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## Influence of Soil Saturation on Survival and Growth of Bottomland Oaks Six and Fourteen Years After Planting

David C. Mercker<sup>1,\*</sup>, Michael H. Schiebout<sup>2</sup>, Joshua S. Bowden<sup>2</sup>, and James R. Kerfoot Jr.<sup>2</sup>

**Abstract** - Bottomland oak restoration projects have been marginally successful because professionals often recommend conventional tree-planting procedures that prove problematic in hydric soils. A reliable method of matching oak species to bottomland sites is needed prior to planting. To address the issue, we planted 8 different species of oak seedlings into previously farmed hydric soil in West Tennessee in 2004. We took measurements after 6 and 14 growing seasons to ascertain survival and growth trends based on soil mottling and the depth to gleyed matrix. The later measurements mostly supported early findings that *Quercus lyrata* (Overcup Oak), *Q. texana* (Nuttall Oak), *Q. palustris* (Pin Oak), and *Q. phellos* (Willow Oak) are most tolerant of poorly drained soil and that as soil drainage improves, species diversity may expand.

### Introduction

Wetlands are a vital component in maintaining a healthy ecosystem. Wetlands purify and store excess water, process nutrients, sequester carbon from the atmosphere, provide diverse wildlife and vegetation habitat, offer recreation opportunities, and curb soil erosion (Johnson et al. 2016, Shrestha et al. 2017, Sweikert and Gigliotti 2019, Yepsen et al. 2014). Yet by the 1980s, 54% of wetlands in the lower 48 states of the US had been lost to agriculture and development (USDA, NRCS 2011). In the US, wetlands have been a high priority for restoration through federal programs for many decades. The Wetland Reserve Program (WRP) and the Conservation Reserve Program (CRP) are designed to restore ecosystem functions. These federal programs intend to protect water and soil resources and play a major role in sequestering atmospheric carbon (Cason et al. 2006). However, many of these tree-planting initiatives have been marginally successful, often due to the mismatching of appropriate species to hydric sites (Stanturf et al. 2001, 2004).

In the southeastern US, forests located on flood plains are known as bottomlands. The restoration of bottomlands involves input from natural resource professionals during the planning and implementation stages. Professionals often follow procedures established for upland planting sites that do not necessarily transfer to bottomland sites (Mercker et al. 2012a, Self 2020). Species selection is difficult when facing the obstacles of bottomland soils, including overland flooding, poor internal drainage, high water tables, and compaction. Survival and growth of

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bottomland hardwoods are dramatically influenced by minor topography changes, soil structure (Hodges and Switzer 1979, Self 2020), and disturbance regime (King and Kein 2019).

A clear understanding of soil drainage is essential when selecting tree species in bottomland plantings. Natural resource professionals routinely use soil color to estimate water table fluctuations and inundation. Soils with gray colors are symptomatic of saturated soils and anaerobic conditions (Baker and Broadfoot 1979, Mercker et al. 2012a). When predicting the survival and growth of planted bottomland *Quercus* spp. (oaks), soil mottling and the gleyed matrix are important determinants. Mottling indicates frequent soil saturation and is apparent when gray or black colors accompany the more normal brown, red, or yellow colors.

The occurrence of a gleyed matrix is common when surface or subsurface water exists for a long duration (3 or more months annually). The gleyed matrix occurs when soil mottling becomes so extreme that 50% or more of the soil profile is gray in color, as is visualized in the Munsell Soil Color Chart (Munsell Color 2000) and Field Indicators of Hydric Soils in the United States (USDA 2018). The closer to the surface that the gleyed matrix occurs in the soil profile (e.g., <9 in), the greater the saturation level, the lower the available oxygen, and the more restrictive is the variety of tree species that can be successfully established (Ponder and Pope 2003).

This project follows the survival and growth of oak seedlings planted in early 2004 on a bottomland site, previously used for row-crop agriculture, in Jackson, TN, at the University of Tennessee West Tennessee Research and Extension Center (WTREC). The site lies next to the South Fork of the Forked Deer River and floods 5 to 6 times annually with up to a 3-day duration (Robert Hayes, University of Tennessee-Jackson, TN, pers. comm.).

