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Cherrybark oak stump sprout survival and development five years following plantation thinning in the lower Mississippi alluvial valley, USA

Brian Roy Lockhart · Jim L. Chambers

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Abstract Cherrybark oak (*Quercus pagoda* Raf.) stump sprouts were studied for 5 years in a 30-year-old plantation thinned to 70–75% stocking (light thinning) and 45–50% stocking (heavy thinning). Sprouting success, survival, number of sprouts per stump, and sprout height differed little between thinning treatments throughout the 5-year study period. Pre-harvest tree d.b.h. also had no influence on sprout survival and development. A 2-year drought reduced survival and may have influenced sprout development. Sprout clump survival dropped from 90% 1 year following thinning to 46% 3 years after thinning. Although sprout height averaged 337 cm 5 years after thinning, annual sprout growth decreased from 166 cm the first year after thinning to 33 cm in each of the last 2 growing seasons. Results indicated that bottomland hardwood regeneration evaluation models may underestimate the potential of oak stump sprouts to contribute to pre-harvest regeneration assessments. Further study in the role of stump sprouts to regenerate bottomland oak species is needed.

Keywords *Quercus pagoda* Raf. · Stump sprouts · Sprouting success · Height growth

Introduction

Sprouts are defined as shoots arising from the stem base or roots (Helms 1998). Three types of sprouts are generally recognized for management purposes: seedling

B. R. Lockhart (✉)
USDA Forest Service, Southern Research Station, Center for Bottomland Hardwoods Research, 432 Stoneville Road, P.O. Box 227, Stoneville, MS 38776, USA
e-mail: blockhart@fs.fed.us

J. L. Chambers
Louisiana Agricultural Research Center, Louisiana State University, 227 Renewable Natural Resources Building, Baton Rouge, LA 70803, USA

sprouts, root sprouts, and stump sprouts. Seedling sprouts are stems that arise from existing or severed seedlings or saplings (≤ 7.6 cm d.b.h.) where the root system may be several to many years older than the stem (McQuilkin 1975). Root sprouts, or suckers, arise from adventitious or suppressed buds on root systems of existing or severed trees (Kormanik and Brown 1967; Hook et al. 1970; Francis 1983), while stump sprouts arise from the base of severed stems and can appear anywhere from the top to the base of the stump (Johnson et al. 2002).

Stump and root sprouts are considered one of four broad classes of oak (*Quercus* spp.) reproduction, the others being new seedlings that develop from acorns which germinated just before or soon after harvest, older seedlings where the shoot and root are the same age but greater than 1 year old, and seedling sprouts (Beck 1983; Sander 1972; McQuilkin 1975). Stump sprouts, along with older seedlings and seedling sprouts, have long been considered important sources of natural reproduction, especially for the various oak species (Sander 1972; Hodges 1987; Johnson et al. 2002). The early rapid height growth of stump sprouts give them a competitive advantage compared to the other classes of reproduction. Furthermore, stump sprouts develop large crowns and vertical structure following a partial or complete overstory harvest with positive implications for wildlife habitat (Shafer 1965; Solomon and Blum 1967).

Oak stump sprout survival and development has been well-studied for a variety of upland species including northern red oak (*Q. rubra* L.), black oak (*Q. velutina* Lam.), and white oak (*Q. alba* L.) (Johnson 1975; McQuilkin 1975; Weigel and Peng 2002). This information has been incorporated into several hardwood regeneration evaluation models designed to determine if sufficient density and stocking of oak regeneration exists prior to a harvest for regeneration success (Sander et al. 1976; Dey 1993; Dey et al. 1996). Oak sprout growth and development has also been used to determine the need for thinning within individual sprout clumps (Johnson and Rogers 1984; Lowell et al. 1987; Johnson et al. 2002).

Less is known about the role of stump sprouting in the regeneration of bottomland oak species (Johnson 1961; Gardiner and Helmig 1997; Golden 1999). Emphasis has focused on swamp species such as water tupelo (*Nyssa aquatica* L.) and swamp tupelo (*N. sylvatica* var. *biflora* (Walt.) Sarg.) (Hook et al. 1967; DeBell 1971; Kennedy 1982). The oak stump sprout component of bottomland hardwood regeneration evaluation models relies on the best information currently available, i.e., local observations, results from upland models, and limited research in bottomlands (Johnson 1980; Johnson and Deen 1993; Hart et al. 1995). Therefore, the objective of this study was to add to the sprouting knowledge of bottomland oak species. Specifically, we examined survival and development of cherrybark oak (*Q. pagoda* Raf.) stump sprouts following two intensities of thinning in a 30-year-old plantation. Five-year results are reported.

