ESTABLISHING PIN OAK REPRODUCTION IN BOTTOMLAND FORESTS IN SOUTHEASTERN MISSOURI

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By

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The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled:

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Presented by Nicholas J. Krekeler

A candidate for the degree of Master of Science

And hereby certify that in their opinion it is worthy of acceptance.

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DEDICATION

I would like to dedicate this thesis to my wife, Melissa and daughter Hailey.

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ABSTRACT

Long term effects of silvicultural treatments on oak reproduction in bottomland forests are not well understood. In pin oak (*Quercus palustris* Muenchh.) bottomland hardwood forests in southeast Missouri, we revisited research plots in clearcuts shelterwood harvests and controls within the Mingo Basin. 17 years later, we found significant changes, in both the change in basal area and changes in trees per acre for each of the species and genera present in the treatments, than were reported five years since the cuttings occurred. Regardless of harvest treatment, the reproduction was dominated by red maple (*Acer rubrum* L.) and green ash (*Fraxinus pennsylvanica* Marsh.), which were originally abundant in the advance reproduction layer. Maple and ash were abundant because they are more tolerant of shade and flooding than pin oak, and consequently had become well established in the understory as advance reproduction at Duck Creek Conservation Area. Successful regeneration of pin oak in bottomland forests will be more likely if a silvicultural prescription includes the control of competing woody vegetation in combination with a reduction in overstory density to increase available sunlight in the understory, and enrichment plantings of oak to ensure adequate numbers of advance reproduction are present.

Predicting the mortality of overstory and midstory trees during a thinning treatment is critical when creating a light environment suitable for the establishment and recruitment of oak reproduction in existing bottomland forests. In greentree reservoirs within the Mingo Basin in southeast Missouri, we compared pretreatment midstory tree species' conditions (crown class, initial dieback, live crown ratio, and diameter) with their mortality following a dormant season herbicide injection given at a rate of 1 mL and hack per three inches in diameter of a 20% Imazipure solution. Tree mortality rates varied significantly by species. Models developed suggest that green ash and American elm (*Ulmus Americana* L.) trees were effectively deadened by the midstory treatment, and sweetgum (*Liquidambar styraciflua* L.) and red maple trees were not deadened effectively. Changes to the herbicide prescription are presented. Utilizing these prediction models will allow managers to write prescriptions that will create light levels that favor oak reproduction in existing bottomland forests.

In greentree reservoirs within the Mingo Basin in southeastern Missouri, we compared the survival and growth of underplanted pin oak 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 without). 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 was significantly less than the other stock types.

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

Although wetlands were recognized for their valuable fish and wildlife resources, they were originally viewed as undesirable and unproductive lands that could not be developed or cultivated by early European settlers (Bowlin 1849). Over time, the fertility of these areas was recognized and many of the wetlands were converted to other uses, primarily agriculture production. Recently, major river wetland productivity has been recognized to be among the highest of all ecosystems (Mitch and Gosselink 1993). Although wetlands do contain mesic prairies and other terrestrial natural communities, many of the wetlands of Eastern United States and Missouri were historically bottomland hardwood forests. Throughout the continental United States, an estimated 53% of wetlands have been cleared and drained for agriculture from the 1780's to 1980 (Dey et al. 2003). In Missouri, an estimated 87% of wetlands have been converted to other uses (Dey et al. 2003). Of the remaining 13%, the largest contiguous tract of wetland containing natural bottomland hardwood forest in Missouri is Mingo National Wildlife Refuge (MNWR) and adjoining Duck Creek Conservation Area (DCCA) (Nigh and Schroeder 2002).

Found at MNWR and DCCA are large tracts of red oak dominated bottomland hardwoods that provide hard mast to migratory waterfowl that utilize these forests in the fall and spring. These forests, too, have gone through many changes to reach their present state and even now the naturally flooded live forests have declined from 1880 to

1983 from 82% to 48% of the total land area of the Mingo Basin (Heitmeyer et al. 1989). Furthermore, the species composition of the mostly oak-dominated bottomland hardwood forests found in the Mingo Basin has been shifting to more shade- and flood-tolerant species such as red maple (*Acer rubrum* L.) and green ash (*Fraxinus pennsylvanica* Marsh.) (Hamilton et al. 1991). Silvicultural treatments, to maintain red oaks as a key component of the forest within the Mingo Basin, are the central focus of this work.

A BRIEF HISTORY OF THE MINGO BASIN

MNWR and DCCA are located in an abandoned channel of the Mississippi River. The migration of the channel occurred an estimated 18,000 years before present (Heitmeyer et al. 1989). After the migration, the St. Francis and Castor Rivers, which still flood the swamp, created alluvial fans in the abandoned channel and slowed the drainage of MNWR and DCCA creating the Mingo wetland complex (Heitmeyer et al. 1989). Within this complex flooding from both a major river (Mississippi) and minor rivers (St. Francis and Castor) continue to influence the present forest composition.

In addition to the rivers, humans have also impacted the bottomland forests found in the wetland basin on MNWR and DCCA. The name Mingo is theorized to be named for Chief Mingo of the Shawnee who once lived nearby (Thomas 1976). Native Americans did not settle Mingo, but the Osage and the Shawnee were known to utilize the abundant wildlife supported by the Mingo Basin (Thomas 1976). Initially, few European settlers lived near the Mingo Swamp, but in the late 1880's logging operations commenced (Forrister 1970). By the 1920's, the forests were cleared for agriculture, roads were built, and 15 drainage ditches were dug reducing the area of natural ponds and sloughs and greatly altering the flooding (Heitmeyer et al. 1989). Forest disturbances and land use by the settlers promoted oak species in mixed bottomland hardwoods, which represented a substantial change from the original cypress-tupelo forest in the Mingo Basin (Thomson 1980).

Over the past 100 years, humans have drastically changed the forest cover and hydrology through major shifts in land use practices. Abandonment of agriculture fields, cattle grazing in forests, and occasional fires in the early 20th century promoted the development of oak dominated forests in the Mingo Basin (Heitmeyer et al. 1989). The naturally-flooded native forest that once occupied 82.1% of the area in 1880 was reduced to 54% of the area by 1983 (Heitmeyer et al. 1989). Of the remaining forest 5.7% of the area was developed as green tree reservoirs (GTRs) (Heitmeyer et al. 1989). Dominant oak species common in this bottomland hardwood forest include pin oak (*Quercus palustris* Muenchh.)(54% of the basal area), overcup oak (*Q. lyrata* Walt.)(10%), willow oak (*Q. phellos* L.)(5%), and cherrybark oak (*Q. pagoda* F.)(1%). Other important species include sweetgum (*Liquidambar styraciflua* L.)(12%), red maple (7%), American elm (*Ulmus americana* L.) (6%), green ash (2%), and persimmon (*Diospyros virginiana* L.) (1%).

Beginning in the 1940's, green tree reservoirs (GTRs) were constructed by building levees in bottomland hardwood forests which containing pin oaks. The levees were used to control the flooding of timber for waterfowl hunting and habitat. Pin oak is highly desired by waterfowl managers because of its mast production. Initially, the pin oak trees in GTRs showed little change in growth, compared to trees in adjacent stands outside the GTRs that experienced more natural flood regimes (Minkler 1967). Pin oak acorn production was greater initially in GTRs than found in adjacent naturally flooded stands (Minkler and McDermott 1960), and later, found not to be reduced (McQuilkin and Musbach 1977). However, Rogers and Sander (1989) found that dormant season flooding in GTRs reduced basal area growth of the residual stands by 10% following two thinning treatments during their 30 year study. Even though flooding reduced basal area growth, that reduction in growth was accepted as a tradeoff for the benefit of the creation of waterfowl habitat by the GTRs (Rogers and Sander 1989). During the past several decades managers observed in these closed-canopy stands that there was (1) a lack of desirable pin oak and other red oak reproduction in the understory, (2) a lack of midstory oak saplings, and (3) an abundance of more shade and flood tolerant red maple, green ash, and American elm in these forest layers (Hamilton et al. 1991). Concerns for the sustainability of pin oak in the GTR stands emerged from this successional shift to non oak species, which was heightened by the beginnings of a decline or an increasing mortality of mature oak.

CURRENT MANAGEMENT CONCERNS

Maintaining the species composition of red oaks in the overstory of future stands requires the establishment of these species in the advance reproduction layer prior to a regeneration harvest. The success of oak regeneration is contingent largely on having adequate numbers of large oak advance reproduction (Johnson 1979, 1992, Janzen and Hodges 1985 and 1987, Hodges 1989, Loftis 1990, Hodges and Gardiner 1993, Rogers et al. 1993, Dey et al. 1996, Lockhart et al. 2000). The problem of producing adequate oak advance reproduction on productive sites has been well documented across many forest types (Clark 1993).

Regeneration of oak species at DCCA and MNWR has been a concern for more than 30 years (Hamilton et al. 1991). Bottomland forests at MNWR and DCCA contain desirable quantities of oaks in the overstory; however, these forests are reaching their physiological maturity. Large mature pin oaks are declining without established advance reproduction layers to take their place in the future stand. Most of the advance regeneration is composed of red maple, American elm, and green ash which are more shade and flood tolerant than desirable species such as pin oak, willow oak, and cherrybark oak (Burns and Hokula 1990).

At DCCA, Hamilton et al. (1991) developed a study to compare the effectiveness a shelterwood cut (Basal area = 30 ft^2/ac), a clearcut (Basal area = 0 ft^2/ac), and a control as methods for regenerating oak inside and outside of GTRs from 1984-1989. The fifth-year results from this study showed that pin oak seedling numbers and heights were greater in units that received shelterwood cuts than in units that received clearcuts. Within GTRs, pin oak height growth was greater on drier sites than on wet sites but pin oak seedling establishment was not affected as much by site wetness. In contrast, red maple regeneration was much more abundant and taller than pin oak regeneration in units regardless of cutting methods and site wetness. Abrams (1998) has reported that red maple seedlings and saplings form a dense canopy in the midstory and exclude less shade tolerant species such as oaks in partially cut stands. Hamilton et al (1991) reported the greatest frequency of tall (>20 in) pin oak seedlings occurred in the shelterwood cut plots. They concluded that shelterwood cuts were better for promoting pin oak regeneration than clearcuts. Young pin oak seedlings were noted along the edges of the clearcuts that came from mature acorn producing trees in the adjacent stands. This anecdotal observation highlights the importance of seed source and indicates that pin oak, considered shade intolerant (McQuilkin 1990), is able to grow in partially shaded conditions, at least as young reproduction.

The results obtained five years after harvest suggested that the shelterwood harvest would likely provide adequate oak regeneration. However, a measurement of the research plots 17 years after harvest showed that there was insufficient oak regeneration in both the shelterwood and clearcut treatment areas (see chapter 2). Regardless of harvest treatment, the reproduction was dominated by red maple and green ash, which were originally abundant in the advance regeneration size class. Maple and ash were abundant because they are more tolerant of shade and flooding than pin oak, and consequently that had become well established in the understory as advance reproduction at Duck Creek.

A study at DCCA by Kabrick and Anderson (2000) showed that pin oak stump sprouts one growing season after a dormant season cutting are not as tall or vigorous as upland oak sprouts, especially on wet sites. Similarly, Lockhart et al. (2002), Gardiner and Helmig (1997), and Golden (1999) found that decreased light levels and other disturbances such as drought or flooding reduce the ability of cherrybark oak, water oak (Quercus nigra L.), and other oak species to successfully produce stump sprouts. This suggests that excessive wetness and reduced light availability from GTR management is decreasing oak vigor and the ability of oak species to produce competitive stump sprouts.

In oaks, stump sprouting probability decreases with increasing diameter (Johnson 1975). The large diameter pin oaks averaging 44 centimeters dbh at DCCA and MNWR are disadvantaged compared to maple and ash which are smaller diameter both averaging 9 centimeters dbh and have high sprouting potential. In 132 by 264 foot rectangular clearcuts in a bottomland mixed oak forest on the floodplain of the Tombigbee River in southwestern Alabama, Golden (1999) noted that the lack of smaller diameter oaks in the reproduction layer prior to harvest gave an advantage to competing species stump sprouts originating from smaller trees. In their regeneration plots at DCCA, Hamilton et al. (1991) noted that the cut pole-sized red maple stems sprouted profusely. When sprouting is unreliable and adequate amounts of desirable advance reproduction are absent, planted stock is often required to establish a reproduction layer to recruit into the overstory following additional overstory treatments.

Other studies have shown that red oaks can establish successfully under a partial overstory. In Missouri, Johnson (1992) underplanted large (1/2 inch caliper) northern red oak (*Quercus rubra* L.) bareroot seedings in an upland shelterwood of 60% stocking, and he controlled undesirable woody vegetation and competing stump sprouts with 2, 4-D plus picloram (Tordon® RTU). Five years after overstory removal, Johnson (1992) found that 60% of the planted oaks were dominant and codominant growing stock. Chambers and Henkel (1989) established Nuttall (*Quercus nuttallii* Palmer) oak seedlings under a partial overstory, however the seedlings were never released nor later evaluated. In a 70-80 year old elm, ash, hackberry (*Celtis occidentalis* L.), boxelder (*Acer negundo* L.), and American sycamore (*Platanus occidentalis* L.) stand in South Carolina, Nix and Cox (1987) found that the increased light intensity reaching the forest floor, with a partial overstory reduction, revitalized undesirable competing vegetation. In northern Arkansas on north to northeast facing slopes in a mixed oak upland forest shelterwood harvest underplanted with northern red oak seedlings, Spetich et al. (2002) found that increasing the intensity of herbicide treatment on competing species reduced the difference between the heights of the planted oak seedlings and their competitors. In treatments that reduced the stocking percentage to 40 and 60, there were greater probabilities of dominant oak than treatments that retained a higher residual stocking percentage of 80% (Spetich et al. 2002). These studies suggest that the key to successful oak regeneration is to reduce overstory density largely to increase light in conjunction with controlling competing vegetation.

In a minor bottomland forest with red oaks and sweetgum in the overstory in Southeast Arkansas, Gardiner and Yeiser (2000) observed excellent survival of cherrybark oak seedlings under a partially overstory with little influence of pre-planting competing vegetation control. In this study, the residual stocking of the overstory following was about 30% and the basal area equaled roughly 35 ft^2 per acre. They expected that post planting vegetation control would be a benefit to future seedling growth and form resulting from the removal of competing woody vegetation (Gardiner and Yeiser 2000). In a stand of mixed oak bottomland forest with a well developed midstory located near Bellamy, Alabama, Peairs et al. (2004) showed that stands with 50 residual square feet of basal area, compared to stands with 30 and 70 square feet of basal area, showed the largest increases in initial oak reproduction density. It was also noted that harvesting in conjunction with a good mast production year tended to enhance initial regeneration (Peairs et al. 2004). Furthermore, Parker and Dey (2008) found, in a mixed red oak dominated stand near Foymount, Ontario, that red oak (*Quercus rubra* L.) had a larger improvement of photosynthetic capacity, with an increase of irradiance in a shelterwood harvest that reduced the crown cover from 97% (control) to between 49 and 80%, than sugar maple (*Acer saccharum* Marsh.). This study shows that adaptations, in this case drought tolerance of northern red oak (Parker and Dey 2008) a mid shade-tolerant species, may give northern red oak a competitive advantage over a shade tolerant species when light is increased with a shelterwood cut.

Season, duration, depth, and frequency of flooding effect tree species' survival in a bottomland hardwood forest. The effects often change over the stages of development in a forest. During the reproduction stage, several bottomland oak species have developed reproduction strategies to grow in a floodplain. For example, overcup oak has a floating acorn and is often found deposited in large quantities in areas where water exits a stand after flood events. Pin oak acorns sink but germinate later in the spring to avoid winter floods. Additionally, their acorns have a waxy coating that allows them to be submerged for more than six months (Kabrick and Dey 2001). Red maple a common competitor at DCCA and MNWR has floating, winged, wind dispersed seeds that mature in the spring and avoid dormant season flooding altogether. From the pole stage through maturity pin oak is moderately flood tolerant, but competitors in the midstory, such as red maple and green ash, are rated as relatively flood tolerant (Burns and Honkala 1990). A shift in both water and light environment as an oak dominated bottomland hardwood forest matures tends to shift the future forest composition away from oak and to a dominance of more shade and flood tolerant species, such as elm and red maple (Kabrick and Dey 2001).

STUDY PURPOSE / OBJECTIVES / HYPOTHESES

The goal of our research is to identify the optimum techniques for regenerating bottomland pin oak stands in both naturally flooded and artificially flooded pools (GTRs) at MNWR and DCCA. To help identify these techniques, we reevaluated the reproduction density and size occurring in an overstory manipulation study first analyzed five years after treatment and now 17 years since treatment. This study is referred to as the Hamilton study. Secondly, a new study was initiated to evaluate natural and artificial pin oak reproduction types following a midstory and understory treatment with and without ground flora control. An examination of the effects of an herbicide treatment, on major tree species competing with pin oak reproduction, was also analyzed.

An understanding of tree species competitive interactions, as well as, the competitive interactions between trees and other vegetation is critical when creating environments suitable for the reproduction and growth of a desired species (Johnson 1992). Low understory light levels, as well as, flooding as a bottomland hardwood forest matures often promote the establishment and growth of undesirable species. The complex midstory and understory interactions of a mature bottomland pin oak forest on future forest composition are not well understood due to limited study and interest in the species because of pin oak's poor merchantability and restricted distribution to sites in the upper Mississippi alluvial valley. Pin oak is a short lived red oak species reaching physiological maturity at 80 to 100 years, but little is known about its maximum longevity (McQuilkin 1990). Furthermore, manipulation of this midstory and understory is critical to understand when creating an environment suitable for the establishment of an advance reproduction layer of pin oak.

The main purpose of this study was to evaluate methods to promote pin oak regeneration though overstory density reduction and control of mid- and understory-competing vegetation. An evaluation was made on various pin oak reproduction types: natural seedlings, direct seeded acorns, 1-0 bareroot seedlings, and 3 gallon RPM® (Dey et al. 2004) containerized seedlings. Under each of the vegetation treatments, survival, height, and diameter growth of was used to assess treatment effects.

The specific objectives of the revisit to the Hamilton study were:

1) To compare changes to the density and size of pin oak reproduction and other non oak species 17 years since a regeneration (clearcut) treatment, shelterwood treatment (Basal area = 30 ft^2/ac), and a control.

Hypotheses tested were:

1. Ho: The change in proportion of reproduction stems (< 8 inches dbh) per acre and reproduction basal area of each species or species group does not differ among treatments (clearcut versus shelterwood cut versus control) from 1989 to 2001.

2. Ho: The change in proportion of reproduction stems (< 8 inches dbh) per acre and basal area of each species or species group does not differ among elevations (wet versus dry sites) from 1989 to 2001.

3. Ho: The change in proportion of reproduction stems (< 8 inches dbh) per acre and basal area of each species or species group does not differ among management (GTRs versus naturally flooded stands) from 1989 to 2001.

The specific objectives of the new study were:

1) Establish a study in the Mingo basin that would compare the competing midstory species mortality resulting from a winter hack and squirt application of a 20% solution of imazapyr herbicide.

   Hypothesis tested was:

   1. Ho: There is no difference in crown dieback between the competing tree species following a winter hack and squirt application of a 20% solution of imazapyr herbicide.

2) To compare the survival and caliper and height growth of natural, bare root, and containerized 3 gallon RPM stock following a midstory competing tree species control treatment with and without a ground flora control in a naturally flooded and in a artificially flooded pool (GTR).

Hypothesis tested was:

1. Ho: There is no difference in the survival, caliper growth, or height growth of natural, bare root, and containerized 3 gallon RPM stock following a midstory competing tree species control treatment with and without a ground flora control in a naturally flooded and artificially flooded pool.

NEW STUDY SITES

Management pools 3 and 8 were selected within the Mingo basin to conduct our new research (Figure 1). Pool 3 is located in DCCA. It is a constructed GTR that has mature pin oaks dominating the overstory with a well developed midstory of red maple, sweetgum, green ash, and American elm. Pool 3 has been flooded annually in the late fall to provide hunters access to hunting blinds located throughout the pool. The mean depth of flooding in the GTR is just over 45 centimeters (Hamilton et al. 1991). The flooding produces habitat for wood ducks and other waterfowl that utilize timberlands during fall migration. After the hunting season is over, water control structures are opened to allow the pool to drain. Even after drawdown, natural flood events can occur by means of onsite rainfall, backwater flooding, and headwater flooding along the ditches (Heitmeyer et al. 1989). Within the pool, three blocks were selected between the drainage ditches and away from the hunting openings so that the entire block was an internally homogeneous mature oak forest typical of that found in the area.

Pool 8 is located in MNWR and is not subject to the controlled annual flooding of the adjacent GTR. Rather, natural flooding from backwater flood events, headwater flood events, and onsite rainfall periodically cause flood disturbances throughout the Pool. Flood events are often short in duration, shallow, and dependant on the minor river systems associated with the basin. Other than the drainage ditches around the pool, small foot bridges allowing access, and informational kiosks located within the pool, very little construction and manipulation of the topography has been conducted in the pool. Pool 8 is utilized by hunters that are allowed to wade and hunt the flooded timber during the fall duck season.

Due to the anticipated increase of dead timber following the herbicide injection in the midstory and heavy use by wading hunters, several considerations were made to this study during its initial planning and layout. First, no marking paint or other obvious marks were to be made on the trees within the study areas. Also, tall metal T-Posts were used to mark the corners of the research areas. They were installed to keep more than four feet of the post exposed to prevent injury to the hunters with the increased trip hazards from the dead or dying midstory. The three research blocks were located adjacent to each other in pool 8 as shown in Figure 1. Areas shown in white received the midstory herbicide treatment. Transparent areas in Figure 1 are control treatment areas.

Soils of both of these pools are mapped as Calhoun silt loam (Butler 1985). These soils have formed in the nearly level floodplain as a result of the formation of the alluvial fans that have impeded the drainage of the basin. They are fine-silty, mixed, active, thermic Typic Glossaqualfs (Butler 1985). These soils are variable in texture with a high water holding capacity, low levels of organic matter, and poor fertility (Butler 1985).

LITERATURE CITED

Abrams, M.D. 1998. The red maple paradox: what explains the widespread expansion of red maple in eastern forests? Bioscience. 48: 355-365.

Bowlin. 1848. Swamp lands in Missouri and Arkansas. House of Representatives Report No. 130. 16pp.

Burns, R.M., and B.H. Honkala, tech. coord. 1990. Silvics of North America: 2. Hardwoods. Agric. Handbook 654. Washington, DC: U.S. Department of Agriculture, Forest Service. 877 pp.

Butler, R.E. 1985. Soil survey of Stoddard County, Missouri. United States Department of Agriculture, Soil Conservation Service. 148 p.

Chambers, J.L., and M.W. Henkel. 1989. Survival and growth of natural and artificial regeneration in bottomland hardwood stands after partial overstory removal. Proceedings of the Fifth Biennial Southern Silvicultural Research Conference; 1988 November 1-3; Memphis, TN. Gen. Tech. Rep. SO-74. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 277-283.

Clark, F.B. 1993. An Historical Perspective of Oak Regeneration. P. 3-13. Eds. David Loftis and Charles McGee. In: The Proceedings of the Oak Regeneration: Serious Problem – Practical Recommendations Symposium; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: Southeastern Forest Experimental Station. 319 pp.

Dey, D.C., P.S. Johnson, and H.E. Garrett. 1996. Modeling the regeneration of oak stands in the Missouri Ozark Highlands. Canadian Jornal of Forest Research. 26(4): 573-583.

Dey, D.C., J.A. Kabrick, J. Grabner, and M.A. Gold. 2003. Restoring oaks in the Missouri River floodplain. In: Proceedings of the thirtieth annual hardwood symposium: current topics in the processing and utilization of hardwood lumber; 2002 May 30-June 1; Fall Creek Falls, TN. [Memphis, TN: National Hardwood Lumber Association]: 8-20.

Dey, D.C., W. Lovelace, J.M. Kabrick, and M.A. Gold. 2004. Production and early field performance of RPM® seedlings in Missouri Floodplains. In: Michler, C.H. and others, eds. Proceedings of the sixth Walnut Council research symposium on black walnut in a new century. Gen. Tech. Rep. NC-243. St. Paul, MN: U.S. Department of Agriculture, Forest Service. North Central Research Station: 59-65.

Forrister, R. H. 1970. History of Stoddard County. Stoddard Historical Society, Puxico, MO.

Gardiner, E.S., and L.M. Helmig. 1997. Development of water oak stump sprouts under a partial overstory. New Forests. 14: 55-62.

Gardiner, E.S., and J.L. Yeiser. 1999. Establishment and growth of cherrybark oak seedlings underplanted beneath a partial overstory in a minor bottom of southwestern Arkansas: First year results. In: Haywood, J.D. ed. Proceedings of the tenth biennial southern silviculture research conference. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 171-175.

Golden, M.S. 1999. Factors affecting sprouting success in a bottomland mixed hardwood forest. In: Haywood, James D., comp. Proceedings of the tenth biennial southern silvicultural research conference; 1999 Febuary 16-18; Shreveport, LA. Gen. Tech. Rpt. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 157-163.