This research is unique in that it examines how soil mottling and the resulting poor internal drainage influences oak seedling and sapling survival and growth. To test the influence of soil-saturation levels on survival and growth, we addressed 3 main research questions: (1) how do oak species' survivorships compare between 2010 and 2018, (2) how do species' diameter at breast heights (dbh) compare between years and soil-saturation levels, and (3) how does the change in mean dbh between years compare across soil saturation types? The specific hypotheses we tested were: (1) there will be variability in survivorship between oak species and years, (2) there will be significant differences in mean dbh across oak species and soil saturation levels, and (3) there will be significant differences in the mean change in dbh across species and soil-saturation levels.

### Field-Site Description

The project is located on a 10.2-ha (25.2-ac) site (35°37'23.637"N, 88°51'19.637"W) with a 2% gradient at the WTREC-owned floodplain adjacent to the South Fork branch of the Forked Deer River, Jackson, TN. Jackson, TN, has an average annual temperature of 15.6 °C (60.1 °F) and receives an average of 137 cm (53.9 in) of rainfall annually (US Climate Data 2017). The site was originally

forested but then in the 1930–1960s was gradually cleared and channelized, with tile drain installed, and was used for row crop agricultural production until the time of planting. Due to poor row-crop yields (a result of growing-season flooding), the land was placed in the CRP and the WRP in 2003. The soils were mapped as Falaya and Waverly (Mercker et al. 2012b). Both are deep, somewhat poorly drained or poorly drained, moderately permeable floodplain soils formed in silty alluvium from loess found in the Southern Mississippi Valley Silty Upland Area (National Cooperative Soil Survey 2002, 2003). The soil series includes Falaya silt loam (coarse-silty, mixed, active, acid, thermic Aeric Fluvaquents), and Waverly silt loam (coarse-silty, mixed, active, acid, thermic Fluvaquentic Endoaquents) (Soil Survey Staff 2015).

## Methods

### Species examined

Bottomlands forests are host to a variety of tree species, but because of their ecological and economic values, the focus of this project was on bottomland oaks. Ten species of bottomland oaks have a natural range extending into the study region (Burns and Honkala 1990, Fowells 1965, Mercker et al. 2006). At the time of planting, we were able to obtain 8 of the 10 species (Table 1); seedlings of *Quercus macrocarpa* Michx. (Bur Oak) and *Quercus pagoda* Raf. (Cherrybark Oak) were not available.

### Experimental design and treatments

In the fall prior to planting (2003), we worked the site (in 2 directions, with the second set of passes oriented 90° from the first) with a 45.7-cm (18-in) single-shank subsoiler to loosen compaction and improve growth. We planted trees at the intersection of the subsoiled rows 816.8 m (2680 ft) long spaced 3.04 m x 3.04 m (10 ft x 10 ft) apart, in pure blocks, 1 block per species, with a minimum of 4 rows per block (Fig. 1). As previously documented in Mercker et al. 2012b, first year seedlings grown at the Tennessee Department of Agriculture Division of Forestry Nursery, Delano, TN, were planted in early 2004 (February and March) using a Whitfield® Tree planter (R. A. Whitfield Manufacturing, Mableton, GA), built especially for hardwood seedlings.

Table 1. Oak species used in the study and initial seedling heights.

Species	Common name	Oak group	Height (cm) ± SE	Height (in) ± SE
<i>Quercus bicolor</i> Willd.	Swamp White Oak	White	Not available	Not available
<i>Quercus lyrata</i> Walt.	Overcup Oak	White	52.8 ± 0.216	20.8 ± 0.138
<i>Quercus michauxii</i> Nutt.	Swamp Chestnut Oak	White	68.4 ± 0.244	25.5 ± 0.152
<i>Quercus nigra</i> L.	Water Oak	Red	46.5 ± 0.155	18.3 ± 0.098
<i>Quercus nuttallii</i> Palmer	Nuttall Oak	Red	40.1 ± 0.135	15.8 ± 0.086
<i>Quercus palustris</i> Muench	Pin Oak	Red	36.3 ± 0.181	14.3 ± 0.115
<i>Quercus phellos</i> L.	Willow Oak	Red	33.3 ± 0.142	13.1 ± 0.090
<i>Quercus shumardii</i> Buckl.	Shumard Oak	Red	41.9 ± 0.194	16.5 ± 0.123

In early 2010, we established 272 permanent experimental plots each consisting of 4 trees, with 34 plots per species. Plots were spaced 24.4 m (80 ft) apart and located between the middle 2 rows within each block (Fig. 1). Plot centers were the same point of measurement for both 2010 and 2018. By placing the plots in the center of the blocks, interspecific competition was eliminated.