Materials and methods

The study was located on the Red River Wildlife Management Area in Concordia Parish, east-central Louisiana, U.S.A. (31°12′ N, 91°38′ W). Soils are Commerce silt loam (fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts) and Bruin silt loam (coarse-silty, mixed, superactive, thermic Oxyaquic Eutrudepts), highly productive soils formed from Mississippi River alluvium. The former soil is deep and somewhat poorly drained while the latter soil is deep and moderately well drained. Cherrybark oak site index, base age 50 years, was estimated at 29 m using a soil/site evaluation method (Baker and Broadfoot 1979). Mean annual precipitation is 1,500 mm and is generally evenly distributed throughout the year although periodic summer droughts occur. Mean annual temperature is 19.4°C with an average of 27.2°C in July and August.

The hardwood plantation was established during 1969–1972 on a 138 ha agriculture field. Planting density was variable but averaged 1,016 seedlings per ha. Cherrybark oak planting accounted for 43% of the total area and was primarily located in one portion of the field. Fifteen, 0.73 ha rectangular plots (60 m by 120 m) were established in the cherrybark oak portion of the plantation in 1998. Each plot consisted of a 0.16-ha interior measurement plot with the remaining area as buffer. Diameter of all trees ≥12.7 cm d.b.h. was measured in each interior plot. These data were used to determine initial stocking (Goelz 1995). Plots were then blocked, 3 plots per block, by initial stocking to reduce pre-harvest variation among treatments. Overall stocking was 89%, with average stocking in each block ranging from 76% in the lightest stocked block to 104% in the heaviest stocked block.

Two thinning treatments were randomly assigned to the plots in each block. Treatments were light thinning with stocking reduced to 70–75% of full stocking and heavy thinning with stocking reduced to 45–50% of full stocking. An unthinned control represented the third plot in each block. Tree marking guidelines were developed using stocking information along with a tree class system (species, crown class, and butt-log grade; Putnam et al. 1960; Meadows 1996) to identify those trees that would serve as future crop trees (preferred stock), those trees that could remain until the next thinning or could be marked for the present thinning (reserve stock), and those trees that should be removed in the present thinning operation (cutting stock). All cutting stock trees were marked, then reserve stock trees were marked as needed until the desired residual stocking was attained. Thinning operations were conducted from September 1998 to February 1999.

A total of 141 cherrybark oak trees were harvested in the treatment plots although only 140 were used in the analyses due to 2 stumps occurring from the same root system. One sprout was not used in the height analyses due to it being severed during the 2003 growing season. Heights from three others sprouts severed in 2003 were included in all analyses since heights were reconstructed from the severed stems. Average d.b.h. of the harvested trees was 27.4 cm with a majority of the trees from 15 to 33 cm d.b.h. classes.

Annual assessments were made of each cherrybark oak stump following the 1999 through 2003 growing seasons. Observations were noted as to whether the stump sprouted, how many sprouts were present, and the height of the tallest sprout. Due to the proliferation of sprouts in a small location on many stumps, only those sprouts that were ≥30 cm tall and located within 7.6 cm of the stump were counted. These criteria allowed us to distinguish sprouts from branches within a sprout and to avoid counting stems that paralleled the surface of the ground despite being >1 m long. Dead sprouts were noted if growth had initiated prior to death.

Sprouting success, calculated as the number of stumps that sprouted, annual sprout survival (excluding stumps that did not sprout), number of sprouts per stump, and height of the tallest sprout on each stump were analyzed using analysis-of-variance in a randomized complete block design. Pre-harvest d.b.h. was used as a covariate in all analyses. Since reference plots contained no stumps, only two treatments, light thinning and heavy thinning, were included in the analyses. All analyses were conducted using PC-SAS (SAS 1985). An alpha level of 0.05 was used to determine significant differences.

Results and discussion

Sprouting success and sprout survival

Of the 140 stumps examined in this study, 114 sprouted for a sprout success of 80%. No difference was found in sprouting success between the light and heavy thinning treatments ($P = 0.5557$) nor did tree d.b.h. influence sprouting success ($P = 0.6789$) Sprouting occurred for all diameter classes with nearly 100% sprouting for trees ≥ 35 cm ($n = 20$).

