedlings where shielded during the herbicide application to minimize their injury caused by drift.

Measurements

In July, the canopy cover above each seedling was measured using a spherical crown densiometer. At this time, we re-measured the heights of all tagged seedlings. All plots were revisited again in late September so that first-year survival of tagged seedlings could be determined, and the basal diameter and height of each seedling could be re-measured.

Hydrology can influence seedling survival and growth, and because we could not be assured that hydrologic conditions would be uniform among treatment units within blocks, we monitored the soil water content. To do this, we buried Watermark sensors (Irrometer Company, Inc., Riverside, CA) 4 inches below the soil surface in the center of each treatment unit. Meter readings were taken weekly during the first growing season from June 18 to September 17, 2003. We conducted a laboratory calibration study with soils from each block to determine the relationship between the meter reading and gravimetric water content. This calibration study allowed us to develop equations for converting meter readings made in the field to estimated gravimetric soil water content.

Analysis

We used the general linear models procedure (SAS version 9.1) to evaluate the overall treatment effects ($\alpha = 0.05$) on the basal diameter and height growth of each of the stock types. We included the gravimetric soil water content and percent canopy cover (averaged by plot) as covariates in this analysis. We also used orthogonal contrasts ($\alpha = 0.05$) to compare growth of each of the artificial stock types to that of the natural stock.

RESULTS

During the application of the midstory and understory thinning treatment, we treated 328 trees per acre (27 square feet per acre). Most of the treated trees were sweetgums, red maples, green ashes, and American elms, all of which were the most prevalent in midstories of these forests. This treatment effectively reduced the canopy cover from 91 to 83 percent (table 2). We found no canopy cover differences between declining (pool 3) and healthy (pool 8) plots.

In thinned plots without ground flora control, the first-year survival of the bareroot, RPM®, and natural stock exceeded 80 percent and was more than 20 percent greater than the survival of natural stock in non-thinned (control) plots (fig. 1). The survival of direct-seeded stock was less than 9 percent but largely because the acorns failed to germinate rather than because they died during the first growing season. We found that the ground flora control treatment decreased the survival of all stock by 5 to 20 percent.

The diameters and heights of the different stocks varied considerably from each other (fig. 2). When planted, the RPM® stock was about 3 feet tall and nearly 0.5 inches in basal diameter, about 30 percent larger than the bareroot stock and more than 5 times larger than the natural seedlings. Of greater interest to our study was the growth increment that occurred during the first growing season. The natural seedlings and direct-seeded stock had significantly greater ($P < 0.01$) diameter growth than did the RPM® and bareroot stock. The bareroot stock produced significantly less ($P < 0.01$) height growth than did the other stock types. We also found that controlling ground flora competition with Garlon® 3A did not significantly improve seedling diameter or height growth ($P > 0.42$). Surprisingly, we also observed that the natural stock in the controls had positive diameter and height growth, comparable to natural stock in the thinned plots.

Neither canopy cover nor gravimetric soil water content were significant covariates in our analyses. This does not mean that these are not important determinants of seedling survival and growth. Rather, the lack of significance shows that we successfully designed the experiment so that it was not confounded by gross differences in canopy cover or gravimetric soil water content.

Table 2—Percent canopy cover thinned and unthinned (control) plots measured 6 months after treatment[a]

Management pool	Canopy cover Control	Thinned
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Pool 3 (declining)	91	86
Pool 8 (healthy)	90	81
Overall	91	83

[a] Thinning treatment included deadening the midstory and understory (approximately 328 stems per acre). Pool three (Duck Creek Conservation Area) was selected because the oaks exhibited moderate or advanced decline and had compromised mast production. Pool eight (Mingo National Wildlife Refuge) was selected because the oaks appeared to be healthy and there was very little observable crown dieback or mortality.

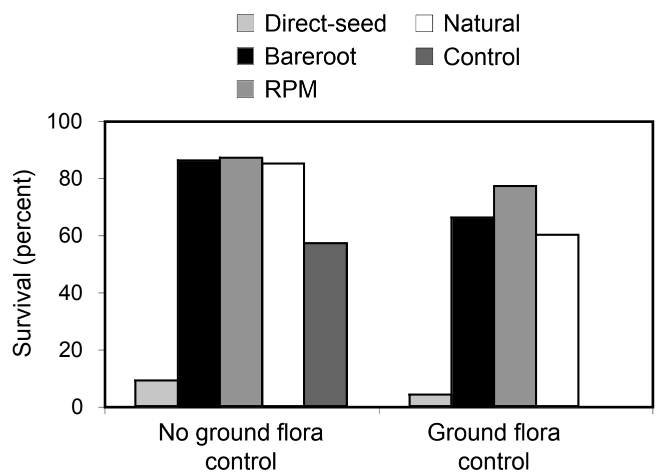

Figure 1—First-year pin oak seedling survival by treatment and the four stock types: natural seedlings, seedlings from direct-seeded acorns, bareroot seedlings, and RPM® container seedlings.