Due to decades of row-cropping, there was no initial herbaceous nor woody plant competition. We planted tree seedlings into corn stubble (Mercker et al. 2012a, 2012b). To minimize the impact of weeds on seedling responses after planting, we sprayed Oust<sup>®</sup> XP (Bayer Environmental Science, Cary, NC) herbicide at a concentration of 110 ml/ha as a 45.7-cm-wide side-dressing (1.5 oz./ac, 18 in) on each side of the rows in the initial (2004) and second (2005) year of planting in early spring before bud break. We periodically mowed the area between rows during the first 3 growing seasons.

We initially measured survival, dbh, and soil samples in February 2010. We used a Lufkin<sup>®</sup> Metric Chrome Clad Diameter Tape (Apex Tools Group, Sparks, MD) to measure dbh at the standardized height 1.3 m (4.5 ft). If branching swell occurred at the measuring height, we measured the dbh immediately above the swell. We took soil cores (Dakota Probe, JMC Soil Samplers, Newton, IA) at the center of each plot representing an area of 9.29 m<sup>2</sup> (100 ft<sup>2</sup>). Cores showed the depth where >50% gleyed matrix, or soil saturation, was achieved. We examined the soils in 7.62-cm (3in) depth increments and placed them into 2 classes based on the depth where gleyed matrix was achieved: poorly drained = 0–22.9 cm (0–9.0 in,  $n = 205$ ) and somewhat poorly drained = 22.9–45.7 cm (>9.1–18.0 in,  $n = 65$ ).

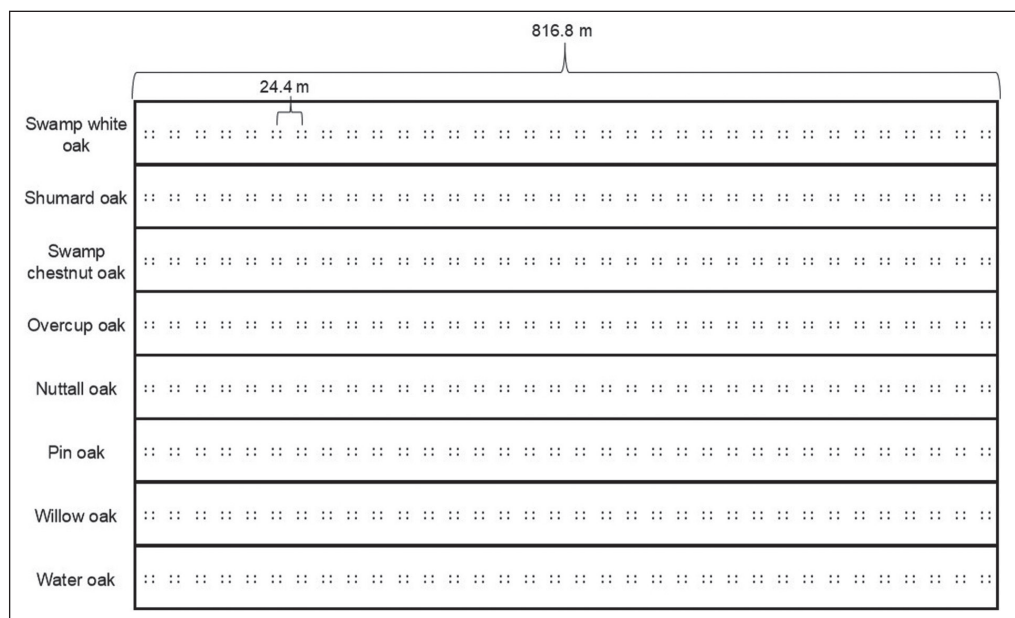


Figure 1. For the study layout, species were planted in pure block rows 816.8 m (2680 ft) long with a minimum of 4 rows per block. Two center rows per block are represented in the figure. Thirty-four plots each consisting of 4 trees were established within each block for each species and spaced 24.4 m (80 ft) apart.