Hamilton, D.A., T.G. Kulowiec, and S.L. Sheriff. 1991. Regeneration of bottomland oaks at Duck Creek Wildlife Area. Study No. 84. Missouri Department of Conservation. 49 pp.

Heitmeyer, M. E., L.H. Fredrickson, and G. F. Krause. 1989. Water and habitat dynamics of the Mingo swamp in Southeastern Missouri. U. S. Fish Wildl. Serv., Fish Wildl. Res. 6. 26 pp.

Hodges, J.D. 1989. Regeneration of bottomland oaks. Forest Farmer. 49(1):10-11.

Hodges, J.D. 1997. Development and ecology of bottomland hardwood sites. Forest Ecology and Management. 90:117-125.

Hodges, J.D., and E.S. Gardiner, 1993. Ecology and Physiology of Oak Regeneration. P. 54-65. Eds. David Loftis and Charles McGee. In: The Proceedings of the Oak Regeneration: Serious Problem - Practical Recommendations Symposium; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: Southeastern Forest Experimental Station. 319 pp.

Hodges, J.D., and G.L. Switzer. 1979. Some aspects of the ecology of southern bottomland hardwoods. In: North America's forests: Gateway to opportunity: 1978 Joint Convention of the Society of American Foresters and the Canadian Institute of Forestry; 1978 October 22-26; St. Louis, MO. Washington, DC: Society of American Foresters: 360-365.

Janzen, G.C., and J.D. Hodges. 1985. Influence of midstory and understory vegetation removal on the establishment and development of oak regeneration. Proceedings of the Third Biennial Southern Silvicultural Research Conference; 1984 November 7-8; Atlanta, GA. Tech. Rep. SO-54. New Orleans, LA: U.S. Department of Agricutlture, Forest Service, Southern Forest Experiment Station: 273-278.

Janzen, G.C., and J.D. Hodges. 1987. Development of advanced oak regeneration as influenced by removal of midstory and understory vegetation. In: Phillips, Douglas R., comp. Proceedings of the fourth biennial southern silvicultural research conference; 1986 November 4-6; Atlanta, GA. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 455-461.

Johnson, P.S. 1975. Growth and structural development of red oak sprout clumps. Forest Science. 21(4):413-418.

Johnson, P.S. 1979. Growth potential and field performance of planted oaks. In: Holt, H.A.; Fischer, B.C. Regenerating oaks in upland hardwood forests. John S. Wright Forestry Conference Proceedings. West Lafayette, IN: Purdue University: 113-119.

Johnson, P.S. 1992. Underplanting northern red oak in Missouri without herbicides. Gen Tech. Rep. NC-152. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 1-4.

Junk, W.J., P.B. Bayley, and R.E. Sparks. 1989. The flood pulse concept in river floodplain systems. Can. Spec. Publ. Fish Aquat. Sci. 106:110-127.

Kabrick, J.M., and M. Anderson. 2000. Oak stump sprouting in mature bottomland forests at Duck Creek Conservation Area. Forest Research Report No. 2. Jefferson City, MO: Missouri Department of Conservation. 9 p.

Kabrick, J.M., and D.C. Dey. 2001. Silvics of Missouri bottomland tree species. Notes for forest managers. No. 5 (May 2001) 8 p.

Lockhart, B.R., J.L. Chambers, and K.L. Wharton. 2002. Stump sprouting 2 years after thinning in a cherrybark oak plantation. In: Outcalt, Kenneth W. ed. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 390-394.

Lockhart, B.R., J.D. Hodges, and E.S. Gardiner, 2000. Response of cherrybark oak reproduction to midstory removal and shoot clipping. Southern Journal of Applied Forestry. 42:45-50.

Loftis, D.L. 1990. A shelterwood method for regenerating red oak in the Southern Appalachians. Forest Science. 36(4):917-929.

McQuilkin, R.A. 1990. Pin oak. In: Burns, Russel M.; Honkala, Barbara H. eds. Silvics of North America, Vol. 2, Hardwoods. U.S. Department of Agriculture, Forest Service. Agriculture Handbook 654.

McQuilkin, R.A., and R.A. Musbach. 1977. Pin oak acorn production on green tree reservoirs in southeastern Missouri. Journal of Wildlife Management. 41(2): 218-225.

Minkler, L.S. 1967. How pin oak stands respond to changes in stand density and structure. Journal of Forestry. 65:256-257.

Minkler, L.S., and R.E. McDermott. 1960. Pin oak production and regeneration as affected by stand density, structure, and flooding. Research Bull. 750. Columbia, MO: University of Missouri, Agricultural Experiment Station. 24 p.

Mitsch, W.J., and J.G. Gosselink.1993. Wetlands, 2nd edn. Van Nostrand Reinhold, New York, 722 pp.

Nigh, T.A., and W.A. Schroeder. 2002. Atlas of Missouri ecoregions. Jefferson City: Missouri Department of Conservation

Nix, L.E., and S.K. Cox. 1987. Cherrybark oak enrichment plantings appear successful after 7 years in South Carolina bottomlands. In: Phillips, D. R., ed. Proceedings, fourth biennial southern silvicultural research conference. 1986 November 4-6; Atlanta, GA. Gen. Tech. Rep. SE-42. Asheville, NC: U. S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 129-132.

Parker, W.C., and D.C. Dey. 2008. Influence of overstory density on the ecophysiology of red oak (*Quercus rubra*) and sugar maple (*Acer saccharum*) seedlings in central Ontario shelterwoods. Tree Physiology 28: 797-804.

Peairs, S.E., A.W. Ezell, K.L. Belli, and J.D. Hodges. 2004. A comparison of oak regeneration conditions following midstory injection and partial overstory removal in a Tombigbee River terrace. In: Connor, Kristen F., ed. Proceedings of the twelfth biennial sourthern silvicultural research conference. Gen. Tech. Rep SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 499-501.

Rogers, R., P.S. Johnson, and D.L. Loftis. 1993. An overview of oak silviculture in the United States: the past, present, and future. Ann. Sci. For. 50:535-542.

Rogers, R., and I. S. Samder. 1989. Flooding, stand structure, and stand density and their effect on pin oak growth in southeastern Missouri. In: Proceedings of the 5th biennial southern silvicultural research conference; 1988 November 1-3; Memphis, TN. Gen. Tech. Rep. SO-74. New Orleans, LA: U.S. Department of Agriculture, Forest Service: 299-302.

Spetich, M.A., D.C. Dey, P.S. Johnson, and D.L. Graney. 2002. Competitive Capacity of *Quercus rubra* L. planted in Arkansas' Boston Mountains. For. Sci. 48(3): 504-517.

Thomas B. 1976. The Swamp. W. W. Norton and Company Inc, New York, 223pp.

Thomson, R.L. 1980. Woody vegetation and floristic affinities of Mingo Wilderness Area, a northern terminus of southern floodplain forests, Missouri. Castanea 45:194-212.

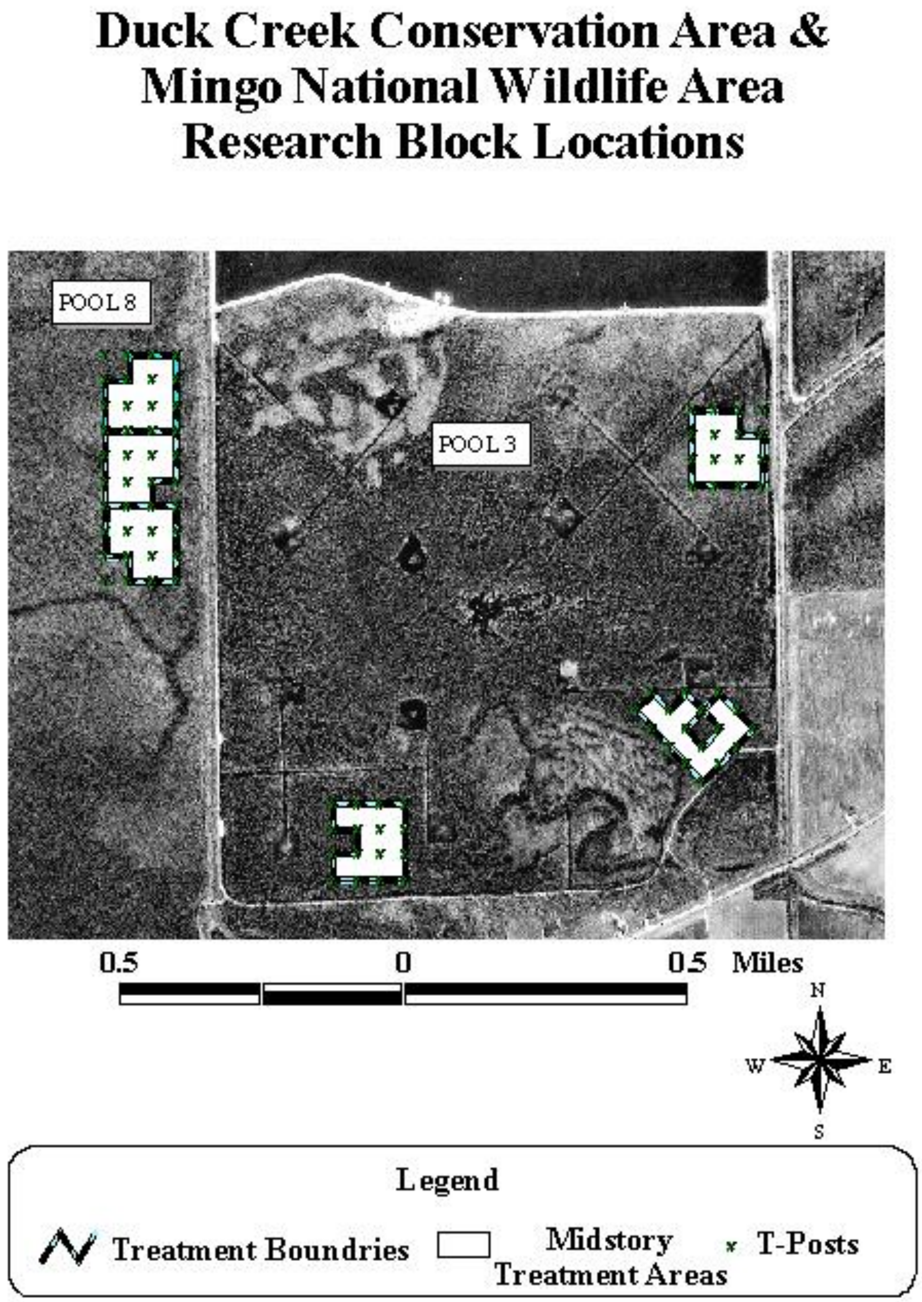


Figure 1. Duck Creek Conservation Area (Pool 3) and Mingo National Wildlife Refuge (Pool 8) research block locations showing the midstory treatment areas in white and T-Post locations. Areas not in white contain control plots in their block.

CHAPTER II

REGENERATION OF BOTTOMLAND OAKS AT DUCK CREEK CONSERVATION AREA 17 YEARS AFTER A SHELTERWOOD, A CLEARCUT, AND A CONTROL TREATMENT

INTRODUCTION

Maintaining the species composition of red oaks in the overstory of future stands requires the establishment of these species in the advance reproduction layer prior to a regeneration harvest. The success of oak regeneration is contingent largely on having adequate numbers of large oak advance reproduction (Johnson 1979, 1992, Janzen and Hodges 1985 and 1987, Hodges 1989, Loftis 1990, Hodges and Gardiner 1993, Rogers et al. 1993, Dey et al. 1996, Lockhart et al. 2000). The problem of producing adequate oak advance reproduction on productive sites has been well documented across many forest types (Clark 1993).

Regeneration of oak species at Duck Creek Conservation Area (DCCA) and Mingo National Wildlife Refuge (MNWR) has been a concern for more than 20 years (Hamilton et al. 1991). Bottomland forests at DCCA and MNWR contain desirable quantities of oaks in the overstory; however, these forests are reaching their physiological maturity. Large mature pin oaks (*Quercus palustris* Muenchh) are declining without established advance reproduction layers to take their place in the future stand. Most of the advance regeneration is composed of red maple (*Acer rubrum* L.), American elm (*Ulmus Americana* L.), and green ash (*Fraxinus pennsylvanica* Marsh.) which are more shade and flood tolerant than desirable species such as pin oak, willow oak (*Quercus phellos*

L.), and cherrybark oak (*Quercus falcata* Michx.) (Burns and Honkala 1990).

At DCCA, Hamilton et al. (1991) developed a study to compare the effectiveness of shelterwood harvest (Basal area = 30 ft^2/ac) and clearcut regeneration harvesting (Basal area = 0 ft^2/ac) for regenerating oak inside and outside of greentree reservoirs (GTRs) from 1984-1989. The fifth-year results from this study showed that pin oak seedling numbers and heights were greater in units that received the shelterwood cut than in units that were clearcut. Within GTRs, pin oak height growth was greater on drier sites than on wet sites but pin oak seedling establishment was not affected as much by site wetness. In contrast, red maple regeneration was much more abundant and taller than pin oak regeneration in units regardless of regeneration method and site wetness. Abrams (1998) reported that red maple seedlings and saplings form a dense canopy in the midstory and exclude less shade-tolerant species such as oaks in partially cut stands. Hamilton et al (1991) reported the greatest frequency of tall (>20 inches) pin oak seedlings occurred in the shelterwood cut plots. They concluded that shelterwood harvests were better for promoting pin oak regeneration than clearcuts. Young pin oak seedlings were noted along the edges of the clearcuts; established from the acorns of mature trees in adjacent stands. This anecdotal observation highlights the importance of seed source and indicates that pin oak, considered shade intolerant (McQuilkin 1990), is able to grow in partially shaded conditions, at least as young reproduction.

Excessive wetness and reduced light availability from GTR management decreases oak tree vigor and the ability to produce competitive stump sprouts for many bottomland oak species. A study at DCCA, in a closed canopy bottomland forest dominated by pin oak with minor amounts of overcup oak (*Quercus lyrata* Walt.), American elm, sweetgum (*Liquidambar styraciflua* L.), red maple, willow oak, and cherrybark oak, by Kabrick and Anderson (2000) showed that pin oak stump sprouts, one growing season after a dormant season cutting, have similar probabilities of sprouting as upland open-grown white oak (*Quercus alba* L.), but were less vigorous and shorter than sprouts reported in the uplands of Missouri and surrounding region. Similarly, Lockhart et al. (2002), Gardiner and Helmig (1997), and Golden (1999) found that decreased light levels and other disturbances such as drought or flooding reduce the ability of cherrybark oak, water oak (*Quercus nigra* L.), and other oak species to successfully produce stump sprouts. In oaks, stump sprouting probability decreases with increasing diameter (Johnson 1975). American elm also produces sprouts vigorously as small stems, and the probability decreases with larger stems (Bey 1990). Red maple is a vigorous sprouter and its sprouting potential increases with diameter to a maximum of 9 to 12 inches dbh (Walters and Yawney 1990). Sapling and pole size green ash are vigorous sprouters (Kennedy 1990). The large diameter pin oaks averaging 17 inches dbh at DCCA and MNWR have lower sprouting potential and are competing with smaller diameter maple ash and elm which average 3.5 inches dbh and have high sprouting potential. In small clearcuts (132 by 264 feet) in a bottomland mixed-oak forest on the floodplain of the Tombigbee River in southwestern Alabama, Golden (1999) noted that the lack of smaller diameter oaks in the reproduction layer prior to harvest gave an advantage to competing species (green ash, hickories (*Carya spp.)*, and sweetgum) stump sprouts originating from smaller trees (<12 inches dbh). In their regeneration plots at DCCA, Hamilton et al. (1991) noted that the pole-sized red maple stems that were cut sprouted profusely. When sprouting is unreliable and adequate amounts of desirable advance reproduction are absent, artificial regeneration by planting or direct seeding is often recommended to establish reproduction that can then be recruited into the overstory following additional overstory treatments.

Other studies have shown that red oaks can establish successfully under a partial overstory. In Missouri, Johnson (1992) underplanted large (0.5 inch caliper) northern red oak (*Quercus rubra* L.) bareroot seedings in an upland shelterwood of 60% stocking, and he controlled undesirable woody vegetation and competing stump sprouts with 2, 4-D plus picloram (Tordon RTU). Five years after overstory removal, Johnson (1992) found that 60% of the planted oaks were dominant and codominant growing stock. Chambers and Henkel (1989) established Nuttall (*Quercus nuttallii* Palmer) oak seedlings under a partial overstory, however the seedlings were never released. In a 70-80 year old elm, ash, hackberry (*Celtis occidentalis* L.), boxelder (*Acer negundo* L.), and American sycamore (*Platanus occidentalis* L.) stand in South Carolina, Nix and Cox (1987) found that partial overstory reduction increased light intensity reaching the forest floor, and revitalized undesirable competing vegetation. In northern Arkansas, Spetich et al. (2002) underplanted northern red oak seedlings on north to northeast facing slopes in a mixed-oak upland forest shelterwood and found that increasing the intensity of herbicide treatment on competing species increased the competitiveness of the planted oak and reduced the difference in height between oak and its competitors. They also reported that there were greater probabilities of dominant oak when the shelterwood was reduced to 40 and 60% stocking than when it was left at a higher residual stocking of 80% . These studies suggest that the key to successful oak regeneration is to reduce stand density largely to increase light in conjunction with controlling competing vegetation in the mid-and understory.

In a minor bottomland forest in southeast Arkansas where red oak and sweetgum were dominant in the overstory, Gardiner and Yeiser (2000) observed excellent survival of cherrybark oak seedlings under a partial overstory (i.e., 30% stocking and 35 ft^2 per acre basal area) with little control of competing vegetation before planting. They expected that post-planting vegetation control would be a benefit to future seedling growth and form resulting from the removal of competing woody vegetation (Gardiner and Yeiser 2000). In a mixed-oak bottomland forest with a well developed midstory located near Bellamy, Alabama, Peairs et al. (2004) showed that the largest increases in initial oak reproduction density occurred in stands with 50 ft^2 per acre residual basal area compared to stands with 30 and 70 ft^2 per acre of basal area. They also noted that harvesting in conjunction with a good mast production year tended to enhance initial regeneration. In a northern red oak – northern hardwood stand near Foymount, Ontario, Parker and Dey (2008) found that northern red oak had a larger increase in photosynthetic capacity than the major competitor, sugar maple (*Acer saccharum* Marsh.) as irradiance increased with increasing reductions in shelterwood density from 97% crown cover (control) to between to 80 and 49%. This study showed that adaptations to changing light environments differences in drought tolerance, and species-specific photosynthetic potential gave northern red oak, an intermediate shade tolerant species, a competitive advantage over the shade tolerant sugar maple when understory light continued to increase above the light saturation point for sugar maple as shelterwood density was reduced.

Mature pin oaks are an important component of the overstory at DCCA, a greentree reservoir that is managed for waterfowl habitat and hunting. Although high densities of pin oak seedlings establish after a good acorn crop, seedlings do not persist over time and fail to recruit into the overstory. In addition, the older (80 to 90 year old) pin oaks are in a state of decline, especially in the artificially flooded management pools where stands are inundated for long periods of time from the fall to spring season. At DCCA, regeneration following an overstory disturbance is often dominated by other non-oak species that have become well established in the midstory and understory of the mature oak forests, and oak advance reproduction is out competed if it is present because it is small in stature. Managers are concerned for the sustainability of pin oak in these forests as oak regeneration is problematic at DCCA.

The long-term effects of silvicultural treatments designed to promote oak regeneration in bottomlands are not well understood and few long-term, experimentally designed studies exist in the eastern United States. In 1984, a study was established by Hamilton et al. (1991) to evaluate various methods to regenerate bottomland oaks at Duck Creek Wildlife Area. In their report they evaluated the fifth-year (1989) response of pin oak and other tree regeneration relative to annual artificial or natural flooding at two elevations, and to clearcut or shelterwood methods of regeneration.

Hamilton et al. (1991) found that the fifth-year (1989) mean height of pin oak seedlings was greatest in the clearcut plots ($P < 0.01$), but that greater densities of seedlings > 20 inches tall were found in the shelterwood plots. They speculated that, five years post cutting, the oak reproduction on the shelterwood plots may be competitive with red maple reproduction, but the pin oak seedlings are currently dominated by red maple reproduction. In addition to the relatively higher proportion of oak reproduction density in the shelterwood plots, a further benefit was seen in leaving residual oak trees to provide a future seed source for the continued establishment of oak seedlings under the shelterwood. They observed that the ability of red maple to stump sprout made it highly competitive and dominant on regeneration plots.

In 2001, we measured the permanent plots used in Hamiltion's study to assess longer-term changes in regeneration and stand development, with special emphasis on the fate of pin oak. We documented stand dynamics 17 years after regeneration by comparing the establishment, growth and survival of pin oak and other species by the regeneration method (clearcut vs. shelterwood vs. uncut control) in two flood regimes (natural and artificial GTR) at "wet" and "dry" elevations at DCCA and MNWR.

METHODS

Study sites

In the summer of 2001, the 48 study plots of the Hamilton et al. (1991) study were reestablished and inventoried. Eight of the treatment plots were located in pool 2, an unmanaged pool which naturally floods 3 out of 5 years for 36 days during the dormant season and 21 days in the growing season to depths ranging from 6 – 14 + inches (Fredrickson 1979). The other eight treatment plots were located in pool 3, a GTR that is flooded yearly for approximately 84 days during the dormant period and 20 days during the growing season at a mean depth of 18 inches (Hamilton et. al 1991). Elevations (wet or dry) were determined in 1984 after flooding events when the pools (2 and 3) were drawn down to half of their surface water holding capacity. The plots that remained covered with surface water were marked as wet plots whereas the plots free of surface water at the same time were marked as dry plots. The effects of microtopography and other drainage features on tree regeneration growth and survival can be examined by comparing the wet and dry plots.

Design

The experiment was a 3x2 factorial experiment nested within 2 flood regimes. Four replications of each treatment x flood regime x management were reestablished giving a total of 48 experimental units (plots). All treatment plots were circular with a radius of 170 feet measured from permanently marked centers. Vegetation sampling was done in the 0.35 acre center (70 foot radii) of each plot. This provided a 100 foot treatment buffer around each experimental unit. All tree stems located within the center 70 foot measurement plot were re-inventoried in 2001.

Treatments

The harvest treatments included 16 shelterwood plots reduced to approximately 30 ft^2/acre of pin oaks, 16 clearcut plots where all stems greater than 2 inches were cut leaving no residual basal area, and 16 control plots where no harvest operations occurred. The prescribed harvest treatments were implemented to all of the treatment plots in the summer of 1984 except for 3 in the unmanaged site, which were treated in the summer of 1985. Therefore, caution should be used when interpreting the results of the analysis because there could be an unknown influence from the treatment year.

Measurements

Data collected for each plot included the initial harvest treatment (control, shelterwood, or clearcut), the flood regime (wet or dry), and management (greentree reservoir (GTR) or Unmanaged). Measurements included a tally of tree species or genera and the dbh for each tree within the 0.35 acre vegetation sample plot. With this inventory, we were able to evaluate the following hypotheses:

1. Ho: The change in proportion of reproduction stems (< 8 inches dbh) per acre and reproduction basal area of each species or species group does not differ among treatments (clearcut verses shelterwood cut verses control) from 1989 to 2001.

2. Ho: The change in proportion of reproduction stems (< 8 inches dbh) per acre and basal area of each species or species group does not differ among elevations (wet verses dry sites) from 1989 to 2001.

3. Ho: The change in proportion of reproduction stems (< 8 inches dbh) per acre and basal area of each species or species group does not differ among management (GTRs verses naturally flooded stands) from 1989 to 2001.

The null hypothesis applies to the following species and species groups: red maple, green ash, sweetgum, pin oak, oak group, and elm group. These hypotheses were tested for stems < 8 inches dbh, which represented the pulse of reproduction released by the harvest treatments and the advance reproduction in the control.

Analysis

We used the general linear models procedure (SAS version 9.1, Statistical Analysis Software, INC., Cary, NC, USA) to evaluate the overall cutting treatment (control verses clearcut verses shelterwood cut) effects ($\alpha = 0.05$) on the change in trees per acre and change in basal area of each of the species and species groups for stems < 8 inches dbh between 1989 and 2001. This same procedure was used to evaluate the overall cutting treatment effects on the 2001 trees per acre and 2001 basal area of the species and species groups for stems < 8 inches dbh. We also evaluated the effects of GTR management verses naturally flooded stands and wet verses dry elevation effects on the change in trees per acre and basal area for stems < 8 inches dbh. Orthogonal contrasts between the control and the shelterwood treatment, control and the clearcut treatment, and shelterwood and the clearcut treatment were used to determine significant differences ($\alpha = 0.05$) in the change in the numbers of stems per acre and basal area for each of the species and species groups from 1989 to 2001 in stems <8 inches dbh. Orthogonal contrasts between the control and the shelterwood treatment, between the control and the clearcut treatment, and between the shelterwood and clearcut treatment were used to determine significant differences ($\alpha = 0.05$) in the numbers of stems per acre and basal area for each of the species and species groups in 2001 for stems < 8 inches dbh.