All sprouts on 11 stumps died during the first growing season after thinning for a stump sprout survival rate of 90% (Fig. 1). Thinning treatments did not differ ($P = 0.3913$) in first-year survival, and survival was independent of tree d.b.h. ($P = 0.7819$). Sprout clump (all sprouts on a given stump) survival appeared to drop to 83% following the second growing season after thinning. But this tally included "live" sprouts ($n = 32$) that had wilted brown leaves during December measurements. These sprouts also had a purplish color to their twigs and seemed to retain more of their leaves later in the winter. Furthermore, on selected sprouts, we cut the bark to expose the wood and noticed the wood was discolored from normal, healthy wood (a brownish–yellow compared to a whitish–yellow). Therefore, we noted these sprout clumps as potentially dead despite their having grown well during the early part of the growing season with multiple flushes, flush lengths ≥1.5 m, and leaves distributed along the stem of each flush–all signs of good sprout vigor.

Analyses of third growing season after thinning data confirmed that all but 2 of the specially noted sprout clumps in December 2000 were dead, resulting in an adjusted 2000 survival of 47% (Fig. 1). The likely cause for the large decrease in survival was 2 years of drought. Rainfall totals at the Marksville, Louisiana gauging

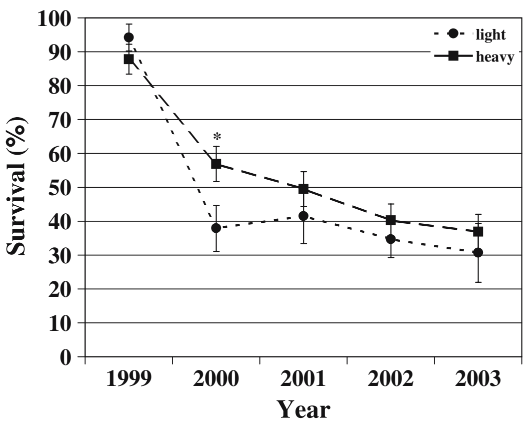

Fig. 1 Cherrybark oak stump sprout survival (percent) in a plantation thinned to 2 different stocking levels. Bars are ±1 standard error. Asterisk indicates a significant difference ($P \leq 0.05$)

station (24 km southwest of the study site) were 75 and 72% of normal for 1999 and 2000, respectively.

Survival following the third growing season after thinning was 46% across the study site, similar to the previous growing season. Rainfall during the 2001 growing season was slightly above normal with no prolonged periods of drought. The slight "increase" in survival for the light thinning treatment was due to one sprout clump specially marked during the previous year as potentially dead actually still alive after the third growing season after thinning. This was the only sprout clump specially marked after the 2000 growing season still alive one year later. Survival decreased slightly following the fourth and fifth growing seasons after thinning with no significant difference between the light and heavy thinning treatments ($P = 0.5080$ and 0.3581, respectively). Survival was also not influenced by pre-harvest tree d.b.h. ($P = 0.9245$ and 0.3986, respectively).

Gardiner and Helmig (1997) reported 100% survival of stump sprouts 1 year following light and heavy thinning in a 28-year-old water oak (*Q. nigra* L.) plantation. In their study, survival decreased considerably by year 2 and continued to gradually decline through year 7. No differences in survival occurred between the thinning treatments until year 7 when survival in the heavy thinning was 23% greater than in the light thinning. They attributed this difference to early crown closure and subsequent decreased light levels in the lightly thinned plots. Similar results were not found in the present study, due largely to the influence of the severe drought. Differences in cherrybark oak stump sprout survival may still occur earlier in the light thinning treatment as the crown canopy closes and reduces light availability to the sprouts sooner than in the heavy thinning treatment. Golden (1999) reported only 13% of cherrybark oak trees had sprouts 3 years following clear felling in 0.32 ha openings. He attributed this low sprouting success and survival primarily to the initial large tree sizes and subsequent large stump sizes. Sprouting success has been shown to decrease with increasing parent tree diameter (Johnson 1975; Weigel and Johnson 1998; Weigel and Peng 2002), possibly due to the inability of suppressed buds to breach the thicker bark associated with larger trees or the inability of sprouts to produce enough photosynthate to keep the large root system alive.

Number of sprouts per stump

No differences were found in the number of sprouts per stump between treatments over the 5 growing seasons following thinning. Sprout numbers averaged 9.5 per stump after the first growing season ($P = 0.8201$) and 8.8 per stump after the second growing season ($P = 0.7043$; Fig. 2). This average dropped to 6.6, 5.8, and 5.4 sprouts per stump after the third ($P = 0.4240$), fourth ($P = 0.4678$), and fifth ($P = 0.3469$) growing seasons, respectively, indicating that self-thinning within sprout clumps was occurring. Pre-harvest tree d.b.h. also had no influence on the number of sprouts per stump ($P = 0.9622$ following the fifth growing season after thinning).