Following 14 growing seasons, we remeasured plots in February and March 2018 to record survival and dbh. At each plot, we measured 4 trees nearest and diagonal to the plot center. We used the original soil data that was detailed in 2010 to allow direct comparison between previous and current data. We recorded data using a Nomad<sup>®</sup> handheld computer (Trimble<sup>®</sup>, Sunnyvale, CA).

### Statistical analysis

*Comparison of survival since 2010.* To compare variability in species survival between 2010 and 2018 growing seasons, we calculated percent survival. To estimate the 2010 percent survival for each species, we divided the number of individuals surviving in 2010 by the number originally planted during 2004. Similarly, for each species, we calculated 2018 percent survival by dividing the number of individuals remaining in 2018 by the number planted during 2004. To evaluate the variability in oak species survival between soil types, we further subdivided the overall percent survival for each species into percent survival of species in poorly drained sites and in somewhat poorly drained sites utilizing the 2018 data (after 14 growing seasons).

*Testing the differences in dbh based on soil saturation types and species.* We calculated mean dbh measures across species and soil saturation types for 2010 and 2018. To assess differences in mean dbh between species and between soil saturation types for 2010 and 2018 data, we utilized separate non-parametric Scheirer–Ray–Hare analyses. We used this test because the data did not conform to the assumptions of a parametric test. These analyses comprised 1 dependent variable, mean dbh, and 2 independent factors, soil saturation type and species. Soil saturation type had 2 levels: (1) poorly drained soil and (2) somewhat poorly drained soil. Species had 8 levels corresponding to the bottomland oak species in this study. We conducted post-hoc analyses utilizing Bonferroni adjusted pairwise Wilcoxon signed-ranks tests to determine which oak species were significantly different based on their mean dbh's for each year.

*Comparing growth in saturated soil (poorly drained).* To assess which oak species grew best in poorly drained soil, we culled 2018 dbh data to only include data from the poorly drained soil treatment. To compare the differences between species, we utilized median dbh data from individuals grown in poorly drained soils in a non-parametric Kruskal–Wallis test. We performed a series of post-hoc pairwise Mann Whitney-U tests to investigate specific differences between species.

*Comparison of dbh change since 2010.* To calculate species-specific dbh changes between 2010 and 2018, we subtracted the sum of the 2010 plot mean dbh measures from the sum of the 2018 plot mean dbh measures and divided by the number of plots. We partitioned changes in mean dbh by soil saturation level. We utilized a non-parametric Scheirer–Ray–Hare analysis to test for significant difference in dbh changes across species and saturation levels. We conducted post-hoc analyses utilizing Bonferroni adjusted pairwise Wilcoxon signed-ranks tests to determine which oak species were significantly different based on their change in mean dbh for each soil saturation level.

All statistical analyses were performed using R Studio (Version 1.2 Orange Blossom; R Studio Team 2019) at an a priori  $\alpha$ -level of 0.05.

## Results

### Comparing survival between 2010 and 2018

Across both soil-drainage classes, survival remained relatively constant between 2010 and 2018 for most species (Fig. 2). *Quercus michauxii* (Swamp Chestnut Oak) and *Q. shumardii* (Shumard Oak) were the exception, with survival dropping 24% and 30%, respectively, from 2010 to 2018. Survival percent for each species in 2018 (vs. 2010) in descending order includes: Swamp White Oak 93% (96%), *Q. Palustris* (Pin Oak; 91 [93]), *Q. nuttallii* (Nuttall Oak; 90 [90]), *Q. nigra* (Water Oak; 88 [88]), *Q. lyrata* (Overcup Oak; 86 [86]), *Q. phellos* (Willow Oak; 81 [82]), Swamp Chestnut Oak 65 (85), and Shumard Oak 52 (74). Willow Oak had relatively low survival after 6 years (82%) but then stabilized. Perhaps low initial survival was a function of that species having the smallest initial size of all species (33.3 cm [13.1 in]) when planted.

Most species had similar survival between poorly drained and somewhat poorly drained soil, with Swamp Chestnut Oak and Shumard Oak being the exceptions and demonstrating noticeably better survival in the somewhat poorly drained soils (Fig. 3). When comparing soil-drainage classes after 14 years, Swamp White Oak maintained the best survival for both soil classes, with a decline in survival of <10% after 14 years for both poorly drained and somewhat poorly drained soils.