RESULTS

The total trees per acre and total basal area are shown in tables 1-4. These tables show the proportion of trees per acre and basal areas for red maple, green ash, sweetgum, overcup oak, pin oak, other red oak (group), and american elm for each flood management regime (GTR or naturally flooded) and at each elevation (wet or dry). In these tables there are several notable trends. First, across the management regimes and elevations pin oak is gaining in or remaining stable in both basal area and trees per acre in the controls for all trees. For trees < 8 inches dbh shown in tables 5-8, pin oak is losing both basal area and trees per acre across the management regimes and elevations. In several plots pin oaks are increasing in basal area and trees per acre in some shelterwood plots on the GTR sites when all diameter class trees are analyzed together (Tables 1-4). Other red oaks show the same trends as the pin oaks. Overcup oak shows a similar trend of remaining stable across the treatments for all trees, but is losing trees per acre and basal area in drier sites. Red maple, green ash and sweetgum are increasing their basal area and trees per acre in the clearcuts and remaining stable in the shelterwood plots. American elm is losing trees per acre and basal area in the shelterwood and clearcut plots, but is stable in the control plots when trees of all diameter classes are analyzed together (Tables 1-4).

Changes in reproduction stems per acre and basal area by cutting treatment

Red maple

The change in trees per acre of red maple trees < 8 inches dbh did not vary significantly from 1989 to 2001 between the control and shelterwood treatments ($P < 0.5454$); or between the control and clearcut treatments ($P < 0.1146$). The trees < 8 inches dbh per acre did vary significantly between the shelterwood treatment and the clearcut from 1989 to 2001 ($P < 0.0334$). The change in density of red maple in this smaller size class (< 8 inches dbh) averaged 20 trees per acre in the control from 1989 to 2001 . For the shelterwood treatment, the change in density averaged -20 trees per acre. For the clearcut treatment, the change in red maple density averaged 140 trees per acre. Although the clearcut plots increased in density more than the other two treatments (figure 2), the change in density among the treatment plots was highly variable and therefore not significant.

In contrast, the change in basal area from 1989 to 2001 of red maple trees less than 8 inches dbh, did vary significantly between the control and shelterwood treatments ($P < 0.0207$); between the control and clearcut treatments ($P < 0.0053$); and between the shelterwood and clearcut treatment ($P < 0.0001$). In figure 2, we see that there is an increase in basal area in the control, slightly less than the increase in the clearcut with the shelterwood treatment plots maintaining the same amount of basal area from 1989 to 2001. Red maple showed no significant differences from the GTR to the naturally flooded stands or from wet plots to dry plots in the change in basal area or trees per acre.

Basal area of the control was significantly different from the clearcut in 2001 ($P < .0005$). We did not find any significant differences in the 2001 data for red maple between the GTR and the naturally flooded stands or between the wet and dry plots.

Green ash

The change in trees per acre of green ash less than 8 inches dbh did not vary significantly from 1989 to 2001 between the control and shelterwood treatments ($P < 0.1322$) but did between the control and clearcut treatments ($P < 0.0016$). The change in density of green ash in this size class (i.e.,trees < 8 inches dbh) for the control was over 5 trees per acre from 1989 to 2001. For the shelterwood treatment, the change in green ash density averaged -20 trees per acre. For the clearcut treatment, the change was over 40 trees per acre. The clearcuts gained many more trees per acre as well as basal area than the other two treatments (Figure 3). Although the clearcut plots gained much more green ash per acre than the other two treatments, the change among the treatment plots was highly variable and not significant.

For green ash trees less than 8 inches dbh, the change in basal area between 1989 and 2001 did not vary significantly between the control and shelterwood treatments ($P < 0.235$), but the change in basal area did vary significantly between the control and clearcut treatments ($P < 0.0004$).

The basal area of green ash was significantly different in the regeneration plots ($P < 0.0137$) than in the shelterwood or the control in 2001. We found no significant differences for green ash in the dry verses wet plots or the GTR verses naturally flooded plots in 2001.

Sweetgum

For all trees less than 8 inches dbh, sweetgum trees per acre did not vary significantly in the change from 1989 to 2001 between the control and shelterwood treatment ($P < 0.1170$) but did between the control and clearcut treatment ($P < 0.0016$). Although the shelterwood plots lost several sweetgum trees per acre, the mean difference was highly variable and therefore not significantly different than the control.

However, for sweetgum trees less than 8 inches dbh, the difference in basal area between 1989 and 2001 did vary significantly between the control and shelterwood treatment ($P < 0.0008$), but the difference in basal area between 1989 and 2001 did not vary significantly between the control and clearcut treatment ($P < 0.1861$).

Sweetgum did gain significantly ($P < 0.0285$) more trees per acre in the dry plots, just over 4.5 trees per acre more than the wet plots. In 2001, sweetgum basal area varied significantly between the control and shelterwood plots and the shelterwood and the clearcut ($P < 0.0103$) Basal area was increasing in the control plots and the clearcut plots and remaining stable in the shelterwood plots (Figure 4). In 2001, sweetgum trees had significantly more basal area ($P < 0.0103$) in the control and clearcut plots than in the shelterwood plots (Figure 4). We found that wet plots had significantly fewer, roughly 18, sweetgum trees than the wet plots ($P < 0.0045$). In 2001 basal area did not vary significantly by management regime (GTR versus naturally flooded sites) or elevation (wet versus dry plots).

Overcup oak

For overcup oak trees less than 8 inches dbh, trees per acre ($P < 0.0001$) and basal area ($P < 0.0065$) did vary significantly in the change from 1989 to 2001 between the control and shelterwood treatment and between the control and clearcut treatment. Overcup oak is gaining trees per acre and basal area in the control plots and losing trees per acre and basal area in both the shelterwood plots and the clearcut plots for trees less than 8 inches (Figure 5). The difference from 1989 to 2001 of the number of trees per acre for trees less than 8 inches DBH for the control was < -2. For the shelterwood treatment, the mean difference was > -2. For the regeneration (clearcut) treatment, the mean difference was > -4.

In 2001, overcup oak significantly ($P < 0.0001$) more (5) trees per acre on GTRs and more (2) trees on wet plots ($P < 0.0020$). Overcup oak had significantly ($P < 0.0059$, $P < 0.0001$) fewer trees per acre and less basal area on both the clearcut plots and shelterwood plots compared with the control in 2001.

Pin oak

For all trees less than 8 inches dbh, pin oak trees per acre varied significantly in the change from 1989 to 2001 between the control and shelterwood treatment ($P < 0.0013$), between the control and clearcut treatment ($P < 0.0001$), and between the shelterwood and clearcut treatment ($P < 0.0389$) . The difference from 1989 to 2001 of mean number of trees per acre for trees less than 8 inches dbh for the control was -8. For the shelterwood treatment, the mean difference was > -2. For the clearcut treatment, the mean difference was about 2. The shelterwood treatments are losing pin oak trees over time in the 1-8 inch diameter classes (Figure 6).

Similarly, for pin oak trees less than 8 inches dbh, the basal area did vary significantly between the control and shelterwood treatment ($P < 0.0001$). The difference from 1989 to 2001 of mean basal area per acre for trees less than 8 inches dbh for the control was -1. For the shelterwood treatment, the mean difference was > -2. For the clearcut treatment, the mean difference was -1.

In 2001, there were significant differences in the basal area between the control, shelterwood, and the clearcut plots ($P < 0.0001$). The pin oak basal area in the control plots averaged over a 40 square foot gain per acre in the control plots, stayed stable at just over 40 square feet per acre in the shelterwood plots, and plummeted from just over 50 square feet per acre to 5 square feet per acre on the clearcut plots.

Other red oak

Other red oak trees were found on 33 of the 48 plots. These oaks were not tallied to species but were likely cherrybark, and willow oak based on a comparison between Hamilton's (1991) data and the our new research plot's inventory. For all trees less than 8 inches DBH, the other red oak trees per acre did not vary significantly in the change from 1989 to 2001 between the control and shelterwood treatment ($P < 0.5443$) or between the control and clearcut treatment ($P < 0.1005$). The difference from 1989 to 2001 of mean number of trees per acre for trees less than 8 inches DBH for the control was 0. For the shelterwood treatment, the mean difference was -0.73. For the regeneration (clearcut) treatment, the mean difference was -2.90.

However, for the other red oak trees less than 8 inches DBH, the basal area did not vary significantly between the control and shelterwood treatment ($P < 0.9212$) but did vary significantly between the control and clearcut treatment ($P < 0.0056$). The difference from 1989 to 2001 of mean basal area per acre for trees less than 8 inches DBH for the control was 1.45. For the shelterwood treatment, the mean difference was 2.02. For the clearcut treatment, the mean difference was -7.81 (Figure 7).

In 2001, we found no significant difference between the trees per acre or basal area of other red oaks between treatments, management regimes, or elevation in trees less than 8 inches dbh.

American elm

For all trees less than 8 inches dbh, American elm trees per acre did vary significantly in the change from 1989 to 2001 between the control and shelterwood treatment ($P < 0.0004$), between the control and clearcut treatment ($P < 0.0277$), but not between the shelterwood and the clearcut treatment. The control treatment gained trees, the shelterwood and the clearcut had lost trees per acre between 1989 and 2001 for trees less than 8 inches dbh (Figure 8). The difference from 1989 to 2001 of mean number of trees per acre for trees less than 8 inches dbh for the control was over 20. For the shelterwood treatment, the mean difference was -100. For the regeneration (clearcut) treatment, the mean difference was -50

For American elm trees less than 8 inches dbh, the basal area did vary significantly between the control and shelterwood treatment ($P < 0.0129$), between the control and clearcut treatment ($P < 0.0236$), but not between the shelterwood and clearcut treatment. The control treatment gained basal area, the shelterwood and the clearcut had lost basal area between 1989 and 2001 for trees less than 8 inches dbh (Figure 8). The difference from 1989 to 2001 of mean basal area per acre for trees less than 8 inches dbh for the control was > 5. For the shelterwood treatment, the mean difference was about 0. For the clearcut treatment, the mean difference was >6.

In 2001, American elm varied significantly ($P < 0.0001$) between treatments for basal area and trees per acre. For American elm trees less than 8 inches dbh, The controls on average contained just over 130 trees per acre with 7 square feet of basal area per acre (Figure 7). The shelterwood harvest had less than 20 trees per acre on average with an average of under 3 square feet of basal area for elms less than 8 inches dbh (Figure 7). The clearcut treatment plots averaged over 50 trees per acre with just over 9 square feet of basal area of American elm trees less than 8 inches dbh (Figure 8).

DISCUSSION

The shelterwood harvest treatments that reduced basal area to 30 ft^2 per acre on average showed results for oak reproduction after 5 years with similar numbers of trees per acre and amounts of basal areas as their major competitors (red maple, green ash, American elm, and sweetgum) (Hamilton et al. 1991), but 17 years after treatment, oak reproduction was not prevalent in trees per acre or basal area in the shelterwood or clearcut plots (Figure 5). Overcup oak, other red oaks, and pin oaks are all decreasing in both trees per acre and basal area in the shelterwood and clearcut treatments. In the control plots the oaks are maintaining the number of trees per acre and gaining basal area.

The clearcut harvest produced an increase in trees per acre and basal area of red maple, green ash, and other competing species. Many studies have shown that shade- and flood-tolerant species of trees that are abundant in the understory and midstory before a regeneration harvest will often dominate or be a prominent component of the next stand leading to a failure to sustain oak as a major component of the future stand. This is especially true for productive oak sites considered to be recalcitrant oak accumulators (Johnson et al. 2002). In Northwest Pennsylvania, Walters and Auchmoody (1993) showed similar reproduction failures of northern red oak on productive upland sites within the Moshanon State Forest and the Allegheny National Forest. In their study the overstory was cut to either 40 or 60% relative density or a control. They found that infrequent seed production, herbivores, and seed predation, as well as competition from faster growing species, such as red maple, led to the poor performance of northern red oak regeneration (Walters and Auchmoody 1993).

The change in basal area between the control and the two harvest treatments shows that green ash is maintaining basal area in the shelterwood and the control plots, but green ash is increasing in basal area in the 1-8 inch diameter classes in the clearcut treatment. This further supports Hamilton’s et al. (1991) conclusion that green ash and other more shade and flood tolerant tree species would out-compete pin oak in clearcuts due to its strong establishment in the mid and understory before harvesting. The shelterwood harvest does not inordinately promote green ash development in the understory of these shelterwoods, what showed stable or modest declines in green ash basal area in the subcanopy. Therefore, the shelterwood method may have potential to favor the development of pin oak advance reproduction if additional measures are done to control competing understory vegetation before or during the shelterwood harvest. In a bottomland cherrybark oak forest in east-central Mississippi, Lockhart et al. (2000) found that a midstory herbicide treatment that controlled green ash and other species facilitated cherrybark oak seedlings to have a greater survival than seedlings without release from the midstory. The released cherrybark oak seedlings were found to be taller than the non-released seedlings only after 3 to 5 years of growth (Lockhart et al. 2000). Lockhart et al. (2000) recommend the midstory treatment and reproduction clipping 5 to 9 years prior to final overstory removal.

Sweetgum is adding less basal area in the shelterwood and clearcut plots than in the control plots. With the basal area increasing over time less than the control, the shelterwood and clearcut treatments do not favor sweetgum reproduction, but show similar results to Lockhart et al. (2005). In an afforested site on the Noxabee National Wildlife Refuge in Mississippi, Lockhart et al. (2005) found that initially sweetgum grew taller and larger than cherrybark oak, but by the 17^{th} year, the growth rate of the oak had attained the same height and diameter of the sweetgum trees. There they had carefully chosen the sweetgum-cherrybark planting mixture based on the silvics of both species to essentially produce a cherrybark-sweetgum stand on an afforested site. In our future efforts, we could consider sweetgum a possible compliment to pin oak given that the two species start together and sweetgum is not well established in the reproduction layer prior to the pin oak establishment. In the case that sweetgum is established prior to pin oak establishment, sweetgum control would be necessary. Sweetgum, with its strong excurrent growth form and canopy that is highly penetrated by sunlight, lends itself to growing with oak. Other trees on DCCA, such as red maple, with denser canopies and decurrent architecture, will limit the oak reproduction's success if they are well established in the midstory and reproduction layer of the stand.

The difference in basal area between the control and the other two treatments shows that overcup oak is losing basal area in the shelterwood and clearcut treatments. The control is gaining basal area, and there the oak reproduction is accumulating. These two treatments reduce the amount of overcup oak reproduction in respect to both trees per acre and basal area. In heavily flooded backwood flats, overcup oak is considered a climax species, but in areas with less flooding and competition from green ash, other oaks, and sweetgum it is considered a subclimax species (Solomon 1990). In the absence of flooding and other disturbances that favor overcup oak, we would expect the natural reduction in trees per acre and basal area our plots are experiencing.

Pin oak is adding less basal area in the shelterwood plots and clearcut plots than in the control plots. This shows that Hamilton and other's (1991) conclusion that the shelterwood plots favored pin oak reproduction actually will not remain true 17 years after the cutting treatments. We found that the pin oak reproduction is unable to survive and recruit in the 1-8 inch diameter classes; therefore, artificial and natural sources of underplanted pin oak reproduction are evaluated in our new study (See Chapter 4). Pin oaks were again noted along the edges of the regeneration harvests, possibly from nearby pin oak trees in the adjacent non-treated stands.

The difference in basal area between the control and the clearcut treatment shows that the other red oak trees are losing basal area in the clearcut treatment. This further emphasizes Hamilton and other's (1991) conclusion that red maple would out-compete oaks on the clearcut treatment due to its strong establishment in the understory prior to treatment and its sprouting vigor. As with pin oak, the shelterwood treatment would require an artificial source of reproduction in the shelterwood treatment to ensure the establishment of other red oaks in the reproduction layer.

The differences in basal area and trees per acre between the control and the other two treatments shows that American elm is not favored in the shelterwood treatment. American elm is adding less basal area in the shelterwood plots than in the control plots; however, the clearcut treatment is gaining basal area of American elm. This further emphasizes Hamilton and other's (1991) conclusion that American elm would out-compete pin oak on the clearcut treatment due to its strong establishment in the understory prior to treatment. With the basal area increasing over time less than the control, the shelterwood cut may not favor the American elm. American elm is losing trees per acre in the shelterwood and clearcut treatment, yet gaining trees per acre in the control.

CONCLUSIONS

Clearcutting favored red maple, sweetgum, and ash over pin oak, overcup oak and other red oak reproduction. These non-oak species are more shade tolerant than the oak species and were established in the understory as advance reproduction (seedlings and saplings) before the clearcut treatment occurred (Hamilton et al. 1991). Stand basal area in shelterwood treatment was similar to the control. However, without control of the competing species in the mid and understory, the ability to recruit oaks in the future stand is questionable, based on stand development following clearcutting.

Regardless of harvest treatment, the reproduction was dominated by red maple and green ash, which were originally abundant in the advance reproduction layer. Maple and ash were abundant because they are more tolerant of shade and flooding than pin oak, and consequently had become well established in the understory as advance reproduction at DCCA. Successful regeneration of pin oak in bottomland forests will be more likely if a silvicultural prescription includes the control of competing woody vegetation in combination with a reduction in overstory density to increase available sunlight in the understory, and enrichment plantings of oak to ensure adequate numbers of advance reproduction are present.

LITERATURE CITED

Abrams, M.D. 1998. The red maple paradox: what explains the widespread expansion of red maple in eastern forests? Bioscience. 48: 355-365.

Bey, C.F. 1990. *Ulmus americana* L. American elm. In: Burns, Russell M.; Honkala, B. H., technical coordinators. Silvics of North America. Vol. 2. Hardwoods. Agric. Handbook 654. Washington, DC: USDA, Forest Service: 801-707.

Burns, R.M., and B.H. Honkala, tech. coord. 1990. Silvics of North America: 2. Hardwoods. Agric. Handbook 654. Washington, DC: USDA, Forest Service. 877 pp.

Clark, F.B. 1993. An Historical Perspective of Oak Regeneration. P. 3-13. Eds. David Loftis and Charles McGee. In: The Proceedings of the Oak Regeneration: Serious Problem - Practical Recommendations Symposium; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: Southeastern Forest Experimental Station. 319 pp.

Dey, D.C., P.S. Johnson, and H.E. Garrett. 1996. Modeling the regeneration of oak stands in the Missouri Ozark Highlands. Canadian Jornal of Forest Research. 26(4): 573-583.

Gardiner, E.S., and L.M. Helmig. 1997. Development of water oak stump sprouts under a partial overstory. New Forests. 14: 55-62.

Gardiner, E.S., and J.L. Yeiser. 1999. Establishment and growth of cherrybark oak seedlings underplanted beneath a partial overstory in a minor bottom of southwestern Arkansas: First year results. In: Haywood, J.D. ed. Proceedings of the tenth biennial southern silviculture research conference. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 171-175.

Golden, M.S. 1999. Factors affecting sprouting success in a bottomland mixed hardwood forest. In: Haywood, James D., comp. Proceedings of the tenth biennial southern silvicultural research conference; 1999 February 16-18; Shreveport, LA. Gen. Tech. Rpt. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 157-163.

Hamilton, D.A., T.G. Kulowiec, and S.L. Sheriff. 1991. Regeneration of bottomland oaks at Duck Creek Wildlife Area. Study No. 84. Missouri Department of Conservation. 49 pp.

Hodges, J.D. 1989. Regeneration of bottomland oaks. Forest Farmer. 49(1):10-11.

Hodges, J.D. and E.S. Gardiner. 1993. Ecology and Physiology of Oak Regeneration. P. 54-65. Eds. David Loftis and Charles McGee. In: The Proceedings of the Oak Regeneration: Serious Problem - Practical Recommendations Symposium; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: Southeastern Forest Experimental Station. 319 pp.

Janzen, G.C., and J.D. Hodges. 1985. Influence of midstory and understory vegetation removal on the establishment and development of oak regeneration. Proceedings of the Third Biennial Southern Silvicultural Research Conference; 1984 November 7-8; Atlanta, GA. Tech. Rep. SO-54. New Orleans, LA: U.S. Department of Agricutlture, Forest Service, Southern Forest Experiment Station: 273-278.

Janzen, G.C., and J.D. Hodges. 1987. Development of advanced oak regeneration as influenced by removal of midstory and understory vegetation. In: Phillips, Douglas R., comp. Proceedings of the fourth biennial southern silvicultural research conference; 1986 November 4-6; Atlanta, GA. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 455-461.

Johnson, P.S. 1975. Growth and structural development of red oak sprout clumps. Forest Science. 21(4):413-418.

Johnson, P.S. 1979. Growth potential and field performance of planted oaks. In: Holt, H.A.; Fischer, B.C. Regenerating oaks in upland hardwood forests. John S. Wright Forestry Conference Proceedings. West Lafayette, IN: Purdue University: 113-119.

Johnson, P.S. 1992. Underplanting northern red oak in Missouri without herbicides. Gen. Tech. Rep. NC-152. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 4 p.

Johnson, P.S., S.R. Shifley, and R.S. Rogers. 2002. The ecology and silviculture of oaks. CABI Publishing, New York. 503 pp.

Kabrick, J.M.; and M. Anderson. 2000. Oak stump sprouting in mature bottomland forests at Duck Creek Conservation Area. Forest Research Report No. 2. Jefferson City, MO: Missouri Department of Conservation. 9 p.

Kennedy, H.E. 1990. *Fraxinus pennsylvanica* Marsh. Green ash. In: Burns, Russell M.; Honkala, B. H., technical coordinators. Silvics of North America. Vol. 2. Hardwoods. Agric. Handb. 654. Washington, DC: USDA, Forest Service: 348-354.

Lockhart, B.R., J.L. Chambers, and K.L. Wharton. 2002. Stump sprouting 2 years after thinning in a cherrybark oak plantation. In: Outcalt, Kenneth W. ed. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 390-394.

Lockhart, B. R., A.W. Ezell, J.D. Hodges, and W.K. Clatterbuck. 2006. Using natural stand development patterns in artificial mixtures: a case study with cherrybark oak and sweetgum in east-central Mississippi, USA. Forest Ecology and Management 222: 202-210.

Lockhart, B.R., J.D. Hodges, and E.S. Gardiner. 2000. Response of cherrybark oak reproduction to midstory removal and shoot clipping. Southern Journal of Applied Forestry. 24:45-50.

Loftis, D.L. 1990. A shelterwood method for regenerating red oak in the Southern Appalachians. Forest Science. 36(4):917-929.

McQuilkin, R.A. 1990. Pin oak. In: Burns, Russel M.; Honkala, Barbara H. eds. Silvics of North America, Vol. 2, Hardwoods. U.S. Department of Agriculture, Forest Service. Agriculture Handbook 654.

Nix, L. E., and S.K. Cox. 1987. Cherrybark oak enrichment plantings appear successful after 7 years in South Carolina bottomlands. In: Phillips, D. R., ed. Proceedings, fourth biennial southern silvicultural research conference. 1986 November 4-6;

Atlanta, GA. Gen. Tech. Rep. SE-42. Asheville, NC: U. S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 129-132.

Parker, W.C., and D.C. Dey. 2008. Influence of overstory density on the ecophysiology of red oak (*Quercus rubra*) and sugar maple (*Acer saccharum*) seedlings in central Ontario shelterwoods. Tree Physiology 28: 797-804.

Peairs, S.E., A.W. Ezell, K.L. Belli, and J.D. Hodges. 2004. A comparison of oak regeneration conditions following midstory injection and partial overstory removal in a Tombigbee River terrace. In: Connor, Kristen F., ed. Proceedings of the twelfth biennial sourthern silvicultural research conference. Gen. Tech. Rep SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 499-501.

Rogers, R.S., P.S. Johnson, and D.L. Loftis. 1993. An overview of oak silviculture in the United States: the past, present, and future. Ann. Sci. For. 50:535-542.

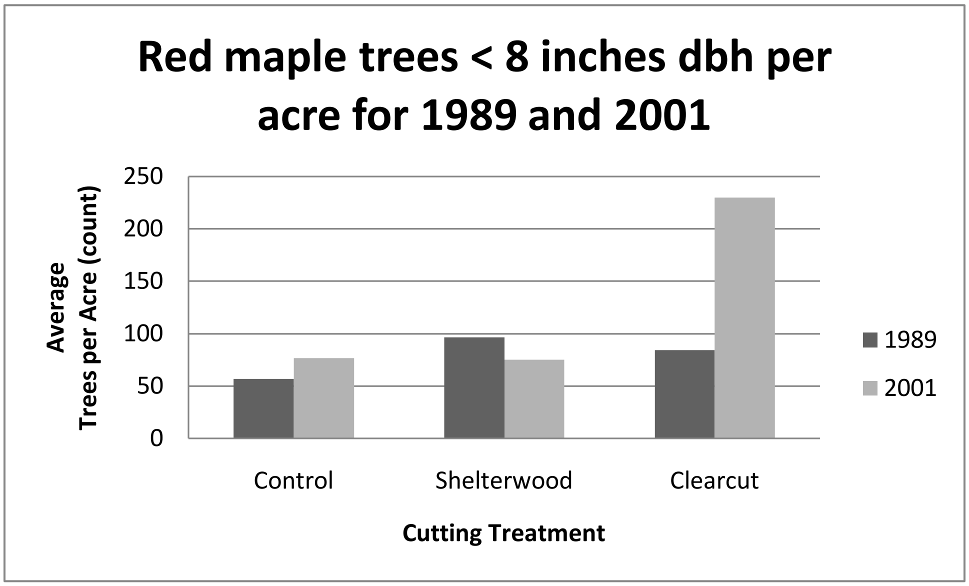
Solomon, J.D. 1990. *Quercus lyrata* Walt. overcup oak. In: Burns, Russell M.; Honkala, B. H., technical coordinators. Silvics of North America. Vol. 2. Hardwoods. Agric. Handb. 654. Washington, DC: USDA, Forest Service: 681-685.