Gardiner and Helmig (1997) noted that 1-year-old water oak sprout clumps averaged 15 stems per stump. They also noted that thinning level did not affect the initial stem number per sprout clump. Their results showed considerable within-stump sprout mortality through the first 4 years before stabilizing at about 4 stems per sprout clump by age 7. A decrease in the stem number per sprout clump was not found with cherrybark oak following the first two growing seasons after thinning.

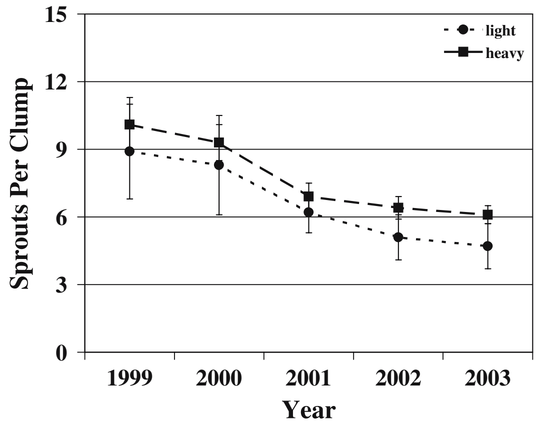

Fig. 2 Number of cherrybark oak sprouts per clump in a plantation thinned to 2 different stocking levels. Bars are ±1 standard error

Only after the third growing season following thinning did sprouts numbers per stump begin to decline appreciably.

Sprout height

Height of the tallest sprout within each sprout clump averaged 166 cm 1 year after thinning. No differences were found in sprout heights between the light and heavy thinning treatments ($P = 0.9036$) nor did pre-thinning tree d.b.h. influence sprout height ($P = 0.3919$). Sprout height increased with increasing tree dbh ($r^2 = 0.68$ for simple linear regression), ranging from 122 cm for the 15 cm d.b.h. class to 272 cm for the 50 cm d.b.h. class.

Sprout height increased to 216 cm following the second growing season after thinning ($P = 0.9525$ between thinning treatments), although the 50 cm in height growth was a 69% decrease from the previous growing season (Fig. 3). Sprout height continued to increase following third, fourth, and fifth growing seasons, at 272, 304, and 337 cm, respectively, though no differences were found between thinning treatments ($P = 0.9476$, 0.9752, and 0.9800, respectively). Sprout height growth in

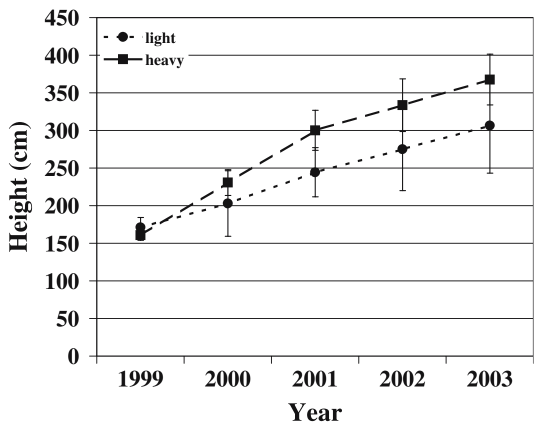

Fig. 3 Cherrybark oak stump sprout height (cm) in a plantation thinned to 2 different stocking levels. Bars are ±1 standard error

the third growing season after thinning was similar to the previous growing season at 56 cm, but decreased to 32 and 33 cm following the fourth and fifth growing seasons, respectively (Fig. 3). Pre-thinning tree d.b.h. had no influence on sprout height throughout the study period ($P = 0.8202$ following the 2003 growing season).

Cherrybark oak sprout heights were considerably lower than those found by Gardiner and Helmig (1997) for water oak following plantation thinning. They reported water oak stump sprout height of 350–450 cm 5 years after thinning with sprouts in the heavy thin treatment significantly greater than in the light thin treatment. Thinning did not influence cherrybark oak sprout height in the present study. Differences between these two studies include species and site conditions. Furthermore, the drought previously mentioned probably confounded the treatments effects in the present study.