For hardwoods planted on a 3.04 m x 3.04 m (10 ft x 10 ft) spacing (611 trees/ha [435/ac]), it is commonly acknowledged that an acceptable survival is 70% or 300 trees per acre (USDA, NRCS 2019). Six of the 8 species met this threshold,

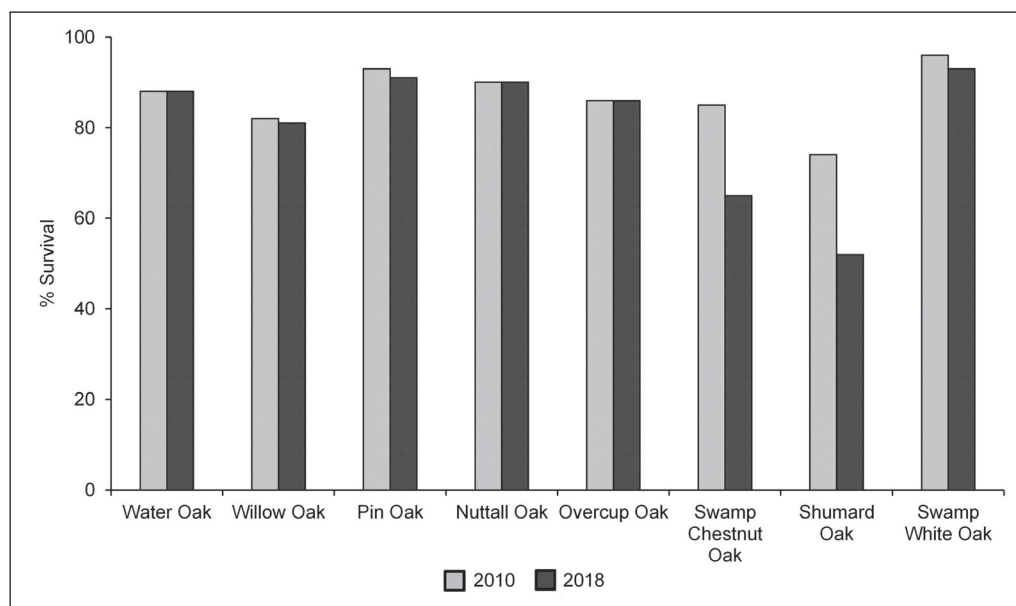


Figure 2. Overall percent survival across oak species from 2010 and 2018.

excluding Swamp Chestnut Oak and Shumard Oak. The number of surviving trees after 14 growing seasons (2018 data) that met this threshold varied from a low for Willow Oak (495 trees/ha [352/ac]) to a high for Swamp White Oak (569 trees/ha [405/ac]).

### Comparing mean dbh between species and soil saturation levels

Examining the 2010 mean dbh data, the Scheirer–Ray–Hare analyses indicated significant differences in mean dbh between oak species ( $H = 307$ ,  $df = 7$ ,  $P < 0.001$ ) and between soil saturation levels ( $H = 21$ ,  $df = 1$ ,  $P < 0.001$ ), and that there was a significant interaction between oak species and soil saturation levels ( $H = 15$ ,  $df = 7$ ,  $P = 0.031$ ) (Fig. 4). Across both soil-drainage classes, mean dbh was largest for Nuttall Oak and Pin Oak species,  $5.19 \pm 0.22$  cm ( $2.04 \pm 0.09$  in) and  $4.66 \pm 0.19$  cm ( $1.83 \pm 0.07$  in), respectively. Shumard Oak and Swamp White Oak species accounted for the smallest mean dbh for 2010 data, with means measuring  $2.56 \pm 0.24$  cm ( $1.01 \pm 0.10$  in) and  $2.79 \pm 0.22$  cm ( $1.10 \pm 0.09$  in), respectively. When grouping mean dbh data by soil saturation level, regardless of species (excluding Overcup Oak), poorly drained soil had a mean dbh ( $3.18 \pm 0.15$  cm [ $1.25 \pm 0.06$  in]) significantly different from somewhat poorly drained soils ( $3.89 \pm 0.25$  cm [ $1.53 \pm 0.10$  in]). The significant interaction suggests that the influence of soil saturation level is species specific. While there is significant influence of soil saturation on mean dbh measures, Nuttall Oak, Overcup Oak, Swamp Chestnut Oak, and Shumard Oak have similarities in their respective mean dbh data regardless of soil saturation levels (Fig. 4).