Spetich, M.A., D.C. Dey, P.S. Johnson, and D.L. Graney. 2002. Competitive Capacity of *Quercus rubra* L. planted in Arkansas' Boston Mountains. For. Sci. 48(3): 504-517.

Walters, R.S., and H.W. Yawney. 1990. *Acer rubrum* L. red maple. In: Burns, Russell M.; Honkala, B. H., technical coordinators. Silvics of North America. Vol. 2. Hardwoods. Agric. Handb. 654. Washington, DC: USDA, Forest Service: 60-69.

Walters, R S., and L.R. Auchmoody. 1993. Factors limiting northern red oak reproduction in Pennsylvania. In: Gillespie, Andrew R.; Parker, George R.; Pope, Phillip E.; Rink, George: eds. Proceedings of the 9th Central Hardwood Forest Conference; Gen. Tech. Rep. NC-161. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 271-280.

(A) Average trees per acre



(B) Average basal area

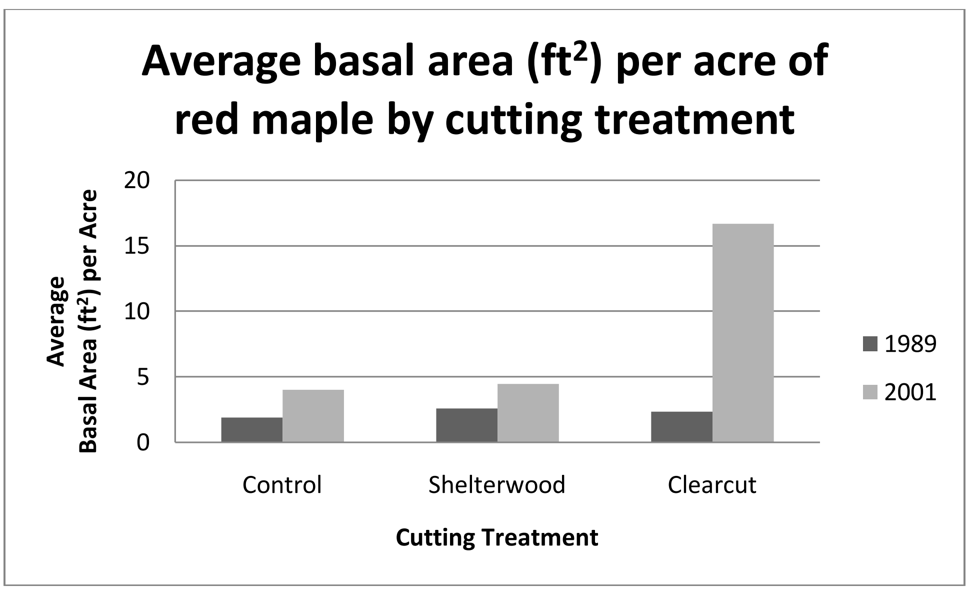
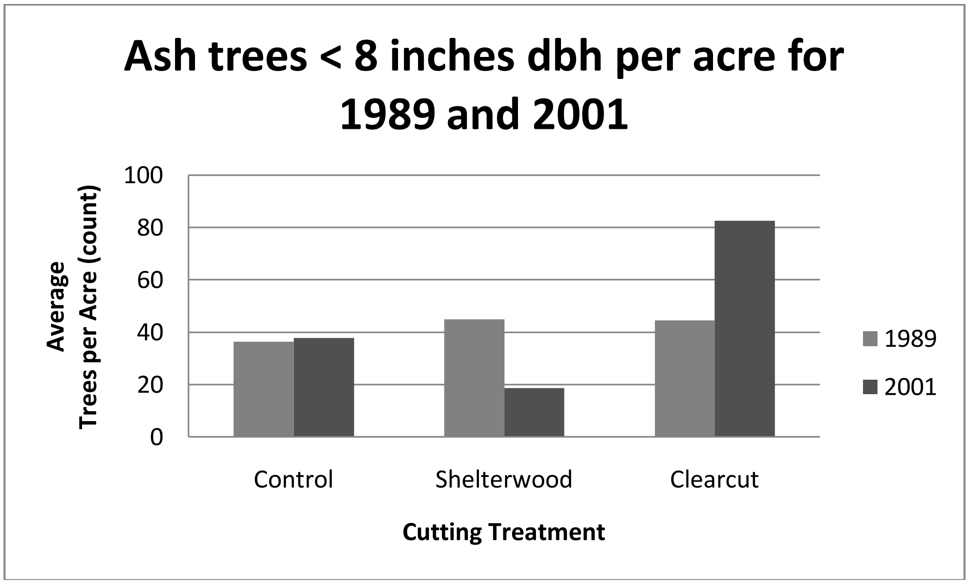


Figure 2. Average trees per acre (A) and average basal area (B) of red maple trees < 8 inches dbh measured in each of the cutting treatments in years 1989 and 2001.

(A) Average trees per acre



(B) Average basal area

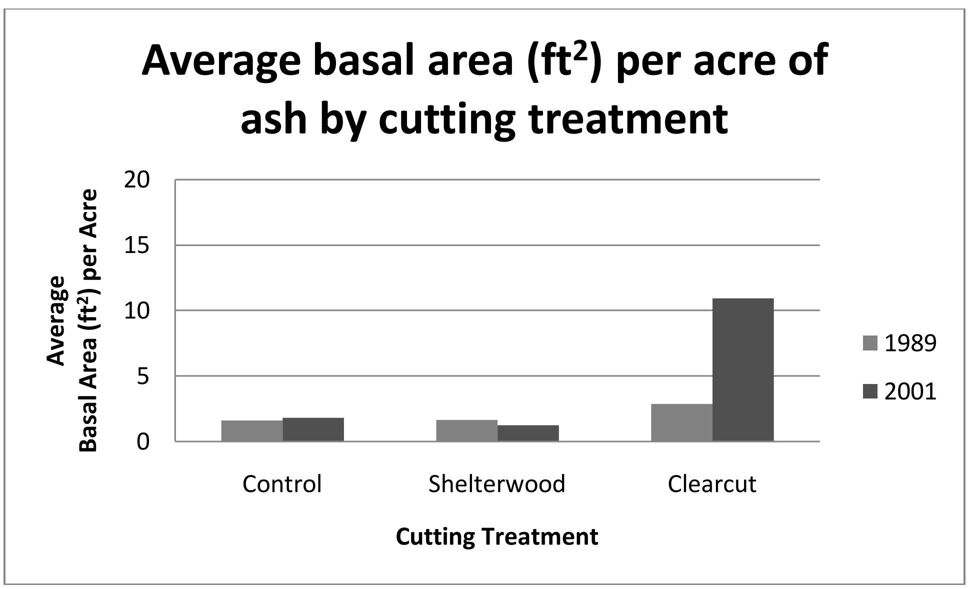
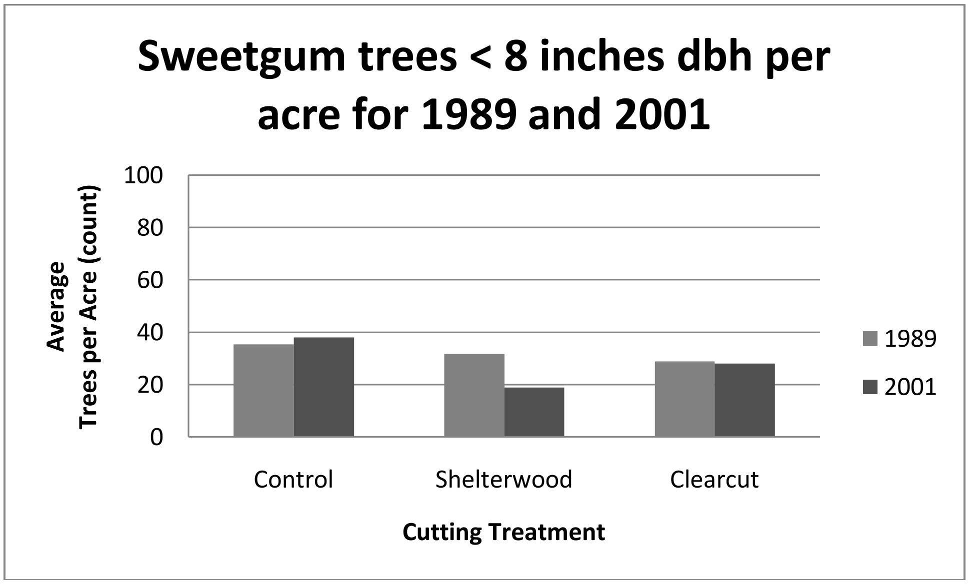


Figure 3. Average trees per acre (A) and average basal area (B) of ash trees < 8 inches dbh measured in each of the cutting treatments in years 1989 and 2001.

(A) Average trees per acre



(B) Average basal area

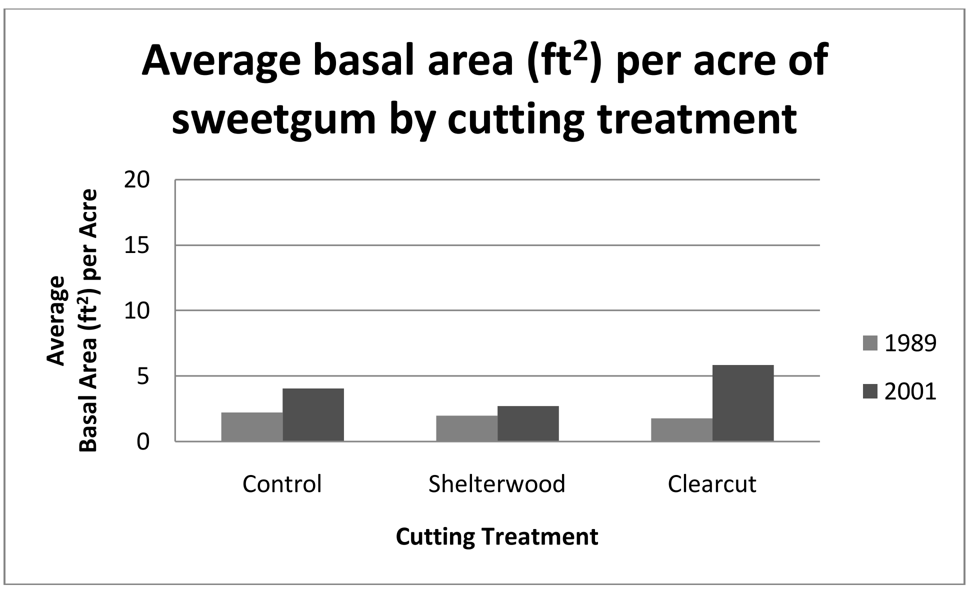
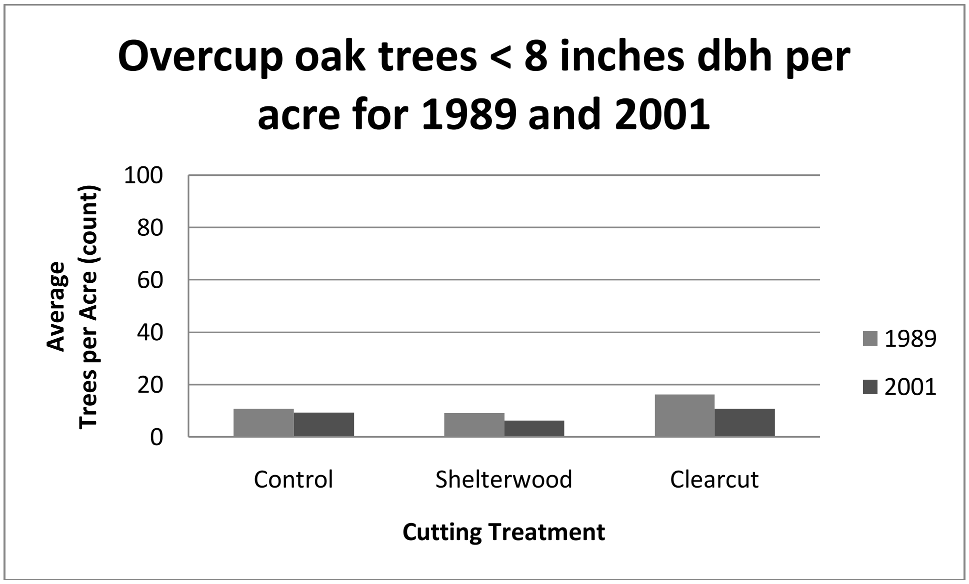


Figure 4. Average trees per acre (A) and average basal area (B) of sweetgum trees < 8 inches dbh measured in each of the cutting treatments in years 1989 and 2001.

(A) Average trees per acre



(B) Average basal area

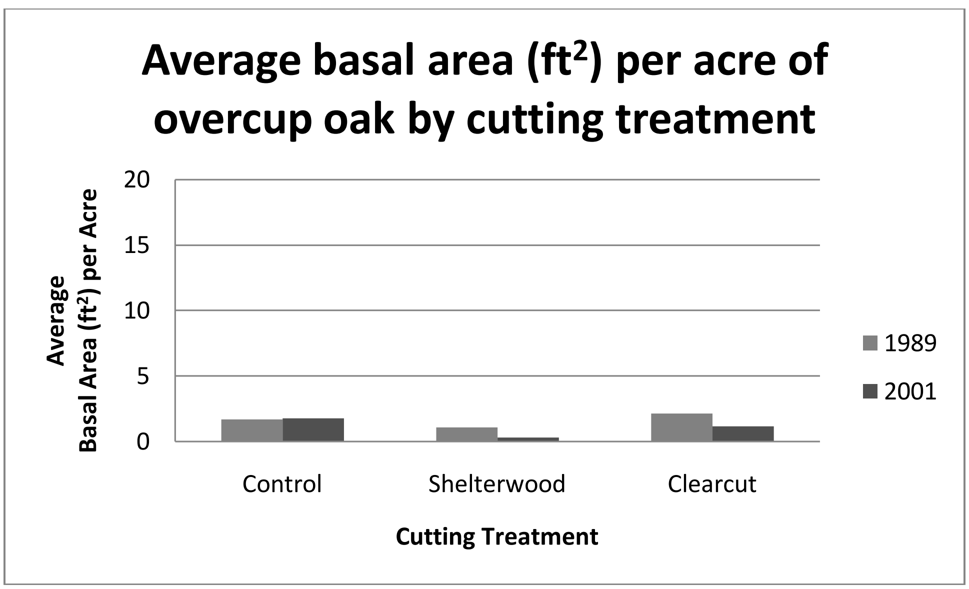
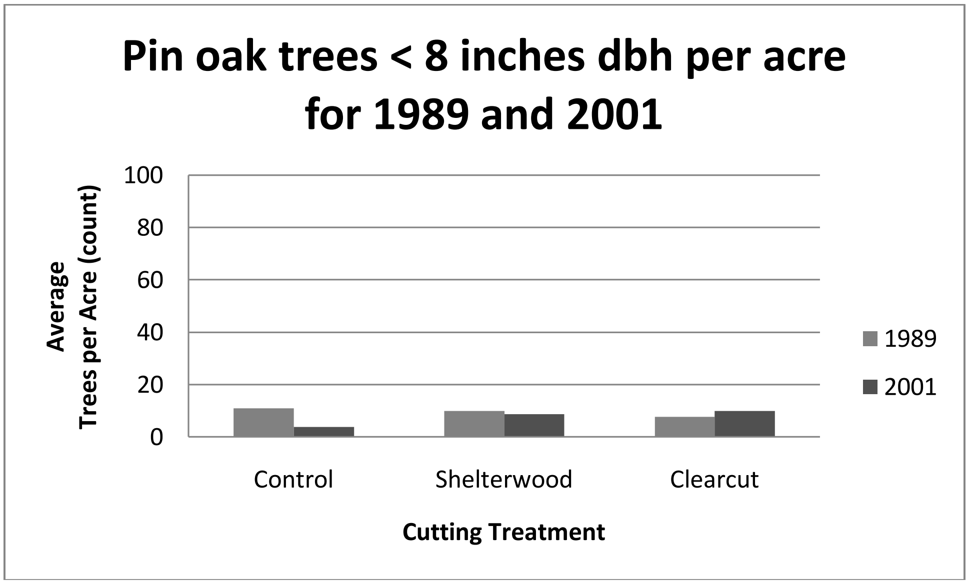


Figure 5. Average trees per acre (A) and average basal area (B) of overcup oak trees < 8 inches dbh measured in each of the cutting treatments in years 1989 and 2001.

(A) Average trees per acre



(B) Average basal area

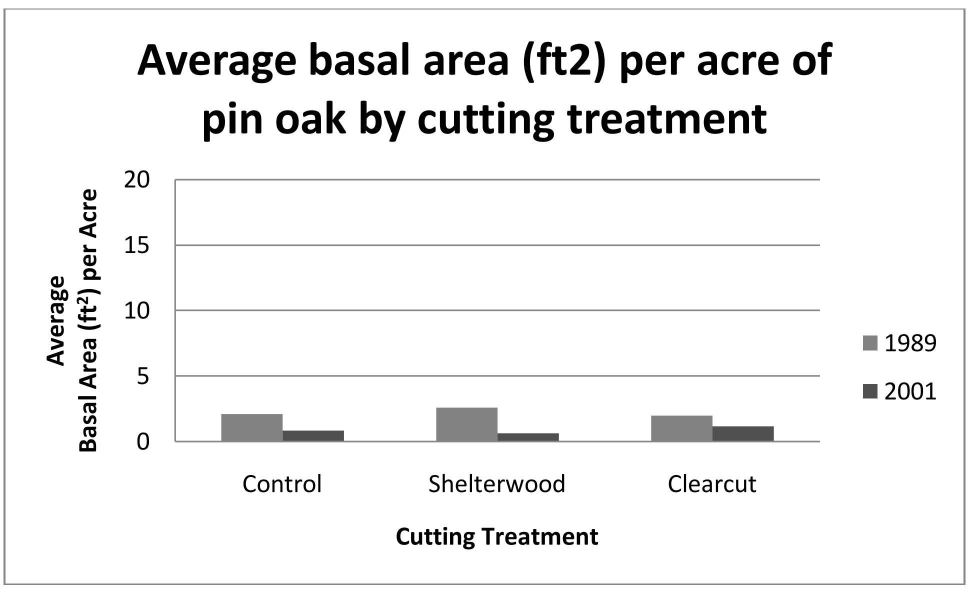
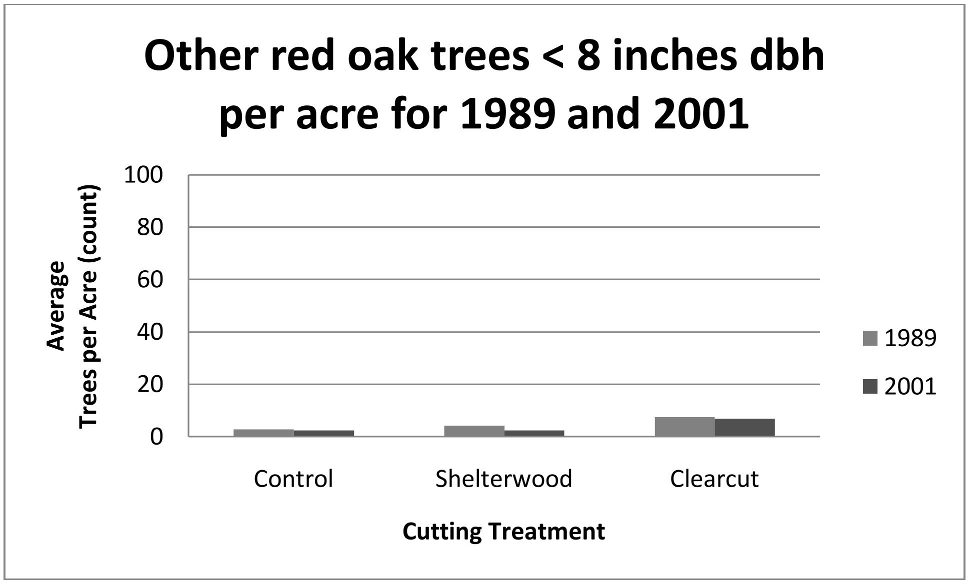


Figure 6. Average trees per acre (A) and average basal area (B) of pin oak trees < 8 inches dbh measured in each of the cutting treatments in years 1989 and 2001.

(A) Average trees per acre



(B) Average basal area

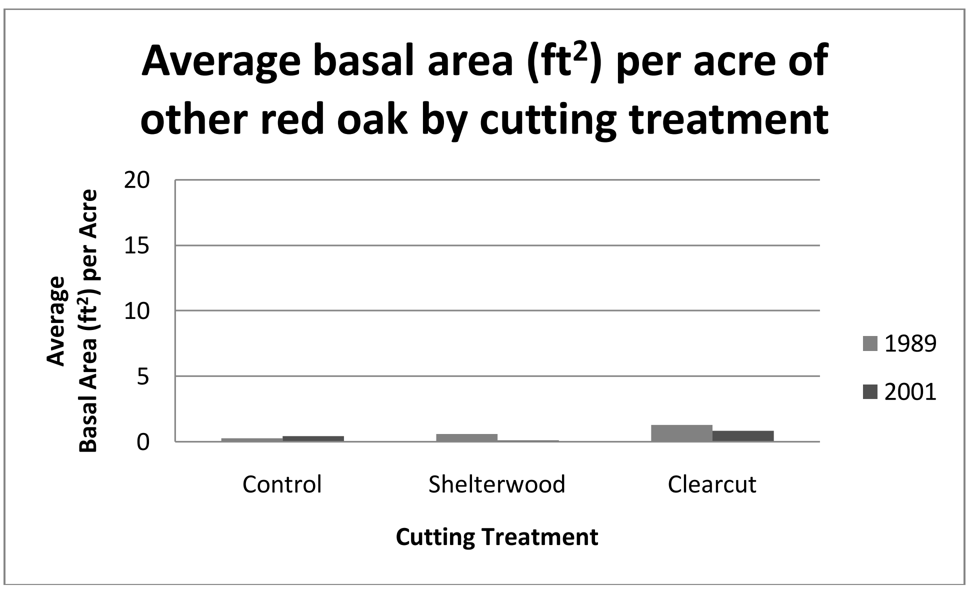
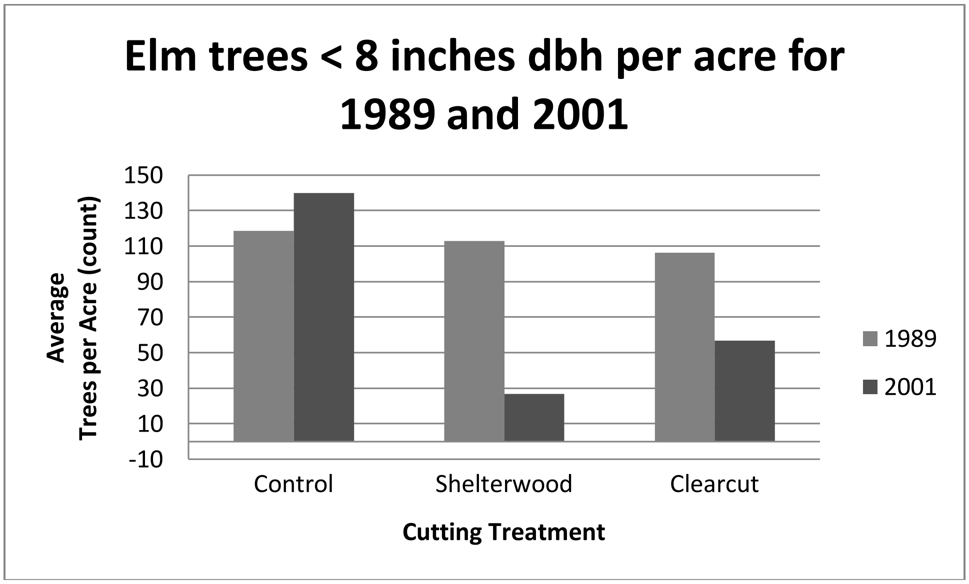


Figure 7. Average trees per acre (A) and average basal area (B) of other red oak trees < 8 inches dbh measured in each of the cutting treatments in years 1989 and 2001.