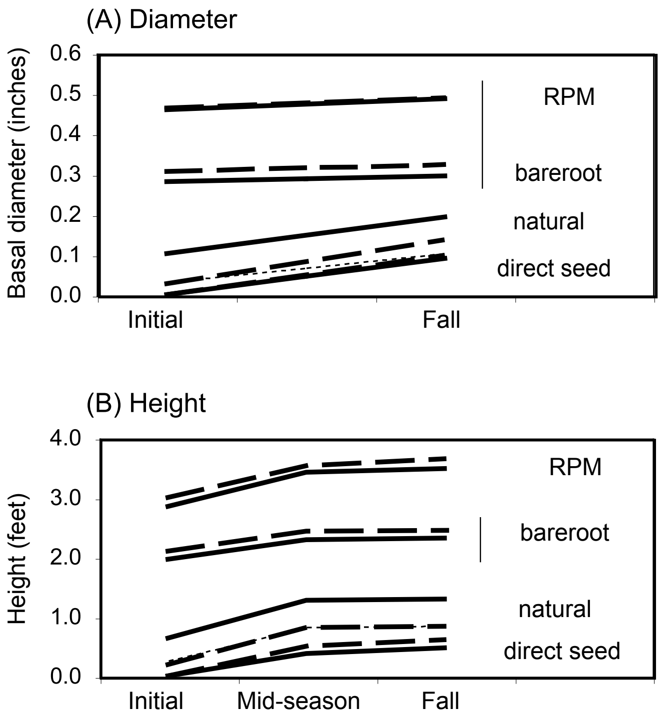

Figure 2—Diameter (A) and height (B) of pin oak seedlings measured during and after the first growing season for the four stock types: natural seedlings, seedlings from direct-seeded acorns, bareroot seedlings, and RPM® container seedlings. Dashed lines indicate data from plots where competing ground flora were controlled with a foliar application of Garlon® 3A; solid lines indicate data from plots where competing ground flora was not controlled. Vertical bars identify a growth increment that was significantly different ($\alpha = 0.05$) from that of the natural stock.

DISCUSSION

The thinning treatment reduced the stand density to similar levels reported by others who applied similar methods to bottomland forests in other regions. Janzen and Hodges (1985) reported that midstory and understory thinning removed about 25 square feet per acre in a bottomland forest located in north-central Mississippi. In our study, most of the stems that we treated (70 percent) were < 4 inches d.b.h. However, we cannot compare the number of stems that we treated to those of Janzen and Hodges (1985), because they only reported data for stems greater > 4 inches d.b.h.

Ultimately, the purpose of the midstory and understory thinning was to increase the PAR reaching the forest floor to benefit the oak seedlings while not releasing competing vegetation. Although we did not measure PAR in our study, we do note that Lockhart and others (2000) reported that midstory thinning in bottomland forests in north-central Mississippi increased PAR by > 4 to 10 times. Moreover, Gardiner and Hodges (1998) demonstrated that cherrybark oak seedlings had greater stem growth and produced more biomass under partial shade than under full sunlight. This was an important finding, because it demonstrated the benefits of partial sunlight to seedlings of species considered to be shade intolerant, as are many other bottomland oaks, including pin oak.

All stock grew well, and first-year growth was comparable to other bottomland oak seedlings in forests (Janzen and Hodges 1987, Lockhart and others 2000) or planted in former crop fields (Kabrick and others 2005, Shaw and others 2003). Even the growth of the natural stock in the non-thinned (control) plots was not significantly less than in the thinned stands, although survival was considerably lower. It probably is too soon to know whether or not the midstory and understory thinning has benefited the seedlings. Most of the underplanting studies in bottomland forests suggest that it may take 3 to 5 years or more before large growth differences caused by midstory and understory thinning are observed (Janzen and Hodges 1987, Lockhart and others 2000).

We cannot explain why the direct-seeded acorns had such low germination rates, and undoubtedly many factors contributed to our poor success. The acorns that we sowed were provided by the Missouri state forest nursery and were collected and screened in the same manner as are all red oak group acorns routinely handled by this facility. We planted the acorns within 24 hours of receiving them from the nursery the following spring, so we assume that the acorns did not became too dry during our handling. However, most direct seeding is done during the fall and consequently, red oak group acorns are not routinely stored and stratified at the nursery for spring planting as were our acorns. We purposely seeded in the spring because we were concerned that acorns sowed in the fall would not only be subjected to extensive flooding but also to predation during waterfowl season. Despite our efforts to ensure higher germination and survival by seeding in the spring, we may have reduced our success by storing the seed. Although our germination rates do not represent the best that can be expected from direct seeding, they probably do represent what can happen following an operational spring seeding.

First-year control of ground flora competition with Garlon® 3A is probably unnecessary, because it decreased the survival and failed to increase the growth of the pin oak seedlings. Oaks, like many other woody species, are susceptible to Garlon® 3A. Despite our efforts to shield the oaks during the foliar application to surrounding competing vegetation, we apparently had sufficient drift or flashback to substantially reduce oak seedling survival. Moreover, the herbaceous and woody competition apparently was not sufficiently severe to reduce seedling growth. Similarly, Gardiner and Yeiser (1999) found that controlling Japanese honeysuckle (*Lonicera japonica* Thunb.) with herbicide in thinned bottomland stands did not increase the first-year survival or growth of underplanted cherrybark oak.

Future measurements include examining the net photosynthesis of the pin oak seedlings to determine if net photosynthetic production is positive under partial canopy cover created by the midstory and understory thinning. We will also continue to monitor seedling survival and growth for the next 3 to 5 years to determine the probability of producing advance pin oak reproduction of a specified caliper and height.

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