Investigating the 2018 mean dbh data, the Scheirer–Ray–Hare analyses revealed significant differences in mean dbh based on soil saturation level ( $H = 18$ ,  $df = 1$ ,  $P < 0.001$ ) and oak species ( $H = 157$ ,  $df = 7$ ,  $P < 0.001$ ). No significant interaction between species and soil saturation level was observed ( $H = 13$ ,  $df = 7$ ,  $P = 0.065$ ), indicating that significant differences in mean dbh based on soil

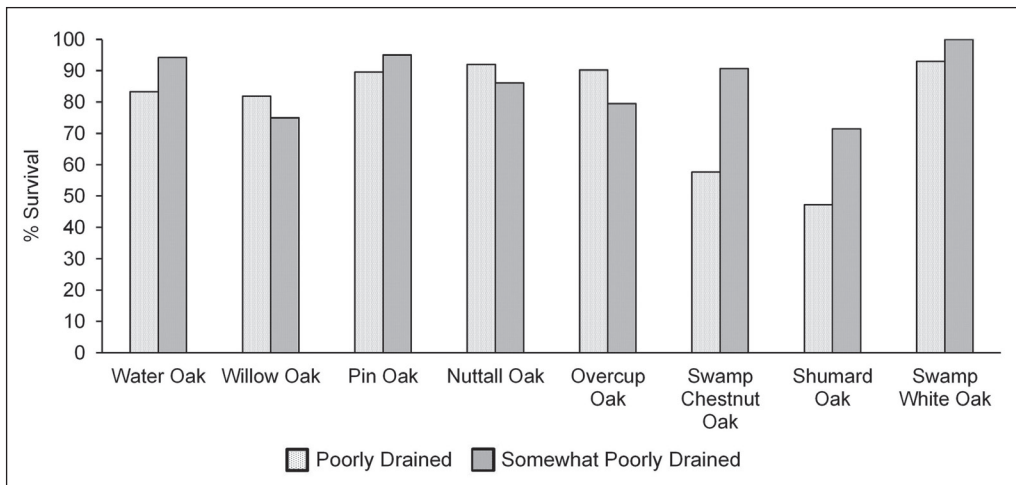


Figure 3. Percent survival across oak species in 2018 for poorly drained soil, and somewhat poorly drained soils.

saturation level and oak species could be explained separately, without evoking the effect of one on the other. Regardless of soil-drainage class, mean dbh was largest and equitable between Overcup Oak, Nuttall Oak, and Pin Oak species:  $12.88 \pm 0.28$  cm ( $5.07 \pm 0.11$  in),  $12.75 \pm 0.28$  cm ( $5.02 \pm 0.11$  in), and  $12.67 \pm 0.38$  cm ( $4.99 \pm 0.12$  in), respectively (Fig. 5). The dbh results support the pattern that species with the largest diameter in 2010, continued to be the largest in 2018.

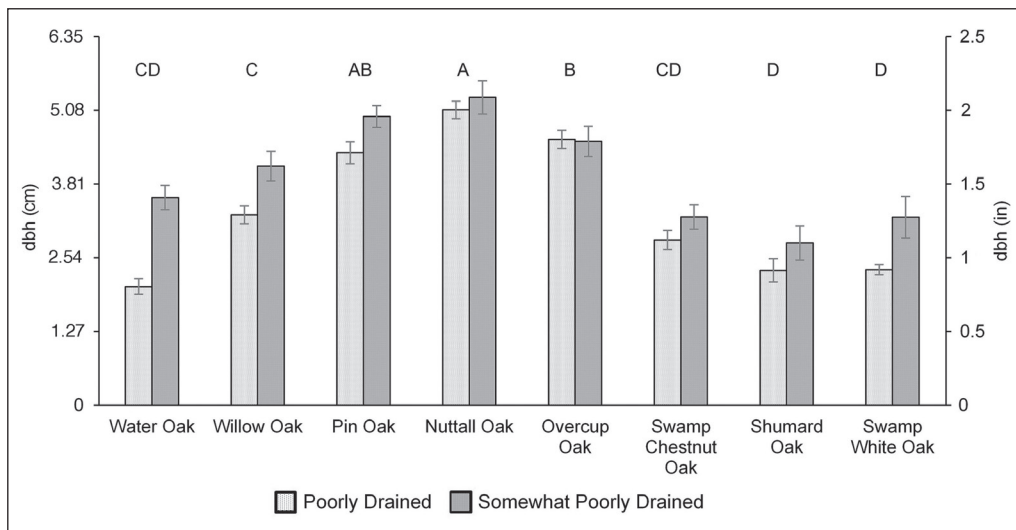


Figure 4. Mean dbh (in cm and inches) across oak species in 2010 for poorly drained and somewhat poorly drained soil. Letters indicate significant differences between species. Error bars represent standard error.