(A) Average trees per acre



(B) Average basal area

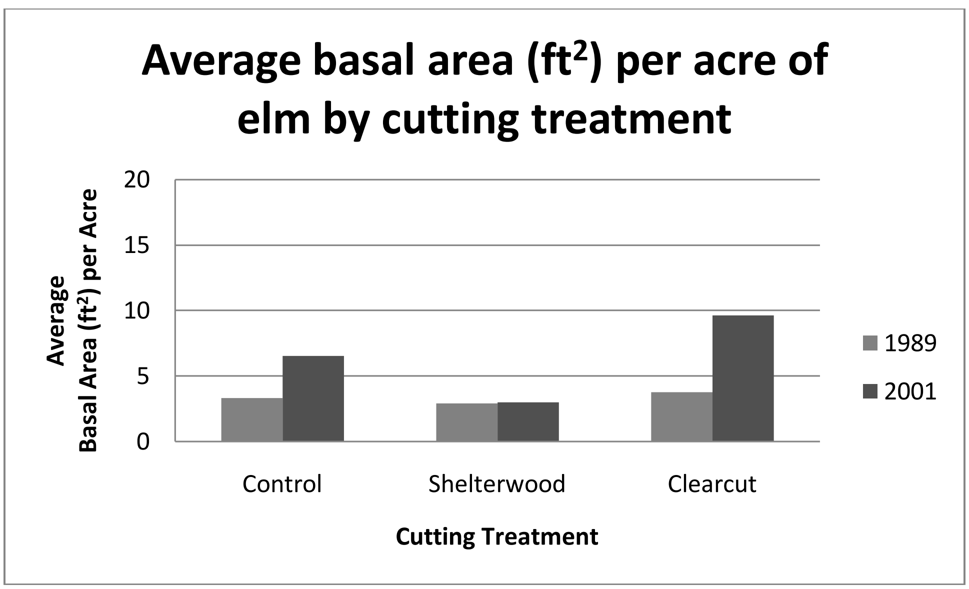


Figure 8. Average trees per acre (A) and average basal area (B) of elm trees < 8 inches dbh measured in each of the cutting treatments in years 1989 and 2001.

Table 1. Average percent of total basal area and average total basal area in 1989 and 2001 for seven species or species groups for the three cutting treatments at the two elevation levels on the GTR site.

SPECIES/GROUP	TREATMENT	DRY 1989	DRY 2001	WET 1989	WET 2001
		----------percent----------			
RED MAPLE	Control	0.64	1.52	1.85	4.03
	Shelterwood	3.44	6.36	3.60	6.27
	Clearcut	1.97	39.08	1.56	32.71
GREEN ASH	Control	0.53	1.15	6.13	5.86
	Shelterwood	0.96	1.81	2.34	1.75
	Clearcut	0.33	22.48	3.37	31.66
SWEETGUM	Control	6.43	8.75	0.80	1.25
	Shelterwood	4.67	7.86	1.62	4.04
	Clearcut	2.94	13.50	2.08	3.18
PIN OAK	Control	25.83	53.83	61.32	61.69
	Shelterwood	26.33	60.80	70.97	65.54
	Clearcut	12.54	3.66	62.18	3.66
RED OAK GROUP	Control	3.79	6.32	0.35	1.92
	Shelterwood	1.66	6.03	2.66	1.91
	Clearcut	25.58	5.96	4.25	0.00
OVERCUP OAK	Control	12.93	18.17	19.97	20.47
	Shelterwood	10.33	13.58	13.28	17.85
	Clearcut	13.74	2.26	15.75	10.25
ELM	Control	2.98	4.83	2.77	1.58
	Shelterwood	4.53	2.03	2.69	1.40
	Clearcut	2.43	9.00	3.85	6.54
		----------total----------			
AVERAGE TOTAL BASAL AREA (feet^2/acre)	Control	76.72	138.18	84.73	165.39
	Shelterwood	77.79	72.28	88.15	70.80
	Clearcut	73.04	68.83	115.10	49.41

Table 2. Average percent of total basal area and average total basal area in 1989 and 2001 for seven species or species groups for the three cutting treatments at the two elevation levels on the unmanaged site.

SPECIES/GROUP	TREATMENT	DRY 1989	DRY 2001	WET 1989	WET 2001
		percent			
RED MAPLE	Control	1.35	4.35	19.21	22.47
	Shelterwood	5.25	5.12	15.23	13.42
	Clearcut	8.46	28.77	7.51	17.87
GREEN ASH	Control	0.75	1.45	2.39	1.13
	Shelterwood	3.23	2.33	6.46	5.78
	Clearcut	3.72	7.95	6.21	12.13
SWEETGUM	Control	8.51	12.91	2.68	2.97
	Shelterwood	6.81	3.42	2.58	2.45
	Clearcut	12.30	20.48	1.79	4.91
PIN OAK	Control	51.45	52.28	32.03	41.52
	Shelterwood	48.52	60.70	30.09	48.58
	Clearcut	57.66	6.05	56.27	10.80
RED OAK GROUP	Control	7.84	0.57	0.00	0.86
	Shelterwood	5.14	5.97	2.46	6.04
	Clearcut	0.27	1.22	2.55	2.05
OVERCUP OAK	Control	11.60	14.43	25.46	20.18
	Shelterwood	15.87	7.55	28.82	15.60
	Clearcut	6.38	0.13	12.76	8.37
ELM	Control	9.31	10.00	8.60	5.84
	Shelterwood	11.15	12.83	10.00	4.31
	Clearcut	7.14	30.57	12.04	26.68
		total			
AVERAGE TOTAL BASAL AREA ($feet^2$/acre)	Control	83.91	152.00	86.72	149.08
	Shelterwood	77.66	77.63	84.74	81.76
	Clearcut	74.98	78.88	95.72	80.09

Table 3. Average percent of total trees per acre and average total trees per acre in 1989 and 2001 for seven species or species groups for the three cutting treatments at the two elevation levels on the GTR site.

		DRY		WET	
SPECIES/GROUP	TREATMENT	1989	2001	1989	2001
		percent			
RED MAPLE	Control	4.17	5.30	8.84	23.55
	Shelterwood	12.37	39.06	29.10	35.23
	Clearcut	24.20	59.36	10.74	31.42
GREEN ASH	Control	5.18	6.51	30.30	24.82
	Shelterwood	4.78	9.69	16.72	9.40
	Clearcut	5.69	17.22	25.26	25.46
SWEETGUM	Control	11.38	14.79	1.01	1.09
	Shelterwood	9.15	15.31	4.98	6.71
	Clearcut	10.06	4.64	5.89	1.23
PIN OAK	Control	13.27	11.15	14.90	14.13
	Shelterwood	9.56	14.06	13.99	25.50
	Clearcut	10.35	2.52	14.53	2.26
RED OAK GROUP	Control	2.02	2.32	0.25	1.09
	Shelterwood	1.56	4.37	1.45	1.01
	Clearcut	8.02	2.99	1.26	0.00
OVERCUP OAK	Control	1.90	4.08	15.66	11.41
	Shelterwood	2.70	3.44	6.27	12.42
	Clearcut	4.08	1.49	16.00	8.62
ELM	Control	29.84	29.91	10.35	7.25
	Shelterwood	33.06	7.19	11.58	4.36
	Clearcut	20.55	4.09	12.63	5.75
		total			
AVERAGE TOTAL TREES PER ACRE	Control	559.78	640.93	280.14	390.50
	Shelterwood	680.55	226.38	440.02	210.81
	Clearcut	485.30	899.85	336.03	344.52

Table 4. Average percent of total trees per acre and average total trees per acre in 1989 and 2001 for seven species or species groups for the three cutting treatments at the two elevation levels on the unmanaged site.

SPECIES/GROUP	TREATMENT	DRY 1989	2001	WET 1989	2001
		----------------------percent---------------------			
RED MAPLE	Control	6.57	12.46	41.14	42.43
	Shelterwood	14.19	29.27	42.27	47.46
	Clearcut	27.45	37.30	23.92	38.10
GREEN ASH	Control	3.00	2.55	5.51	3.78
	Shelterwood	16.05	12.20	9.69	9.06
	Clearcut	6.33	9.24	11.51	14.31
SWEETGUM	Control	13.70	12.46	7.57	5.78
	Shelterwood	6.05	9.76	8.66	6.88
	Clearcut	13.05	15.99	2.34	4.11
PIN OAK	Control	6.19	6.16	4.48	7.37
	Shelterwood	7.67	9.76	5.77	6.52
	Clearcut	5.76	1.60	7.19	2.15
RED OAK GROUP	Control	2.25	0.15	0.00	0.20
	Shelterwood	1.63	1.63	0.41	1.45
	Clearcut	0.96	0.89	1.26	0.18
OVERCUP OAK	Control	1.50	1.95	4.82	5.18
	Shelterwood	3.49	3.25	5.57	3.99
	Clearcut	1.54	0.18	3.78	1.43
ELM	Control	44.84	51.80	28.92	29.88
	Shelterwood	37.21	30.08	21.44	16.67
	Clearcut	33.59	27.00	42.09	23.26
		----------------------total----------------------			
AVERAGE TOTAL TREES PER ACRE	Control	377.06	471.15	411.02	355.13
	Shelterwood	304.19	174.03	343.10	195.25
	Clearcut	368.57	398.28	393.33	395.45

Table 5. Average percent of total basal area and average total basal area in 1989 and 2001 for seven species or species groups for the three cutting treatments at the two elevation levels on the GTR site for trees less than 8 inches dbh.

		DRY		WET	
SPECIES/GROUP	**TREATMENT**	**1989**	**2001**	**1989**	**2001**
		percent			
RED MAPLE	**Control**	2.92	6.21	3.39	15.96
	Shelterwood	8.04	30.67	14.42	38.27
	Clearcut	7.91	40.93	10.53	28.46
GREEN ASH	**Control**	2.44	5.91	26.48	23.60
	Shelterwood	3.91	8.72	11.55	10.67
	Clearcut	1.33	25.50	22.80	35.60
SWEETGUM	**Control**	20.14	29.32	4.49	1.95
	Shelterwood	17.44	35.87	9.77	22.20
	Clearcut	11.79	13.34	8.73	2.01
PIN OAK	**Control**	37.26	9.43	3.76	1.55
	Shelterwood	28.67	10.63	26.58	7.94
	Clearcut	22.02	2.65	10.39	3.53
RED OAK GROUP	**Control**	4.94	5.47	0.00	1.24
	Shelterwood	6.79	0.83	5.07	0.01
	Clearcut	27.02	4.53	0.05	0.00
OVERCUP OAK	**Control**	2.52	7.07	31.65	23.89
	Shelterwood	4.72	0.39	14.18	9.64
	Clearcut	10.01	0.92	28.11	9.32
ELM	**Control**	13.70	24.80	9.17	12.12
	Shelterwood	18.48	9.79	10.89	8.57
	Clearcut	9.74	8.85	9.31	7.44
		total			
AVERAGE TOTAL BASAL AREA (feet^2/acre)	**Control**	16.71597	27.15435	15.06698	18.78324
	Shelterwood	19.07359	14.9964	14.64827	11.5914
	Clearcut	18.20032	60.75374	17.00689	39.35124

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Table 6. Average percent of total basal area and average total basal area in 1989 and 2001 for seven species or species groups for the three cutting treatments at the two elevation levels on the unmanaged site for trees less than 8 inches dbh.

SPECIES/GROUP	TREATMENT	DRY 1989	DRY 2001	WET 1989	WET 2001
		percent			
RED MAPLE	Control	9.36	15.77	31.62	45.45
	Shelterwood	12.79	22.04	37.92	48.17
	Clearcut	23.62	33.31	14.08	24.76
GREEN ASH	Control	5.22	2.77	8.23	3.61
	Shelterwood	14.86	14.59	18.46	5.34
	Clearcut	11.91	9.05	27.28	18.95
SWEETGUM	Control	27.60	23.25	9.23	12.39
	Shelterwood	13.18	9.51	12.16	13.69
	Clearcut	22.56	20.50	1.56	6.26
PIN OAK	Control	8.14	1.05	3.85	1.68
	Shelterwood	2.67	0.00	5.17	0.00
	Clearcut	7.60	1.26	5.03	1.82
RED OAK GROUP	Control	1.79	0.00	0.00	0.00
	Shelterwood	2.87	1.59	0.00	0.14
	Clearcut	1.45	1.04	0.04	0.00
OVERCUP OAK	Control	0.21	0.41	9.02	2.87
	Shelterwood	6.15	0.02	4.72	1.03
	Clearcut	1.54	0.18	8.80	0.57
ELM	Control	35.45	48.35	31.08	31.03
	Shelterwood	38.63	47.73	17.68	28.20
	Clearcut	25.57	31.49	39.19	26.05
		total			
AVERAGE TOTAL BASAL AREA ($feet^2$/acre)	Control	12.07448	25.21727	17.07255	16.09796
	Shelterwood	10.44924	12.39086	14.13141	12.49851
	Clearcut	13.85995	56.09836	20.74371	48.09358

Table 7. Average percent of total trees per acre and average total trees per acre in 1989 and 2001 for seven species or species groups for the three cutting treatments at the two elevation levels on the GTR site for trees less than 8 inches dbh.

SPECIES/GROUP	TREATMENT	DRY 1989	DRY 2001	WET 1989	WET 2001
		percent			
RED MAPLE	Control	4.58	6.01	10.51	29.71
	Shelterwood	13.11	45.96	33.52	42.68
	Clearcut	27.39	60.55	13.14	30.54
GREEN ASH	Control	5.69	7.54	37.26	29.71
	Shelterwood	5.20	11.40	19.40	11.38
	Clearcut	6.44	17.70	30.93	26.02
SWEETGUM	Control	12.08	15.98	1.27	0.72
	Shelterwood	9.83	17.65	5.84	7.72
	Clearcut	11.39	4.45	6.44	0.86
PIN OAK	Control	6.67	2.30	1.91	0.48
	Shelterwood	3.39	4.41	3.77	15.04
	Clearcut	3.80	2.43	2.58	2.15
RED OAK GROUP	Control	1.81	1.41	0.00	0.48
	Shelterwood	1.69	2.94	0.94	0.41
	Clearcut	5.78	2.83	0.26	0.00
OVERCUP OAK	Control	0.97	2.30	14.01	7.49
	Shelterwood	1.92	1.10	5.08	11.38
	Clearcut	2.81	1.46	15.98	8.39
ELM	Control	32.78	34.65	12.74	9.42
	Shelterwood	35.93	8.46	13.37	5.28
	Clearcut	23.27	4.04	14.95	5.81
		total			
AVERAGE TOTAL TREES PER ACRE	Control	509.35	553.21	222.13	292.87
	Shelterwood	626.07	192.42	375.64	174.03
	Clearcut	428.70	875.09	274.48	328.95

Table 8. Average percent of total trees per acre and average total trees per acre in 1989 and 2001 for seven species or species groups for the three cutting treatments at the two elevation levels on the unmanaged site for trees less than 8 inches dbh.

SPECIES/GROUP	TREATMENT	DRY 1989	DRY 2001	WET 1989	WET 2001
		percent			
RED MAPLE	Control	7.53	13.76	43.89	47.18
	Shelterwood	16.11	34.48	48.37	55.31
	Clearcut	29.25	38.91	25.41	40.90
GREEN ASH	Control	3.44	2.44	6.21	4.36
	Shelterwood	18.61	14.78	9.52	7.08
	Clearcut	6.45	9.53	13.02	15.26
SWEETGUM	Control	14.41	10.80	8.42	6.41
	Shelterwood	5.56	10.34	10.28	7.96
	Clearcut	12.69	15.18	2.07	4.11
PIN OAK	Control	1.08	0.17	0.60	0.26
	Shelterwood	0.56	0.00	1.00	0.00
	Clearcut	1.08	1.36	1.03	1.76
RED OAK GROUP	Control	0.65	0.00	0.00	0.00
	Shelterwood	1.11	0.99	0.00	0.88
	Clearcut	1.08	0.78	0.21	0.00
OVERCUP OAK	Control	0.22	0.17	1.80	0.51
	Shelterwood	1.11	1.48	0.75	0.44
	Clearcut	0.43	0.19	2.07	0.59
ELM	Control	49.68	58.89	32.67	36.67
	Shelterwood	42.50	33.99	24.31	20.35
	Clearcut	37.42	26.46	47.11	21.14
		total			
AVERAGE TOTAL TREES PER ACRE	Control	328.95	406.06	353.01	275.90
	Shelterwood	254.67	143.61	282.26	159.88
	Clearcut	328.95	363.62	342.39	361.50

CHAPTER III

COMPARING FOUR TREE SPECIES RESPONSE TO A MIDSTORY HERBICIDE TREATMENT IN A BOTTOMLAND HARDWOOD FOREST MANAGED AS A GREENTREE RESERVOIR IN SOUTHEAST MISSOURI

INTRODUCTION

Acorn production is an important habitat component for waterfowl and other wetland species in forests managed as greentree reservoirs. Sustaining acorn production is a challenge in these bottomland ecosystems because seed yields decline in older trees due to senescence and impaired tree health from prolonged flooding during the fall and winter months. Simultaneously, accumulation of large oak advance reproduction is inhibited due to low light levels in the understory of these fully stocked stands and long-term inundation of oak seedlings (Johnson et al. 2002). Often, lack of silviculture in these stands has permitted dense mid- and understories of shade tolerant trees and shrubs to develop, which further reduce light in the forest understory. Regeneration of oak is fundamental to sustaining oak and acorn production in these forests.

New oak germinants present at the time of regeneration harvesting, or that establish in the years following harvesting are not competitive due to the inherent slow initial shoot growth rates, hence they are suppressed by other vegetation, especially on highly productive sites (Beck 1970, Johnson 1975, Sander 1977, Hodges and Switzer 1979, and Clatterbuck and Meadows 1993). Stump sprouts, the most competitive source of oak reproduction, cannot be relied upon to sustain current or higher levels of oak stocking for not all oak stumps produce sprouts (Dey et al. 1996, Johnson et al. 2002);

and oak stump sprouts growing in the partial or dense shade of an overstory canopy have reduced growth and survival (Gardiner and Helmig 1997, Kabrick and Anderson 2000, Dey et al. 2008). The key then to successful oak regeneration is an abundance of large oak advance reproduction before final removal of the overstory (Johnson et al. 2002). Since oak species are fairly intolerant to shade, and do not survive in forest understories where light levels are commonly below 5% of full sunlight, it is difficult to accumulate adequate numbers of large oak advance reproduction, which is the primary cause of oak regeneration failures (Burns and Honkala 1990, Johnson et al. 2002).

In bottomland hardwood forests, ensuring adequate light levels by removing competing woody vegetation is a major goal for regenerating and maintaining oak stocking in future stands (Johnson 1979, Janzen and Hodges 1985 and 1987, Hodges 1989, Rogers and Sander 1989, Loftis 1990, Lockhart 1999). Increasing light is needed to promote oak seedling survival and growth. Growth of first-year oak seedlings is dependent on stored energy in the acorn (Crow 1988), but subsequent growth requires adequate light, moisture and nutrients after the acorn's energy has been depleted (Johnson 1979, Crow 1988). Large patches of one-year-old oak seedlings often carpet the floor of mixed-oak forests following good crops of acorns but seedling populations are ephemeral in the heavy shade of fully stocked forests, especially on mesic and hydric sites (Beck 1970, Loftis 1988, Crow 1992). Such has been the observation at Duck Creek Conservation Area (DCCA) and Mingo National Wildlife Refuge (MNWR), which are managed as greentree reservoirs in the Missouri Bootheel.

At DCCA and MNWR, a dense midstory of red maple (*Acer rubrum* L.), sweetgum (*Liquidambar styraciflua* L.), green ash (*Fraxinus pennsylvanica* Marsh.), and

American elm (*Ulmus americana* L.) limits the development and recruitment into the overstory of pin oak (*Quercus palustris* Muenchh.) reproduction, which is a highly prized mast producer in greentree reservoir management. Additionally, long-term flooding that overtops the seedlings from September to March contributes to the loss of the entire oak cohort over the course of several years.

Key to establishing and developing advance reproduction for natural regeneration is the regulation of light reaching the forest floor (Hodges 1989). Full sunlight may promote faster growing species than oak, while limited light may benefit more shade tolerant species (Clatterbuck and Meadows 1993). There is a narrow range of sunlight that favors the growth of bottomland oak species without aggravating the degree of competition from other woody species. Bottomland oak species such as cherrybark oak (*Quercus pagoda* Raf.), Nuttall oak (*Q. nuttallii* Palm.) and overcup oak (*Q. lyrata* Walt.) require between 25 to 50% of available sunlight for light saturation of photosynthesis (Gardiner 2002). Gardiner and Hodges (1998) reported that the growth of bottomland oak species was greatest when available sunlight was between 27 and 53%.

The removal of the midstory has been used to increase understory light and improve survival and growth for oak advance reproduction (Lorimer et al. 1994, Lockhart et al. 2000). The reduction of competing woody vegetation as well a reduction of part of the overstory has been found to promote the development of larger oak advance reproduction, both natural and planted oak seedlings (Loftis 1990, Schlesinger et al. 1993, Lorimer et al. 1994). Many have found the stem injection of herbicides to be an effective means of reducing density in the midstory and lower crown classes of the overstory. In several bottomland hardwood forests in Mississippi, Ezell et al. (1999) found that imazapyr caused mortality or severe crown reduction to injected stems, enhanced regeneration of cherrybark oak seedlings and did not damage crop stems.

We evaluated the effect of a 20% solution of Arsenal® AC (imazapyr) solution applied by the hack and squirt injection method in the late winter to trees in the midstory and lower crown classes of the overstory, which was done to increase light available to oak seedlings in the understory of bottomland forests in a DCCA green tree reservoir and a MNWR naturally flooded pool. Our objective was to compare the effectiveness of the herbicide treatment to deaden the major tree species in the understory and midstory that were competing with pin oak reproduction. We also developed models to predict the degree of dieback or death of trees treated with Arsenal® AC for the more common bottomland hardwood species in mature forests of the Missouri Bootheel region so area managers can develop prescriptions to better regulate the light levels in forest understories to promote the development of large oak advance reproduction.

We modeled tree mortality by diameter, pretreatment crown dieback, crown position, and live crown ratio. We also assessed the affect of herbicide treatment on forest canopy crown cover in treated stands. By focusing on tree responses by species and individual tree attributes including diameter, crown position, live crown ratio, and initial crown condition, we are better able to anticipate and predict the results of additional late winter herbicide injections of Arsenal® AC (imazapyr).

METHODS

Study sites

The study was conducted at DCCA and MNWR in Southeast Missouri. Two management pools were selected based on the condition of the mature pin oak, i.e., healthy (pool 8 MNWR) or in decline (pool 3 DCCA), and the flood regime, i.e., natural functioning hydrology (pool 8 MNWR) or managed greentree reservoir (GTR) for waterfowl hunting (pool 3 DCCA). Pool 3, DCCA, is a GTR flooded annually in the fall for duck hunting. Since the GTRs construction in the 1940's, the pool was artificially flooded in October and not drawn down until the late winter or early spring. Differences in soil chemistry such as a lower pH and greater amounts of litter decomposition have been found in the GTRs compared to adjacent naturally flooded pools (Heitmeyer et al. 1989). Pool 8, MNWR, is not a GTR, but experiences natural flood events from the St. Francis and Castor Rivers during the fall and winter. On pool 8, rainfall and puddling, backwater flooding from the St. Francis and Castor Rivers, and headwater flooding flood the area. Each of these methods of flooding is closely tied to the weather and seldom does the flood water remain on the pool for long periods during the fall through the spring. Forests in Pool 3 are experiencing high levels of crown decline and mortality in the mature pin oak, due to advanced tree age and unnatural flood regime. However there was no difference in pin oak mortality before the herbicide treatment between the two management pools. We compared all of the pin oaks present in our overstory plots and found 23% of the pin oaks were dead in pool 3, DCCA, and 24% of the pin oaks were dead in pool 8, MNWR.

Soils of both of these pools are mapped as Calhoun silt loam (Butler 1985). These soils were formed in the nearly level floodplain as a result of the formation of the alluvial fans that have impeded the drainage of the basin. They are fine-silty, mixed, active, thermic Typic Glossaqualfs (Butler 1985). These soils are variable in texture with a high water holding capacity, low levels of organic matter, and poor fertility (Butler 1985).

For all trees in these two pools, pin oak was the dominant species (54% of the basal area). Other important species included sweetgum (12%), overcup oak (10%), red maple (7%), American elm (6%), willow oak (*Q. phellos* L.) (5%), green ash (2%), persimmon (*Diospyros virginiana* L.) (1%) and cherrybark oak (*Q. pagoda* Raf.) (1%).

In the midstory and understory of the two pools, sweetgum was the most prevalent species (31% of the basal area). Other important species in the midstory and understory include red maple (19%), American elm (18%), overcup oak (9%), pin oak (6%), green ash (5%), persimmon (4%), and willow oak (3%).

Red maple was most commonly present (87%) in advance reproduction plots (trees less than 1.5 inches DBH and greater than 4.5 feet tall). Other species of trees commonly present in the advanced reproduction plots were green ash (47%), persimmon (40%), sweetgum (30%), American elm (23%), roughleaf dogwood (*Cornus drummondii* C.A. Mey) (21%), common buttonbush (*Cephalanthus occidentalis* L.) (21%), Deciduous holly (*Ilex decidua*) (16%), pin oak (10%), water hickory (*Carya aquatica* Nutt.) (9%), overcup oak (8%), blackgum (*Nyssa sylvatica* Marsh.) (7%), winged elm (*Ulmus alata* Michx.) (6 percent), water locust (*Gleditsia aquatica* Marsh.) (5 percent), willow oak (3%), hawthorn (*Crataegus spp.* L.) (2%), alternateleaf dogwood (*Cornus alternifolia* L.

f.) (1%), and cherrybark oak (1%). Trumpet creeper (*Campsis radicans* (L.) Seem. ex Bureau) was a common vine appearing in 58% of the advance reproduction plots. Trumpet creeper has a fast growth rate and can quickly overtop the advance reproduction layer.