A pattern of decreasing height growth with increasing sprout age has been noted by others (Cobb et al. 1985; Gardiner and Helmig 1997). Cobb et al. (1985) found annual reductions in scarlet oak (*Q. coccinea* Muenchh.) height growth ranged from 7 to 33% during the first 5 years of development following clearcutting in the upper Piedmont of South Carolina. Gardiner and Helmig (1997) also found sprout height growth decreased following thinning in a water oak plantation, from 51 cm annual growth for the first 5 years after thinning to 28 cm the next 2 years. Apparently, the rapid early height growth exhibited by sprouts decreases over time as the above-ground and below-ground portions of the plant comes into balance. Keep in mind that Gardiner and Helmig (1997) and the present study involved competition from adjacent overstory canopy trees that influenced development of the stump sprouts. Most oak stump sprout studies report results following a clearcut regeneration harvest with no overstory canopy influence on sprout development.

Bottomland hardwood regeneration evaluation model

Hart et al. (1995) modification of Johnson's (1980) bottomland hardwood regeneration evaluation model gives 3 points for trees 5.1–12.7 cm (2–5 in) d.b.h., 2 points for trees 12.8–25.4 cm (6–10 in) d.b.h., 1 point for trees 25.5–38.1 cm (11–15 in) d.b.h., and no points to trees ≥38.2 cm (16 in) d.b.h. Points are also given for density and size of advance reproduction. A minimum of 12 points is needed for a 0.004 ha regeneration plot to be considered adequately stocked with advance reproduction or have sufficient regeneration potential from stump sprouts. The 12-point criteria indicates the likelihood that one tree of desirable species will be free-to-grow 3 years following a complete overstory removal (Hart et al. 1995). Technically, it would take 4 trees in the smallest d.b.h. class (12.8–25.4 cm) or 12 trees in the 25.5–38.1 cm d.b.h. class for a plot to be considered stocked, assuming no advance reproduction was present. In other words, if a regeneration evaluation plot contained only trees 25.5–38.1 cm d.b.h. and no advance reproduction, it would take 12 trees to produce 1 free-to-grow stump sprout. Data used in the modification of Johnson's (1980) model involved primarily seedlings and saplings; limited data existed for trees ≥5.1 cm d.b.h. to adequately evaluate the role of stump sprouts in regenerating bottomland oak stands.

Results from the present study indicate that more weight (points) should be given for trees in larger d.b.h. classes. We found 33% survival of 28 cm d.b.h. trees; therefore, only 3 trees, instead of 11, would be needed before harvest for a regeneration plot to be considered adequately stocked. Keep in mind the present study was not designed to test the adequacy of bottomland oak stump sprouts in the hardwood regeneration evaluation model. The present study was limited to 140 harvested cherrybark oak trees growing on a good site subjected to unusual weather conditions over 2 consecutive years of the 5-year-study period. Furthermore, the current bottomland hardwood regeneration model was developed for use in stands that will receive a clearcut regeneration harvest; the subsequent reproduction will respond to open conditions. The present study involved trees that were harvested as part of a thinning operation in which an overstory canopy still exists. Shading from this overstory will influence development of oak sprouts. Also, sprouts in the present study arose from trees that were judged inferior to the residual trees; therefore, sprout development from these trees may differ from sprouts which develop from the residual, more vigorous crop trees. Finally, trees were harvested from 14 to 51 cm d.b.h. range. Oak trees in mature bottomland hardwood stands subjected to regeneration harvests are typically larger than these diameters. These trees may not sprout as readily as oak trees of smaller d.b.h. (Golden 1999). Furthermore, smaller d.b.h. oak trees in a mature stand will likely be much older than the 30-year-old trees in the present study. Research with upland oak species has indicated that stump sprouting declines as the trees get older (McGee 1978).

Conclusions

Information on oak sprout development following partial cutting in southern bottomland forests is limited. Results with cherrybark oak in a thinned plantation are generally in agreement with Gardiner and Helmig's (1997) study of water oak sprout development in a thinned water oak plantation. Stump sprout success and growth are dependent on available resources. As these resources, especially light, diminish, slower growth and increased mortality should be expected. Gardiner and Helmig (1997) mentioned thinning within sprout clumps could possibly extend sprout survival and growth, based on work conducted with upland oak species (Lamson 1983; Johnson and Rogers 1984; Groninger et al. 1998). Such treatments require additional research with bottomland hardwood species. Much work remains on the role of stump sprouts in regenerating bottomland hardwood stands, including tree age and size relationships to sprout survival and development, and how this will influence bottomland oak regeneration evaluation models.

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