Design

A randomized complete block design was used with a total of six blocks, each containing nine treatment units. The nine treatment units are part of another study described in detail by Krekeler et al. (2006). During the summer of 2002 in each of the two management pools, we established three 10-acre blocks containing nine 1.1-acre treatment units that were 220 by 220 ft 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, diameter, crown position, live crown ratio, and crown dieback of all trees greater than 1.5 inches DBH prior to treatment. Each of trees inventoried in the plots labeled for midstory competition control was used as a sample unit in the analysis of our treatment.

Treatment

The midstory thinning treatment was conducted during February, 2003, to remove all non-oak woody vegetation. This was done by spraying 0.34 ounces of Arsenal® AC (20% concentration) into horizontal hacks made in the tree bole with a 1.25 inch hatchet. One hack (plus herbicide application) was made per three inches DBH evenly spaced around the stem at approximately 4.5 feet above the ground. Except for the control unit in each of the six blocks, the entire 1.1 acre experimental unit was treated.

On pool 3 and pool 8, we axe-girdled all non-oak trees except baldcypress greater than five feet tall and less than seven inches in diameter at breast height (DBH). In areas where there was extensive oak mortality in the overstory, and there were no trees greater than seven inches DBH, select midstory tree species were left on a 25 by 25 foot spacing. Select trees were those of good form listed in order of preference: persimmon, sweetgum, elm, ash, and maple. Least preferred species were maple and ash.

Measurements

In July, 2002, circular 1/5th acre plots were established and marked with a blue surveying flag in the center of each of the treatment areas. Within the 1/5th acre plot, all trees greater than 1.5 inches in diameter were inventoried. Data taken for each tree included a distance (feet and tenths) and azimuth (0-360˚) to the center of the stem from the center of the plot, species, diameter at breast height (inches and tenths), crown class (dominant, codominant, intermediate, and overtopped) (Smith et al. 1997), live crown ratio (percent of the stem that supported live crown) (Smith et al. 1997), and pretreatment crown dieback (percent of the crown that had died in addition to natural branch pruning). Each tree was tagged at its base with an aluminum tag and nail with a unique number. These tags were placed facing the center of the circular plot. In the center of each plot, a spherical densiometer was used to estimate the percentage of open sky in the forest canopy. Diameter was a continuous variable. Live crown ratio (Smith et al. 1997) was measured as a continuous variable but was placed into one of two classes for analysis: 0-29% crown ratio or 30% and greater. The break point of 30% was selected because trees under this percentage were considered suppressed, whereas, trees with greater live crown ratios had no reduction in growth due to insufficient crown (Smith et al. 1997). Pretreatment crown dieback or initial dieback (ID) was also measured as a continuous variable and then put into one of three classes for analysis: 1. No prior decline, 2. 1-49% dieback, and 3. Greater than 50% dieback.

Following the dormant season herbicide treatment, each tagged tree was inventoried during July, 2003. Measurements included crown class, live crown ratio, crown dieback, and the number of hacks around the individual stems. Pretreatment conditions for each factor listed above were used as covariates to model the results of the herbicide treatment. A spherical densiometer was used in the center of each plot to estimate the percentage of skylight reaching the forest floor during the first growing season after the herbicide treatment.

Analysis

Only trees that received the herbicide treatment were used to develop the models that predict the probability of an individual tree being in one of four dieback classes. Two statistical procedures were used to analyze the data set.

First, we used the general linear models procedure (SAS version 9.1, Statistical Analysis Software, INC., Cary, NC, USA) to compare the post treatment crown dieback percentages of the individual species ($\alpha = 0.05$). The response variable was the final dieback percentage of each tree treated with herbicide. Each tree species was used as a predictor variable. Each tree was a sample unit. The Tukey's test was used to compare the post treatment crown dieback between tree species. The hypothesis tested was:

Ho: There is no difference in crown dieback between the tree species.

Second, the logistic procedure (SAS version 9.1, Statistical Analysis Software, INC., Cary, NC, USA) was used to select models predicting the probability that an individual tree would be in one of four dieback classes following a dormant season herbicide injection. The response variables were the four crown dieback classes. The four crown dieback classes were: Dead 100% dieback, severe 70-99% dieback, moderate 30-69% dieback, and no apparent, or slight dieback 0-29% dieback. For each tree species (red maple, green ash, sweetgum, and American elm), four single variable models were compared. Each model contained one predictor variable. The predictor variables compared were: 1. Diameter, a continuous variable; 2. crown class as listed in the measurements section was coded 1, 0 for crown class 3 (codominant), 0, 1 for crown class 4 (intermediate), and -1, -1 for crown class 5 (overtopped or suppressed); 3. Live crown ratio was coded 1 for trees with less than 30% live crown ratios and -1 for trees with greater than 30% live crown ratios; 4. Prior dieback class as stated in the measurements section was coded 1, 0 for no prior dieback, 0, 1 for 1-49% dieback, and -1, -1 for greater than 50% dieback. The Chi-square statistic (Likelihood ratio test), the ΔAICc, the likelihood of a model, and Akaike weights were used to evaluate the significance of each variable tested and select the models that were the best fit. There were insufficient numbers of sample units of each species to evaluate interactions among the predictor variables.

RESULTS

Post treatment crown dieback

Of the four major competitors in the midstory and understory, green ash exhibited the highest level of crown dieback of 99.29%. Sweetgum exhibited the second highest level of crown dieback at 91.44%. American elm exhibited the third highest level of crown dieback at 87.49%, and red maple exhibited the least crown dieback with an average percentage of 72.11% (Table 9). Of the four species only sweetgum and American elm did not vary significantly for one another. Three groups of tree species varied significantly from one another ($P < 0.0001$). The first group contained red maple, as denoted by the superscript a, had significantly lower dieback than the other two groups. The second group had significantly greater dieback than red maple and less dieback than green ash, denoted by the superscript b, contained sweetgum and American elm. The third group, denoted by superscript c, contained green ash showed greater dieback than the other three species. This finding that the four major competitors differed in their mean percentage of crown dieback following the herbicide treatment warranted further investigation of the four species.

Changes in forest canopy cover

During the application of the midstory and understory thinning treatment, we treated 328 trees per acre (27 ft^2 ac^{-1}). 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% (Table 10); and there were no significant differences in forest canopy cover between the decline (pool 3) and healthy (pool 8) plots.

Table 9. Mean crown dieback percentage of the four major competing tree species in the midstory and understory[a].

Species	Crown Reduction Mean
	-------%------
Red maple	72.11[a]
Green ash	99.29[c]
Sweetgum	91.43[b]
American elm	87.49[b]

[a] The superscripts a, b, and c represent the values of crown dieback percentages that are significantly different from each other (P<0.0001).

Table 10. Percent canopy cover in thinned (herbicide treatment) and unthinned (control) plots measured 6 months after treatment[a].

Management Pool	Canopy Cover	
	Control	Thinned
	- - - - - % - - - - -	
Pool 3 (decline)	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 3 (Duck Creek Conservation Area) was selected because the oaks exhibited moderate or advanced decline and had compromised mast production. Pool 8 (Mingo National Wildlife Refuge) was selected because the oaks appeared to be healthy and there was very little observable crown dieback or mortality.

Distribution of trees by species and dieback class

Over 43% of the trees treated were killed by the herbicide, regardless of species (Table 11). The herbicide treatment showed no to moderate sights of dieback in less than 17% of all the treated stems (Table 11). Of the four major competitors, green ash and sweetgum had the highest percentage of trees in the dead dieback class (79.4 and 66.2%, respectively). The herbicide was less effective in controlling red maple or American elm. Almost one-quarter of the red maple showed no apparent sign of decline during first growing season after herbicide application.

Table 11. Percent of trees in each of the four dieback classes during the first growing season after herbicide treatment.

Species	No apparent dieback	Moderate dieback	Severe dieback	Dead	Total # of stems
	----------Percent----------				(n)
Red Maple	21.1	11.2	38.8	28.9	793
Green Ash	0.3	0.0	20.2	79.4	287
Sweetgum	4.3	6.0	23.5	66.2	1069
American Elm	2.7	10.6	75.6	11.1	913
All Species	8.4	8.3	40.3	43.1	3549

Modeling the probability of dieback for the four major competitors of pin oak

Four single variable models containing the four dieback classes as the response variable contained diameter, crown class, live crown ratio, or prior dieback class as the test variable for red maple, green ash, American elm, and sweetgum.

Red maple

Of the four single-variable models tested, the models with dbh or crown class were selected as the best models for estimating the probability of being in a specific dieback class using logistic regression (Table 12). Models were selected for best fit based on the likelihood ratio test < 0.05, small ΔAICc, and an Akaike weight within 1/8th of the best fit model. If the model fails to meet any one of these parameters it is not within the set of best models (Burnham and Anderson 2002).

Although the probability of X^2 is less than 0.05 for the models containing live crown ratio and initial dieback as predictor variables, they were not chosen in the set of best models because their ΔAICc was too high when compared with the dbh model, which had the lowest AICc score (Burnham and Anderson 2002). The conclusion to not include these models is also supported by the likelihood estimates, and the Akaike weights for the models with crown ratio and initial dieback were outside of 1/8th of the Akaike weight of the best fit model (Table 12). The logistic regression models predicting the probability of an individual red maple tree being in one of four dieback classes after herbicide treatment by either diameter or crown class are shown in Table 13.

The probability of being in the dead dieback class is negatively correlated with diameter, whereas the probability of being in the no apparent or slight dieback class is positively correlated with diameter (Figure 9). This model shows that trees larger than 5 inches dbh are less likely to be in the dead dieback class than they are to be in the no apparent or slight dieback class. Therefore, the herbicide treatment as applied in this study is not consistently effective across the diameter classes.

Codominant and overtopped red maple trees are more likely to die than red maples that were in the intermediate crown class (Figure 10). In contrast, red maples in the intermediate crown class were most likely to show no apparent or slight crown dieback compared to maples in other crown classes.

Table 12. Logistic regression test statistics for models of dieback probabilities for red maple. Probabilities are estimated for red maple being in one of four dieback classes (Dead 100% dieback, severe 70-99% dieback, moderate 30-69% dieback, and no apparent, or slight 0-29% dieback) one season after herbicide application based on either its initial DBH = diameter breast height at time of herbicide application, CC = crown class (suppressed, intermediate, codominant and dominant), CR = live crown ratio class (<30% or ≥30%), or ID = initial dieback class (no dieback, 1-49% dieback, ≥50% dieback).

	Red Maple Models n = 783	K	Likelihood Ratio Test $Pr>X^2$	AIC	AICc	ΔAICc	Likelihood of a Model	Akaike Weights
*	**DBH**	4	< 0.0001	2000	1999.77	0.00	1.00	0.63
*	**CC**	5	< 0.0001	2001	2000.80	1.03	0.60	0.37
	CR	4	0.0007	2032	2032.54	32.77	0.00	0.00
	ID	5	0.0371	2039	2039.41	39.64	0.00	0.00

* indicates model selected for best fit based on the likelihood ratio test < 0.05, small ΔAICc, and an Akaike weight within 1/8th of the best fit model. If the model fails to meet any one of these parameters it is not presented as a model of best fit.

Table 13. Red maple logistic regression parameters for diameter (DBH) and crown class (CC) models.

Red Maple Models [a] n = 783	First βo	Second βo	Third βo	β1*DBH	β2*CC3	β3*CC4	β4*CC5
DBH	-2.1216	-1.524	0.2132	0.226	…	…	…
CC	-1.4998	-0.8932	0.8531	…	-0.4608	0.6819	-0.2211

[a] Models are of the form: $P=[1+\exp[-(\beta o+\beta_1 X_{1+\ldots}+\beta_n X_{n)})]]^{-1}$ and
P = the probability that a red maple of given DBH or CC will be in one of four dieback classes one growing season after herbicide treatment
DBH = diameter breast height (inches)
CC is crown class where CC3 = codominant, CC4 = intermediate, and CC5 = overtopped

The probability (P1) of a tree being in the no apparent or slight dieback class is computed with the logistic model using the first intercept; the joint probability (P2) of a tree being in either the no apparent or slight dieback, or moderate decline classes is computed with the logistic model using the second intercept; the joint probability (P3) of a tree being in either the no apparent or slight dieback , moderate dieback, or the severe dieback classes is computed with the logistic model using the third intercept; the probability of a tree being in the moderate dieback class is calculated by (P2 - P1) ; the probability of a tree being in the severe dieback class is calculated by (P3 - P2) ; and the probability of being in the dead dieback class is determined by subtracting (1 -P3).

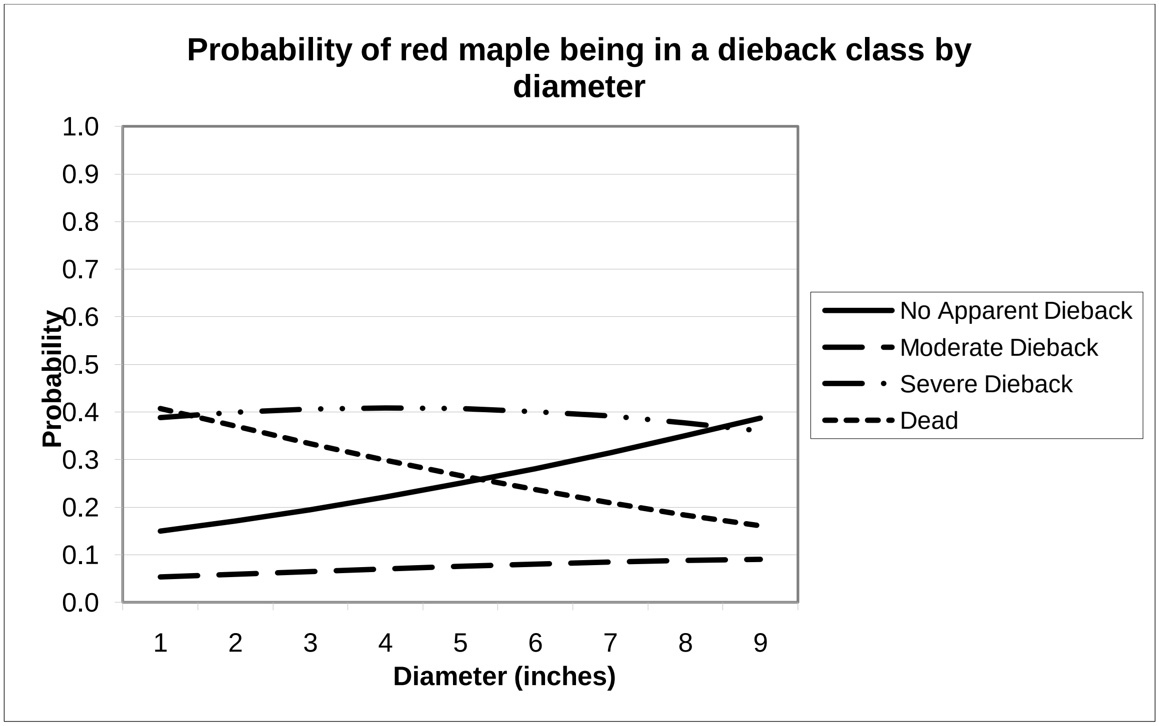

Figure 9. Probability of red maple being in a dieback class one growing season after herbicide treatment by diameter (dbh). The four crown dieback classes are: Dead 100 percent dieback, severe 70-99% dieback, moderate 30-69% dieback, and no apparent or slight 0-29% dieback.

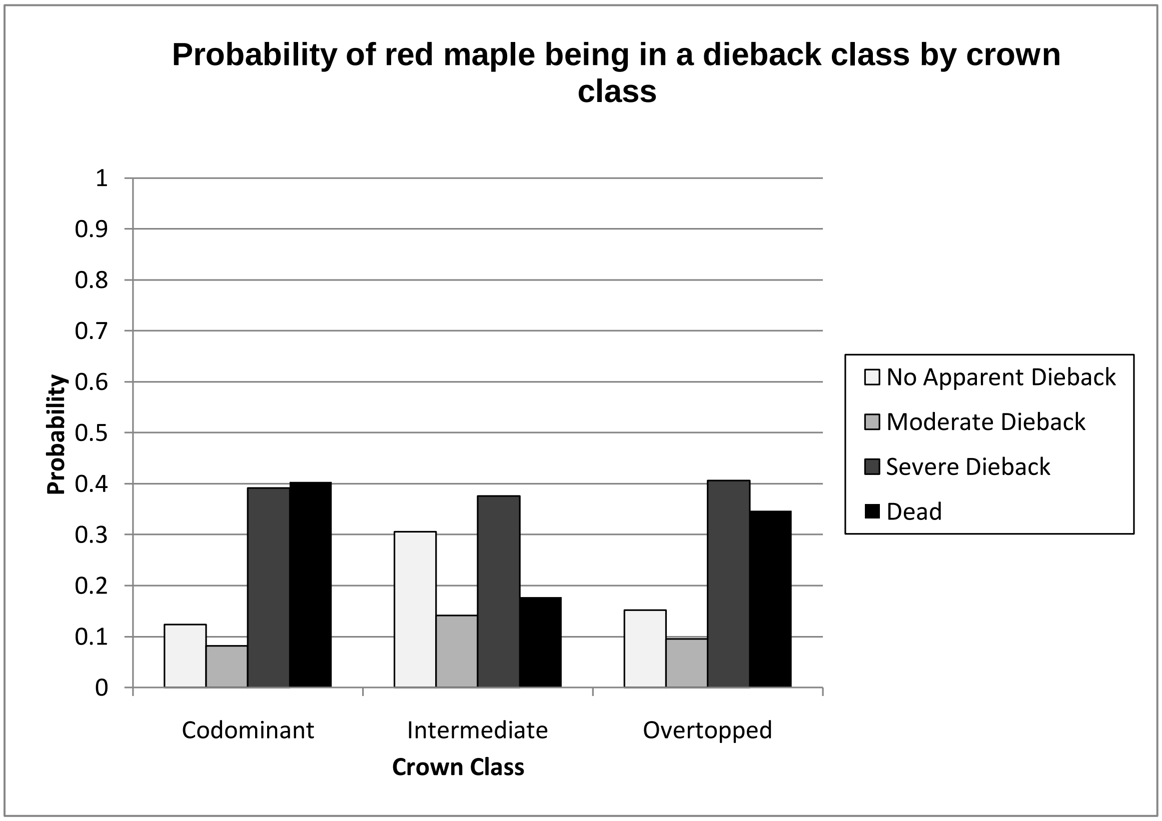

Figure 10. Probability of red maple entering a dieback class by crown class one growing season after herbicide treatment. The four crown dieback classes are: Dead 100% dieback, severe 70-99% dieback, moderate 30-69% dieback, and no apparent or slight0-29% dieback. No trees in the dominant crown class were treated with herbicides.

Green ash

Of the four variables tested, only dbh was important (Table 14). The likelihood ratio test was < 0.05 for dbh. The probability of a green ash being in the dead dieback class during the first growing season after herbicide treatment was positively correlated with dbh (Figure 11). The herbicide treatment was effective in killing green ash in the larger diameter classes. Smaller green ash trees were not as effectively deadened as larger trees. Smaller trees may need a larger percentage of herbicide or additional hacks to be deadened as effectively as the larger trees. Crown class (CC), live crown ratio (CR), and initial crown dieback were not significant variables for predicting dieback probabilities for green ash. The parameters for the best green ash model are shown in Table 15. There were no trees in the moderate dieback class, so the 2^{nd} βo was null.

Table 14. Logistic regression test statistics for models of dieback probabilities for green ash. Probabilities are estimated for green ash being in one of four dieback classes (Dead 100% dieback, severe 70-99% dieback, moderate 30-69% dieback, and no apparent, or slight 0-29% dieback) one season after herbicide application based on either its initial DBH = diameter breast height at time of herbicide application, CC = crown class (suppressed, intermediate, codominant and dominant), CR = live crown ratio class (<30% or ≥30%), or ID = initial dieback class (no dieback, 1-49% dieback, ≥50% dieback).

	Green Ash Model n = 280	K	Likelihood Ratio Test $Pr>X^2$	AIC	AICc	ΔAICc	Likelihood of a Model	Akaike Weights
*	**DBH**	3	0.04	300.34	300.42	0.00	1.00	0.48
	CC	5	0.06	300.74	300.82	0.40	0.82	0.39
	CR	3	0.31	303.46	303.49	3.07	0.22	0.10
	ID	4	0.96	306.41	306.46	6.04	0.05	0.02

* indicates model selected for best fit based on the likelihood ratio test < 0.05, small ΔAICc, and an Akaike weight within 1/8th of the best fit model. If the model fails to meet any one of these parameters it is not presented as a model of best fit.

Table 15. Green ash model parameters for the best model predicting the probability of a tree of given dbh being in a future dieback class one growing season after herbicide treatment.

Green Ash Model [a] n = 280	**1st β_o**	**2nd β_o**	**3rd β_o**	**β_1*DBH**
DBH	-4.98	…	-0.65	-0.23

[a] Model is of the form: $P=[1+\exp[-(\beta_o+\beta_{1DBH})]]^{-1}$ and
P = the probability that a green ash of given DBH will be in one of four dieback classes one growing season after herbicide treatment
DBH = diameter breast height (inches)

The probability (P1) of a tree being in the class of no apparent or slight dieback is computed with the logistic model using the first intercept ; the joint probability (P2) of a tree being in the no apparent or slight or severe dieback classes is computed with the logistic model using the third intercept; the probability (P3) of a tree entering the severe dieback class is calculated by (P2 – P1); and the probability of being in the dead dieback class is determined by (1-P2).

There were no trees measured in the moderate dieback class following the herbicide treatment, so there is no 2nd βo.

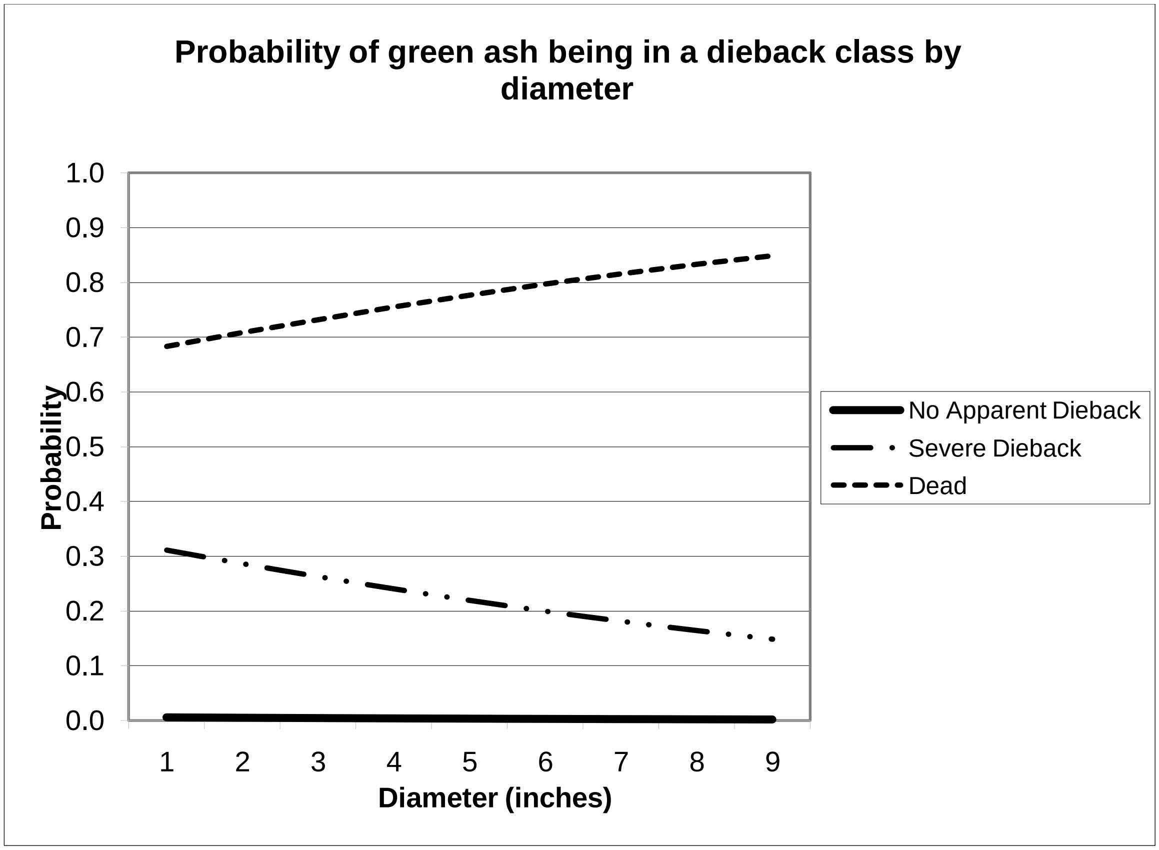

Figure 11. Probability of green ash being in a dieback class by diameter one growing season after herbicide treatment. The four crown dieback classes are: Dead 100% dieback, severe 70-99% dieback, and no apparent or slight 0-29% dieback.

American elm

The dbh of an American elm tree was not an important variable for predicting the probability of it being in one of the four dieback classes (Figure 12). American elm trees were top killed, but many trees exhibited advantageous growth from dormant buds along the lower bole and roots showing they were not completely dead. These trees had very small live crown ratios following the treatment and many were in the severe decline class. The probability of an American elm tree being in one of the four dieback classes is not positively or negatively correlated with dbh. Although all trees were not killed, this result shows the herbicide treatment was as effective in that it severely reduced the competitiveness of American elm by greatly reducing its crown. Only live crown ratio and initial crown dieback models were identified as significant based on the logistic regression analysis (Table 16). The best models are shown in Table 17.

American elm trees in the live crown ratio class above 30% were less likely to enter the dead dieback class than the American elm trees in the live crown ratio class below 30% (Figure 13). The probability of a tree being in the no apparent or slight dieback class, and the moderate dieback class was positively correlated with live crown ratios above 30% (Figure 13). There was no effect on the probability of being in the severe dieback class with live crown ratio class (Figure 13).

As the initial crown dieback class changed from no apparent dieback to severe initial dieback, the probability of being in the dead dieback class increased (Figure 14). The probability of a tree being in the no apparent or slight dieback class, and the moderate dieback class was negatively correlated with increasingly poor initial crown dieback (Figure 14). There was no correlation between the probabilities of being in the severe dieback class with a declining initial crown dieback (Figure 14).

Table 16. Logistic regression test statistics for models of dieback probabilities for American elm. Probabilities are estimated for American elm being in one of four dieback classes (Dead 100% dieback, severe 70-99% dieback, moderate 30-69% dieback, and no apparent, or slight 0-29% dieback) one season after herbicide application based on either its initial DBH = diameter breast height at time of herbicide application, CC = crown class (suppressed, intermediate, codominant and dominant), CR = live crown ratio class (<30% or ≥30%), or ID = initial dieback class (no dieback, 1-49% dieback, ≥50% dieback).

	American Elm Models	K	Likelihood Ratio Test	AIC	AICc	ΔAICc	Likelihood of a Model	Akaike Weights
	n = 902							
	DBH	3	0.70	1404.34	1404.37	6.58	0.04	0.02
	CC	5	0.72	1405.83	1405.90	8.11	0.02	0.01
*	**CR**	3	0.02	1399.30	1399.32	1.54	0.46	0.31
*	**ID**	4	0.01	1397.74	1397.79	0.00	1.00	0.66

* indicates model selected for best fit based on the likelihood ratio test < 0.05, small ΔAICc, and an Akaike weight within 1/8th of the best fit model. If the model fails to meet any one of these parameters it is not presented as a model of best fit.

Table 17. American elm model parameters for the best models predicting the probability of a tree of given live crown ratio (CR) or initial crown dieback (ID) being in a future dieback class one growing season after herbicide treatment.

American Elm Models[a] n = 902	1st βo	2nd Bo	3rd Bo	β5*CR1	β6*CR2	β7*ID1	β8*ID2	β9*ID3
CR	-3.74	-2.04	2.04	-0.25	0.25	…	…	…
ID	-3.99	-2.29	1.81	…	…	0.50	-0.17	-0.33

[a] Models are of the form: $P=[1+\exp[-(\beta o+\beta_1 X_{1+\ldots}+\beta_n X_{n})]]^{-1}$ and
P = the probability that a red maple of given CR or ID will be in one of four dieback classes one growing season after herbicide treatment and
CR = live crown ratio class (<30% or ≥30%)
ID = initial dieback class (no dieback, 1-49% dieback, ≥50% dieback)

The probability (P1) of a tree being in the no apparent or slight dieback class is computed with the logistic model using the first intercept; the joint probability (P2) of a tree being in either the no apparent or slight dieback, or moderate decline classes is computed with the logistic model using the second intercept; the joint probability (P3) of a tree being in either the no apparent or slight dieback , moderate dieback, or the severe dieback classes is computed with the logistic model using the third intercept; the probability of a tree being in the moderate dieback class is calculated by (P2 - P1) ; the probability of a tree being in the severe dieback class is calculated by (P3 - P2) ; and the probability of being in the dead dieback class is determined by subtracting (1 -P3).

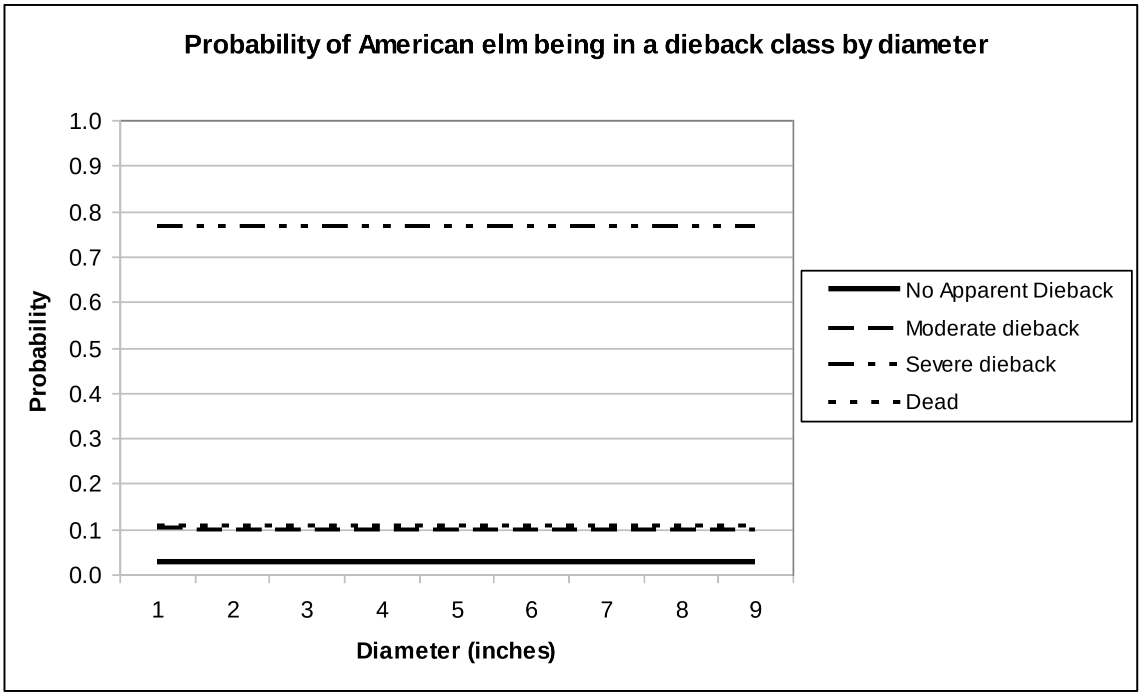

Figure 12. Probability of American elm being in a dieback class by diameter one growing season after herbicide treatment. The four crown dieback classes are: Dead 100% dieback, severe 70-99% dieback, moderate 30-69% dieback, and no apparent or slight 0-29% dieback.

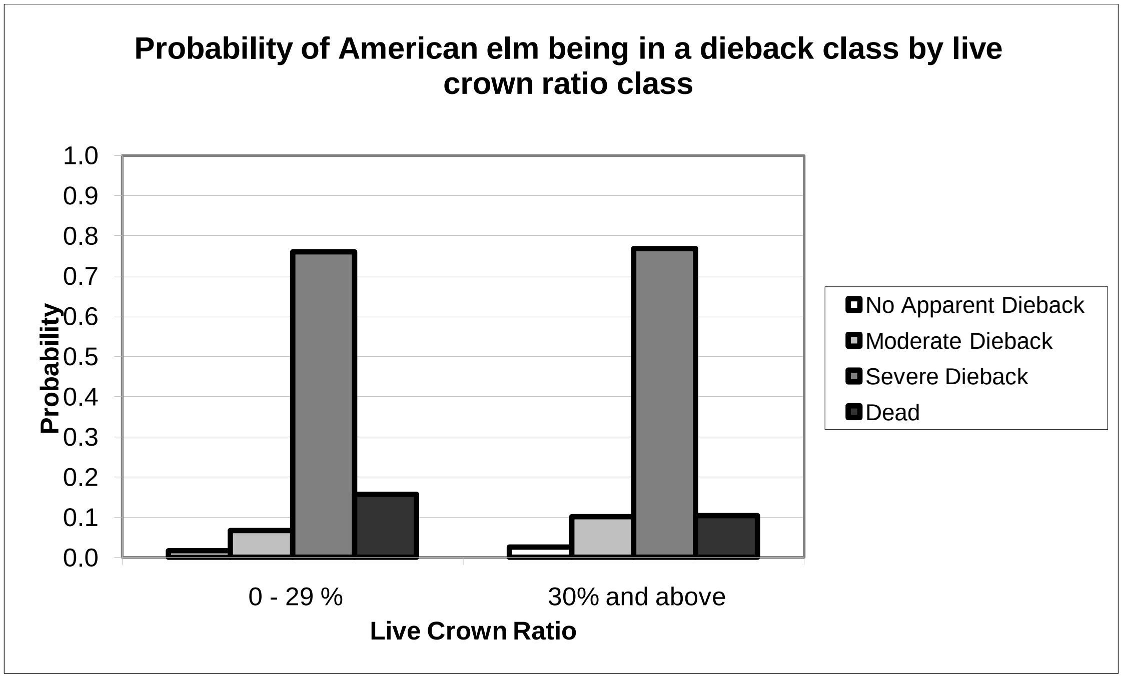

Figure 13. Probability of American elm being in a dieback class by live crown ratio one growing season after herbicide treatment. The four crown dieback classes are: Dead 100% dieback, severe 70-99% dieback, moderate 30-69% dieback, and no apparent or slight 0-29% dieback.

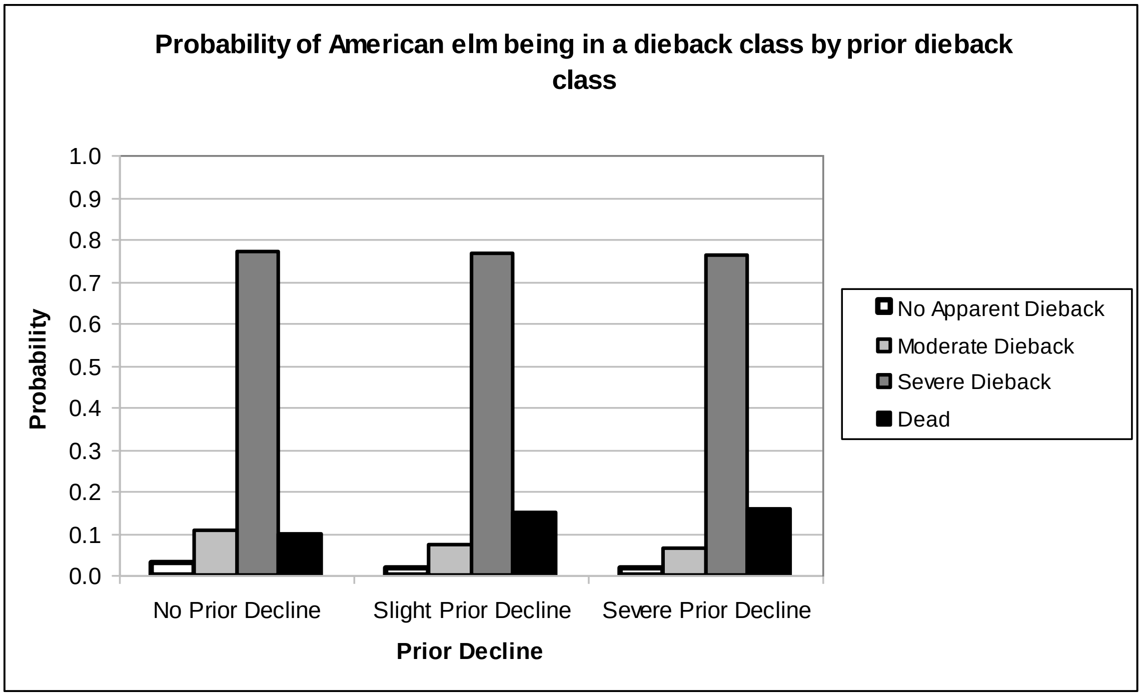

Figure 14. Probability of American elm being in a dieback class by prior dieback class one growing season after herbicide treatment. The four crown dieback classes are: Dead 100% dieback, severe 70-99% dieback, moderate 30-69% dieback, and no apparent or slight 0-29% dieback.

Sweetgum

The model with dbh was the only significant model of those evaluated by logistic regression (Table 18). The best model is given in Table 19. The smaller sweetgum trees (1 to 8 inches dbh) had the highest probability of dying, which decreased sharply as dbh increased above 8 inches (Figure 15). This suggests that the herbicide treatment is not as effective in deadening the larger diameter sweetgum trees. Conversely, the probabilities of entering the no apparent or slight dieback, moderate dieback, or severe dieback classes are positively correlated with diameter. Trees larger than 6 inches dbh are more likely to be in the severe dieback class that the dead class, and trees larger than 7 inches dbh are more likely to be in the no apparent effect class than the dead class (Figure 15).

Table 18. Logistic regression test statistics for models of dieback probabilities for sweetgum. Probabilities are estimated for sweetgum being in one of four dieback classes (Dead 100% dieback, severe 70-99% dieback, moderate 30-69% dieback, and no apparent, or slight 0-29% dieback) one season after herbicide application based on either its initial DBH = diameter breast height at time of herbicide application, CC = crown class (suppressed, intermediate, codominant and dominant), CR = live crown ratio class (<30% or ≥30%), or ID = initial decline class (no decline, 1-49% decline, ≥50% decline).

	Sweetgum Models n = 1059	K	Likelihood Ratio Test	AIC	AICc	ΔAICc	Likelyhood of a Model	Akaike Weights
*	**DBH**	4	<.0001	1726.20	1726.23	0.00	1	1
	CP	5	<.0001	1877.08	1877.13	150.90	1.708E-33	1.7E-33
	CR	3	0.0098	1953.70	1953.72	227.49	3.992E-50	4E-50
	Prior Decline	4	0.5282	1961.10	1961.14	234.90	9.8E-52	9.8E-52

* indicates model selected for best fit based on the likelihood ratio test < 0.05, small ΔAICc, and an Akaike weight within 1/8th of the best fit model. If the model fails to meet any one of these parameters it is not presented as a model of best fit.

Table 19. Sweetgum model parameters for the best models predicting the probability of a tree of given DBH being in a future dieback class one growing season after herbicide treatment.

Sweetgum Model [a] **n = 1059**	**1st βo**	**2nd βo**	**3rd Bo**	**β1*DBH**
DBH	-5.59	-4.54	-2.73	0.52

[a] Models are of the form: $P=[1+\exp[-(\beta o+\beta_1 DBH_1)]]^{-1}$ and
P = the probability that a sweetgum of given DBH will be in one of four dieback classes one growing season after herbicide treatment
DBH = diameter breast height (inches)

The probability (P1) of a tree being in the no apparent or slight dieback class is computed with the logistic model using the first intercept; the joint probability (P2) of a tree being in either the no apparent or slight dieback, or moderate decline classes is computed with the logistic model using the second intercept; the joint probability (P3) of a tree being in either the no apparent or slight dieback , moderate dieback, or the severe dieback classes is computed with the logistic model using the third intercept; the probability of a tree being in the moderate dieback class is calculated by (P2 - P1) ; the probability of a tree being in the severe dieback class is calculated by (P3 - P2) ; and the probability of being in the dead dieback class is determined by subtracting (1 -P3).

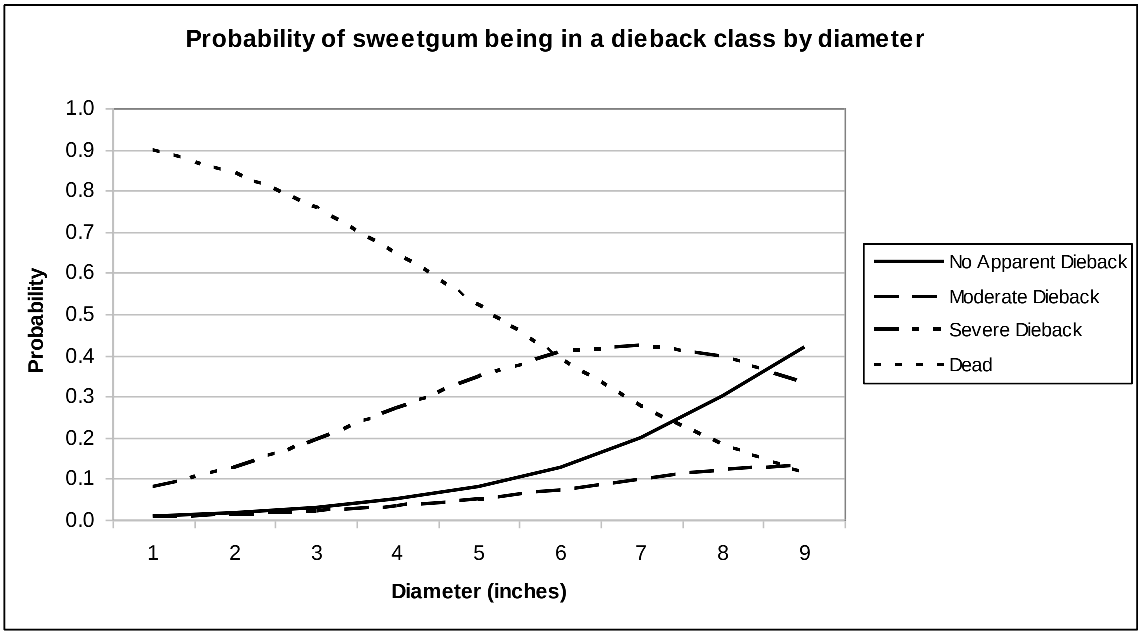

Figure 15. The probability of a sweetgum tree being in a dieback class one growing season after herbicide treatment by diameter (dbh). The four crown dieback classes are: Dead 100% dieback, severe 70-99% dieback, moderate 30-69% dieback, and no apparent or slight0-29-0% dieback.

DISCUSSION

The overall percent of crown dieback and mortality of the four major competing species in this study was lower than has been reported for late growing season and dormant season applications of herbicide. On the Ward Bayou near Pascagoula, MS, Ezell et al. (1999) achieved a complete kill (100% crown dieback) of sweetgum and a near complete mortality of 98.3% crown dieback for red maple following a late growing season application of a 25% solution of Arsenal AC® applied in the same manner as was done in this study. Red maple treated in Ezell et al. (1999) ranged from 0 to 9 inches dbh. Ezell et al. (1999) also reported 98% crown dieback for red maple and sweetgum respectively using a 20% solution of Chopper® in a dormant season injection at the John W. Starr Memorial Forest in Winston County, MS. The crown dieback of 72.11% for red maple and 91.43% for sweetgum was similar to Ezell et al.'s (1999) findings of 79.9% and 86.8% for red maple and sweetgum in their 20% Chopper® early growing season injection conducted in May on the Noxubee Refuge in Winston County, MS.

On a southern bottomland Piedmont site in east-central Alabama, Miller (1997) reported that a basal streamline application in April of 10% Chopper® (imazapyr) mixed with diesel solution resulted in an over 80% crown dieback in sweetgum ranging from 0.5 to 3 inches in basal caliper. Although our treatment was not to be conducted during the spring or heavy sapflow events, sapflow may be partially responsible for the lower mortality rates observed in this study, especially in the red maple. A late growing season or early dormant season application of a 20 to 25% Arsenal AC® solution is likely to give better control over unwanted stems of elm, maple, ash and sweetgum.

Although mortality was relatively low for American elm, no change to the method of application in this study is recommended Because treated stems were no longer competitive even though there were advantageous sprouts from American elm and the stems were technically still alive. American elms with larger initial live crown ratios and healthy crowns may show less crown dieback; however, the difference is minimal.

Green ash was effectively removed from the stand by the herbicide treatment, but models do show evidence that the trees in the smaller diameter classes may need a higher concentration of herbicide. Modification of the herbicide treatment may be necessary where stands contain large numbers of small green ash stems. Effectiveness may be increased by applying herbicides early in the dormant season or in the late growing season, or by applying herbicides at a higher concentration and rate if there are high densities of small diameter green ash.

To improve control over red maple and sweetgum would require either a higher concentration or a larger amount of the 0.34 ounces of Arsenal® AC (20% concentration) applied to larger diameter trees, i.e., larger than 5 inches in dbh for red maple and 6 inches dbh for sweetgum. This could increase the probability of the trees either dying or experiencing severe dieback. Although the herbicide treatment was halted on days when sapflow was exuding from the hack wounds, sap flow could have occurred in the days following the herbicide treatment, thus affecting the mortality and dieback probabilities. Conducting the herbicide treatment during seasons when sapflow is low, particularly the late growing season or early dormant season, would improve effectiveness of control in red maple and sweetgum. Managers with red maple mostly in the intermediate crown class may want to alter their herbicide prescription by increasing herbicide concentration or amount with additional hacks placed around the stem in the intermediate crown position class for a late winter hack and spray using Arsenal® AC herbicide.

Ultimately, the purpose of the midstory and understory thinning was to increase the available sunlight, or photosynthetically active radiation (PAR), reaching the forest floor to benefit the oak reproduction while not unduly releasing competing vegetation. Although we did not measure PAR in our study, we do note that Lockhart et al. (2000) reported that midstory thinning in bottomland forests in north-central Mississippi increased PAR by more than four to ten 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 is an important finding because it demonstrates the benefits of partial sunlight to seedlings of species considered to be shade intolerant, as is pin oak and many other bottomland oaks.

CONCLUSIONS

Understanding the effects on the midstory of herbicide treatments is critical when trying to promote understory reinitiation of oak in bottomland hardwood forests. The ability to better predict the effectiveness of herbicide treatment and understand how it varies by species and individual tree characteristics such as diameter, live crown ratio, crown class and crown health will help managers in developing detailed stand prescriptions to favor the establishment, survival, and growth of oak reproduction in existing bottomland hardwood forests. Control of midstory competing tree species is critical to the establishment, survival and growth of oak and other desirable reproduction in existing bottomland hardwood forests.

Our prescription to control the major competing species by the hack and spray method using Arsenal® AC (20% concentration; at a rate of 0.34 ounces per hack; one hack per 3 inches in dbh) in the late dormant season was effective in controlling American elm. Better control of sweetgum, green ash, and red maple could be improved by either increasing the concentration and rate of application, or by changing the season of application from late to early dormant season. The models developed to estimate the probability of crown dieback from pretreatment inventories of species, DBH, crown class, live crown ratio, and initial crown health/vigor can be used to develop silvicultural stand prescriptions that would increase understory light levels to favor oak reproduction.

LITERATURE CITED

Burnham, K.P. and D.R. Anderson. 2002. Model selection and multimodel inference. New York, NY: Springer. 488 p.

Beck, D.E. 1970. Effect of competition on survival and height growth of red oak seedlings. Res. Pap. SE-56. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 7 pp.

Butler, R.E. 1985. Soil survey of Stoddard County, Missouri. United States Department of Agriculture, Soil Conservation Service. 148 p.

Clatterbuck, W., and S. Meadows. 1993. Regenerating Oaks in the Bottomlands. P. 184-195. Eds. David Loftis and Charles McGee. In: The Proceedings of the Oak Regeneration: Serious Problem - Practical Recommendations Symposium; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: Southeastern Forest Experimental Station. 319 pp.

Crow, T.R. 1988. Reproductive mode and mechanisms for self-replacement of northern red oak (Quercus rubra) -- a review. Forest Science. 34(1):19-40.

Dey, D.C., R.G. Jensen, and M.J. Wallendorf. 2008. Single-tree harvesting reduces survival and growth of oak stump sprouts in the Missouri Ozark Highlands. In: Jacobs, D.F.; Michler, C.H., eds. 2008. Proceedings, 16th Central Hardwood Forest Conference; 2008 April 8-9; West Lafayette, IN. Gen. Tech. Rep. NRS-P-24. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 26-37.

Ezell, A.W., J. Lowery, B. Leopold, and P.J. Minogue. 1999. Use of imazapyr injection to promote oak regeneration and wildlife stand improvement in bottomland hardwood stands. In: Haywood, J.D., ed. Proceedings of the tenth biennial southern silvicultural research conference; 1999 February 16-18; Shreveport, LA, Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 151-153.

Gardiner, E.S. 2002. Photosynthetic light response of bottomland oak seedlings raised under partial sunlight. Proceedings of the eleventh biennial southern silvicultural research conference; 2002; Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 86-91.

Gardiner, E.S., and L.M. Helmig. 1997. Development of water oak stump sprouts under a partial overstory. New Forests. 14: 55-62.

Gardiner, E.S., and J.D. Hodges. 1998. Growth and biomass distribution of cherrybark oak (*Quercus pagoda* Raf.) seedlings as influenced by light availability. Forest Ecology and Management. 108:127-134.

Hodges, J.D. 1989. Regeneration of bottomland oaks. Forest Farmer. 49(1):10-11.

Hodges, J.D., and G.L. Switzer. 1979. Some aspects of the ecology of southern bottomland hardwoods. In: North America's forests: Gateway to opportunity: 1978 Joint Convention of the Society of American Foresters and the Canadian Institute of Forestry; 1978 October 22-26; St. Louis, MO. Washington, DC: Society of American Foresters: 360-365.

Janzen, G.C., and J.D. Hodges. 1985. Influence of midstory and understory vegetation removal on the establishment and development of oak regeneration. Proceedings of the Third Biennial Southern Silvicultural Research Conference; 1984 November 7-8; Atlanta, GA. Tech. Rep. SO-54. New Orleans, LA: U.S. Department of Agricutlture, Forest Service, Southern Forest Experiment Station: 273-278.

Janzen, G.C., and J.D. Hodges. 1987. Development of advanced oak regeneration as influenced by removal of midstory and understory vegetation. In: Phillips, Douglas R., comp. Proceedings of the fourth biennial southern silvicultural research conference; 1986 November 4-6; Atlanta, GA. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 455-461.

Johnson, R.L. 1975. Natural regeneration and development of Nuttall oak and associated species. Res. Pap. SO-104. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 12 pp.

Johnson, R.L. 1979. Adequate oak regeneration -- a problem without a solution. In: Management and utilization of oak: Proceedings of the 7th annual hardwood symposium of the Hardwood Research Council; 1979 May; Cashiers, NC. Asheville, NC: Hardwood Research Council: 59-65.

Kabrick, J.M., and M. Anderson. 2000. Oak stump sprouting in mature bottomland forests at Duck Creek Conservation Area. Forest Research Report No. 2. Jefferson City, MO: Missouri Department of Conservation. 9 p.

Krekeler, N.J., J.M. Kabrick, D.C. Dey, and M. Wallendorf. 2006. Comparing natural and artificial methods for establishing pin oak reproduction in bottomland forests managed as greentree reservoirs. In: Conner, Kristina F., ed. Proceedings of the 13th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-92. Asheville, NC: U. S. Department of Agriculture, Forest Service, southern Research Station. 640 p.

Lockhart, B.R., J.D. Hodges, and E.S. Gardiner, 2000. Response of cherrybark oak reproduction to midstory removal and shoot clipping. Southern Journal of Applied Forestry. 42:45-50.

Loftis, David L. 1990. Predicting post-harvest performance of advanced red oak reproduction in the Southern Appalachians. Forest Science. 36(4):908-916.

Lorimer, C. G., J.W. Chapman, and W.D. Lambert. 1994. Tall understory vegetation as a factor in the poor development of oak seedlings beneath mature stands. J. Ecol 82:227–237.

Miller J.H. 1997. Basal streamline sprays for hardwood resprout control: herbicide concentrations and streaks per stem. Proc. South. Weed Sc. 50: 88-93

Rogers, R.S., and I.S. Samder. 1989. Flooding, stand structure, and stand density and their effect on pin oak growth in southeastern Missouri. In: Proceedings of the 5th biennial southern silvicultural research conference; 1988 November 1-3; Memphis, TN. Gen. Tech. Rep. SO-74. New Orleans, LA: U.S. Department of Agriculture, Forest Service: 299-302.

Sander, I. L. 1977. Managers handbook for oaks in the North Central States. Gen. Tech. Rep. NC-37. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 35 pp.

Schlesinger, R.C., I.L. Sander, and K.R. Davidson, 1993. Oak regeneration potential increased by shelterwood treatments. North. J. Appl. For. 10, 149-153.

Smith D.M., B.C. Larson, M.J. Kelty, and M.S. Ashton. 1997. The practice of silviculture. Ninth Ed. John Wiley and Sons, Inc. 537 pp.

CHAPTER IV

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

INTRODUCTION

Obtaining adequate oak regeneration to sustain oak stocking has remained an important forest management issue for decades and has proven to be particularly problematic on mesic sites (Johnson et al. 2002, Loftis and McGee 1993, Lorimer 1993). On mesic sites, adequate advance reproduction is critical for regenerating oaks (Johnson et al. 2002, Lockhart et al. 2000). However, oak advance reproduction generally does not accumulate readily in mesic sites (Hodges and Gardiner 1993, Johnson et al. 2002) and oak seedlings are less competitive than mesophytic species following release by harvesting (Hodges and Gardiner 1993, Johnson et al. 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 such as eastern cottonwood (*Populus deltoides* Bartr. Ex Marsh) and silver maple (*Acer saccharinum* L.)(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 and 1987, Lockhart et al. 2000). Most studies have focused on midstory and understory thinning with and without herbicides to control competition and increase light levels reaching the forest floor in an effort to increase the density and size of advance reproduction (Janzen and Hodges 1985 and 1987, Lockhart et al. 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 and 1987) as well as underplanted stock (Lockhart et al. 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 advanced 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. However, there has been no research 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 mid-story 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 et al. 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.

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, Missouri. 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 during 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 three years, and longer than average durations once every three 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% of the basal area). Other important species included sweetgum (*Liquidambar styraciflua* L.) (12%), overcup oak (*Q. lyrata* Walt.) (10%), red maple (*Acer rubrum* L.) (7%), American elm (*Ulmus americana* L.) (6%), willow oak (*Q. phellos* L.) (5%), green ash (*Fraxinus pennsylvanica*

Marsh.) (2%), persimmon (*Diospyros virginiana* L.) (1%) and cherrybark oak (*Q. pagoda* Raf.) (1%).

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 three 10-acre blocks containing nine 1.1-acre treatment units that were 220 by 220 ft 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 all trees > 1.5 inches dbh. Within 0.2-acre plots, trees < 1.5 inch dbh 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 20). 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 a reasonable comparison 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.

The thinning treatment was conducted during February, 2003, to remove all non-oaks in the midstory and understory as small as 0.5 inches dbh. This was done by spraying 0.34 ounces of Arsenal® AC (20% 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 three inches dbh approximately 4.5 ft 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, forty acorns were planted by hand 3 inches deep approximately 15 ft apart in concentric circles around the plot center. All planting locations were marked with a numbered wire tag.

Also in April, 2003, we planted twenty-two bareroot pin oaks and twenty-two RPM® pin oak container seedlings, each in their respective designated treatment units. These were planted approximately 20 ft 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 twenty-two 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 (2 gallons chemical in 10 gallons water) with a Solo® backpack sprayer to the foliage of all woody and herbaceous vegetation surrounding each tagged pin oak seedling (both natural and artificial stock). Tagged seedlings were 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) four 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 $ft^2\ ac^{-1}$). 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% (Table 21). We found no significant 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%, and was more than 20% greater than the survival of natural stock in un-thinned (control) plots (Figure 16). The survival of direct-seeded stock was less than 9%, 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%.

The diameters and heights of the different stocks varied considerably from each other (Figure 17). When planted, the RPM® stock was about 3 ft tall and nearly 0.5 inches in basal diameter, about 30% larger than the bareroot stock and more than five 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 diameter growth than did the RPM® and bareroot stock. The bareroot stock produced significantly less height growth than did the other stock types. We also found that controlling ground flora competition with Garlon® 3A did not significantly improve seedling growth. 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 such that it was not confounded by gross differences in canopy cover or gravimetric soil water content.

DISCUSSION

The thinning treatment significantly reduced the number of stems and the forest basal area. Our post-treatment findings were similar to those of Janzen and Hodges (1985) who reported that midstory and understory thinning removed about 25 ft^2 ac^{-1} in a bottomland forest located in north-central Mississippi. In our study, most of the stems that we treated (70%) were < 4 inches dbh. 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 dbh.

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 more than four to ten 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 is an important finding because it demonstrates the benefits of partial sunlight to seedlings of species considered to be shade intolerant, as are many other bottomland oaks such as pin oak.

Overall, all stock grew well and first-year growth was comparable to other bottomland oak seedlings in forests (Janzen and Hodges 1987, Lockhart et al. 2000) or planted in former crop fields (Shaw et al. 2003; Kabrick et al. 2005). Even the growth of the natural stock in the un-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 three to five years or more before large growth differences caused by midstory and understory thinning are observed (Janzen and Hodges 1987, Lockhart et al. 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 cannot assume that the acorns 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, as are many other woody species, are susceptible to Garlon® 3A and despite our efforts to shield the oaks during the foliar application to surrounding competing vegetation, we appeared to have 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 honey suckle (*Lonicera Japonica* Thunberg) 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 of the pin oak seedlings 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 three to five years to determine the probability of producing advance pin oak reproduction of a specified caliper and height. Following seedling establishment seedlings should be tracked through an overstory removal to determine if these methods will recruit adequate numbers of oaks into the overstory of future stands.

LITERATURE CITED

Clatterbuck, W.K., and J.S.Meadows. 1993. Regenerating oaks in the bottomlands. In: Loftis, D.L.; McGee, C.E., eds. Oak regeneration: Serious problems, practical solutions. Symposium proceedings; 1992 September 8-10; Knoxville, Tennessee. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 184-195.

Dey, D.C., W. Lovelace, J.M. Kabrick, and M.A. Gold. 2004. Production and early field performance of RPM® seedlings in Missouri Floodplains. In: Michler, C.H. and others, eds. Proceedings of the sixth Walnut Council research symposium on black walnut in a new century. Gen. Tech. Rep. NC-243. St. Paul, MN: U.S. Department of Agriculture, Forest Service. North Central Research Station: 59-65.

Gardiner, E.S., and J.D. Hodges. 1998. Growth and biomass distribution of cherrybark oak (*Quercus pagoda* Raf.) seedlings as influenced by light availability. Forest Ecology and Management. 108:127-134.

Gardiner, E.S., and J.L. Yeiser. 1999. Establishment and growth of cherrybark oak seedlings underplanted beneath a partial overstory in a minor bottom of southwestern Arkansas: First year results. In: Haywood, J.D. ed. Proceedings of the tenth biennial southern silviculture research conference. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 171-175.

Hicks, R.R. 1998. Ecology and management of Central Hardwood forests. John Wiley and Sons, New York. 412 p.

Hodges, J.D., and E.S. Gardiner. 1993. Ecology and physiology of oak regeneration. In: In: Loftis, D.L.; McGee, C.E., eds. Oak regeneration: Serious problems, practical solutions. Symposium proceedings; 1992 September 8-10; Knoxville, Tennessee. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 54-65.

Janzen, G.C., and J.D. Hodges. 1985. Influence of midstory and understory vegetation removal on the establishment and development of oak regeneration. In: Shoulders, E. ed. Proceedings of the third biennial southern silvicultural research conference. Gen. Tech. Rep. SO-54. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 273-278.

Janzen, G.C., and J.D. Hodges. 1987. Development of oak advanced regeneration as influenced by removal of midstory and understory vegetation. In: Phillips, D.R., comp. Proceedings of the fourth biennial southern silvicultural research conference. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 455-461.

Johnson, P.S., S.R. Shifley, and R.S. Rogers. 2002. The ecology and silviculture of oaks. Wallingford, Oxon, UK: CABI Publishing, CAB International. 503p.

Kabrick, J.M., D.C. Dey, J.W. Van Sambeek, M. Wallendorf, and M.A. Gold. 2005. Soil properties and growth of swamp white oak and pin oak on bedded soils in the lower Missouri River Floodplain. Forest Ecology and Management. 204:315-327.

Lockhart, B.R.; J.D. Hodges, and E.S. Gardiner. 2000. Response of cherrybark oak reproduction to midstory removal and shoot clipping. Southern Journal of Applied Forestry. 42:45-50.

Loftis, D.L. 1983. Regenerating southern Appalachians mixed hardwoods with the shelterwood method. Southern Journal of Applied Forestry. 7:212-217.

Loftis, D.L., and C.E. McGee, eds. 1993. Oak regeneration: Serious problems, practical recommendations. Symposium proceedings; 1992 September 8-10; Knoxville, Tennessee. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 319p.

Lorimer, C.G. 1993. Causes of the oak regeneration problem. In: Loftis, D.L.; McGee, C.E., eds. Oak regeneration: Serious problems, practical solutions. Symposium proceedings; 1992 September 8-10; Knoxville, Tennessee. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 14-39.

Missouri Department of Conservation. 1999. Duck Creek Conservation Area Management Plan. Missouri Department of Conservation internal publication.

Shaw, G.W., D.C. Dey, J.M. Kabrick, J. Grabner, and R.M. Muzika. 2003. Comparison of site preparation methods and stock types for artificial regeneration of oaks in bottomlands. In: Van Sambeek, J.W., and others, eds. Proceedings of the 13th Central Hardwood Forest Conference 1-3 April 2002. Urbana-Champaign, IL. General Technical Report NC 234. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 186-198.

Smith, D.W. 1993. Oak regeneration: The scope of the problem. In: Loftis, D.L.; McGee, C.E., eds. Oak regeneration: Serious problems, practical solutions. Symposium proceedings; 1992 September 8-10; Knoxville, Tennessee. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 40-53.

Table 20. 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 dbh. 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.

Table 21. Percent canopy cover thinned and unthinned (control) plots measured 6 months after treatment[a].

Management Pool	Canopy Cover	
	Control	Thinned
	- - - - - % - - - - -	
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 8 (Mingo National Wildlife Refuge) was selected because the oaks appeared to be healthy and there was very little observable crown dieback or mortality.

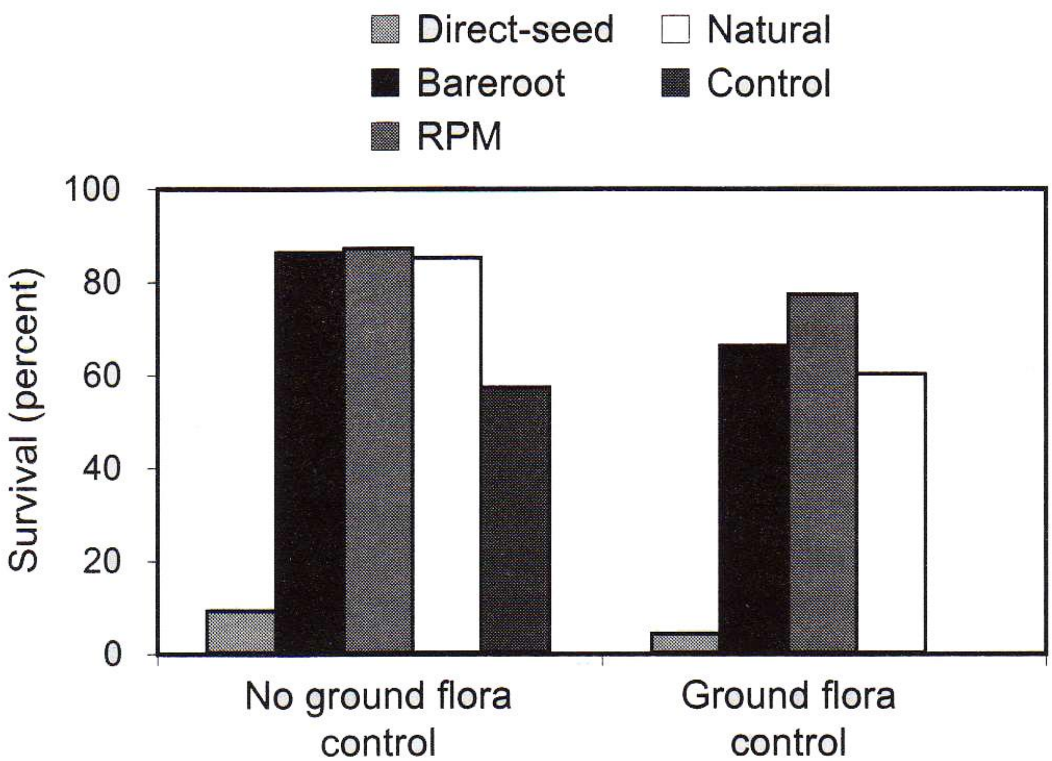

Figure 16. First-year pin oak seedling survival by treatment and the four stock types: natural seedlings, seedlings from direct seeded acorns, bareroot seedlings, and RPM® (3 gallon) container seedlings.

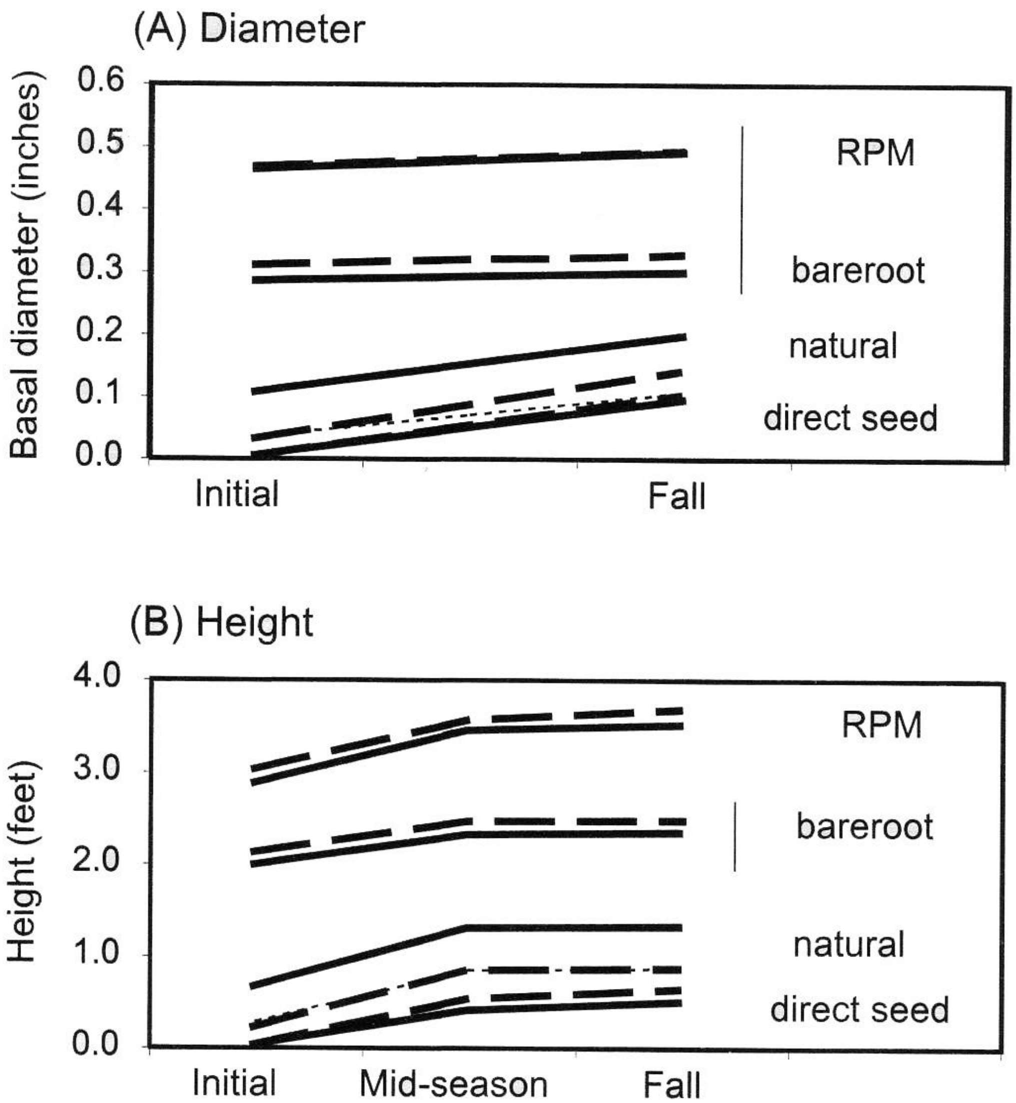

Figure 17. Diameter (A) and height (B) of pin oak seedlings measured during and after the first growing season for the four stock types: natural seedlings, seedlings from direct-seeded acorns, bareroot seedlings, and RPM® (3 gallon) container seedlings. Dashed lines indicate data from plots where ground 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 (α = 0.05) from that of the natural stock.

CHAPTER V

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

CONCLUSIONS

Our understanding of pin oak reproduction in existing bottomland hardwood forests in the Mingo Basin of southeast Missouri has been improved as a result of this research in three ways. First, clearcutting and shelterwood cutting alone did not favor oak reproduction in bottomland hardwood pin oak forests even after 17 years. Both of these treatments favored competing tree species that were well established in the reproduction layer prior to harvest activities. Oak reproduction does not readily accumulate in bottomlands, unlike upland oak forests common in the region. Although natural oak reproduction is often present in the bottomland hardwood forests of the Mingo Basin, both natural and artificial flooding and shade from a dense midstory of competing tree species either kills the reproduction or hinders its ability to grow.

Second, the control of shade tolerant midstory species in conjunction with regeneration harvesting is essential to favor pin oak reproduction. Control of midstory flood and shade tolerant tree species (red maple, green ash, sweetgum, and American elm) by a late winter treatment of 0.34 ounces per hack of a 20% Arsenal® AC applied at one hack per three inches in diameter evenly spaced around the tree had varied results in the first growing season following treatment. American elm trees < 8 inches dbh are effectively controlled. Red maple trees > 5 inches dbh are more likely to exhibit no apparent effect from the treatment than to die as a result of the treatment. Larger diameter green ash trees are more likely to die than smaller diameter trees. Sweetgum trees > 6 inches dbh are more likely to live than die. Other studies have found that altering the growing season application of the herbicide treatment or varying the concentration of the applied chemical can result in better control of the midstory competing species. Prior to this research, no study had examined the individual tree responses to this specific herbicide treatment before and after herbicide application. As a result, the models developed in this research can be used to predict effectiveness of herbicide treatment based on a simple inventory of trees in the stand.

Third, the first-year growth and survival of bareroot, 3 gallon RPM® containerized stock, and natural reproduction showed positive response to the midstory treatment. However, it is too early to conclude long-term benefits of the treatments on pin oak reproduction success among the different stock types. Direct-seeded acorn germination and survival (< 7%) was poor and did not offer promising results in the first growing season; planting seedlings (bareroot and containter) was superior to direct seeding in establishment of pin oak.

MANAGEMENT RECOMMENDATIONS

Shelterwood and clearcut treatments alone are not recommended to promote oak in the bottomland hardwood forests of the Mingo Basin. What is need is a combination of silvicultural treatments that consider existing stand structure and composition and the regeneration ecology of the species that are likely to compete with pin oak, and reduce the density of the midstory to increase light at the forest floor while at the same time decreasing the intensity of competition from shade tolerant species. Reductions in the density of the overstory canopy layer may provide additional benefits to the development of pin oak in the understory, however, caution must prevail in reducing the overstory to avoid release of fast growing shade tolerant species. An inventory that includes trees density, tree diameter, tree health, vigor, and crown class and canopy cover is needed to write an effective silvicultural prescription to promote oak reproduction in existing bottomland forests. For example, the initial inventory in this study showed that 56% of the overstory was dominated by pin oak trees; but that 24% of the pin oak overstory was dead. Crown closure was 91%, resulting in low light conditions in the understory. The midstory and understory were primarily sweetgum, red maple, green ash, and American elm. Treatment of the mid- and understory competing tree species < 8 inches DBH with a 20% solution of Arsenal® AC herbicide treatment removed on average 328 trees per acre and decreased the crown cover from 91% to roughly 83%. While this increased the light reaching the forest floor, others have found that many oak species benefit when crown cover is reduced to 70 to 50%, which meets the light requirements for good oak growth while not providing additional light to shade intolerant competitors.

In stands experiencing 24% overstory pin oak mortality or less, reductions in overstory density of 30 to 50% are recommended to favor pin oak advance reproduction. In this study, that would be achieved by increasing the upper threshold dbh from 8 to 10 inches. In stands experiencing more than 24% overstory pin oak mortality, it is recommend to treat stems up to 8 inches in diameter as described in chapter 3. As natural pin mortality increases, a higher initial canopy cover (stand density) will ensure maintaining a minimum of 50% crown closure that is important to promote oak reproduction and retard the growth of shade intolerant species.

Areas with large amounts of red maple, sweetgum, and green ash, may benefit from altering either the timing of the herbicide treatment or amount of herbicide applied. In areas with large amounts of red maple, sweetgum, and green ash, a late growing season herbicide treatment may improve the effectiveness of the treatment over the results of a late winter application used in this study. In the late winter, sapflow on warm days, especially common in maple species, can reduce the effectiveness of the herbicide. For red maple and sweetgum, increasing the amount of the herbicide may increase mortality in stems > 5 inches dbh. Mortality in green ash trees < 5 inches dbh should increase with an increase in amount of herbicide applied. Although application rates should not exceed the label rates, this research inidicates that either a change in the season of application to the summer, or increasing the amount of herbicide applied per tree based on diameter is needed to get better control of competing vegetation.

Conducting mast surveys and timing release treatments in years of good acorn production will help promote natural reproduction establishment and growth. Sowing acorns, as done in this study, is not recommended in the Mingo Basin. Other methods of acorn sowing, e.g., lightly disking the area and broadcasting acorns, may promote acorn germination and survival, but these methods are not tested. Again, documenting these trials is critical to future efforts. When budgets allow, both bareroot stock and RPM® containerized stock many be used in areas where natural acorn production is compromised due to poor vigor or high levels of mortality of the overstory pin oak trees. In the 1940s, fires occurred in the Mingo Basin. Fire, too, may be used to promote oak reproduction development once it is well established. The application of prescribed burning may be problematic in greentree reservoirs, but it is a reasonable treatment that needs further study.