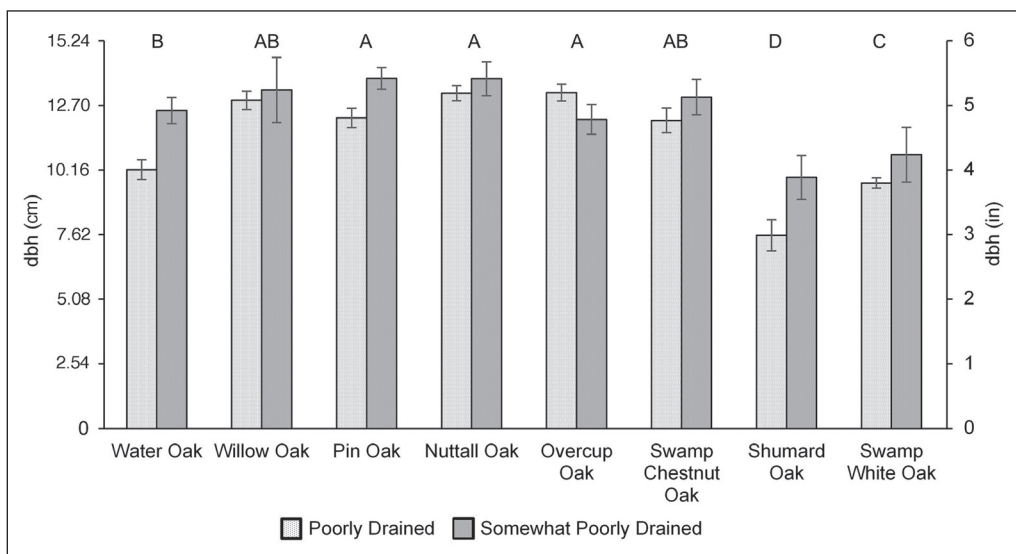


Figure 5. Mean dbh (in cm and inches) across oak species in 2018 for poorly drained and somewhat poorly drained soil. Letters indicate significant differences between species. Error bars represent standard error.

Again, Shumard Oak and Swamp White Oak species accounted for the smallest mean dbh for 2018 data, with means measuring  $8.23 \pm 0.51$  cm ( $3.24 \pm 0.20$  in) and  $9.68 \pm 0.20$  cm ( $3.81 \pm 0.08$  in), respectively (Fig. 5). Inspecting soil saturation levels, measurements of dbh from trees in poorly drained soils varied from 7.58 to 13.20 cm (3.00 to 5.20 in); whereas those in somewhat poorly drained soils varied from 9.87 to 13.80 cm (3.90 to 5.40 in) (Fig. 5). Mean dbh's across all species located in poorly drained soils were significantly different ( $11.51 \pm 0.15$  cm [ $4.53 \pm 0.06$  in]) than those in somewhat poorly drained soils ( $12.65 \pm 0.25$  cm [ $4.98 \pm 0.10$  in]). As soil drainage improved to the somewhat poorly drained category, differences in dbh narrowed in 2018.

Seventy-six percent of the plots were classified as poorly drained soil. Investigating the poorly drained soil dataset for 2018, Overcup Oak ( $13.2 \pm 0.33$  cm [ $5.2 \pm 0.13$  in]), Nuttall Oak ( $13.2 \pm 0.30$  cm [ $5.2 \pm 0.12$  in]), Willow Oak ( $12.9 \pm 0.36$  cm [ $5.1 \pm 0.14$  in]), and Pin Oak ( $12.2 \pm 0.38$  cm [ $4.8 \pm 0.15$  in]) displayed the largest mean dbh, while Swamp White Oak ( $9.64 \pm 0.20$  cm [ $3.8 \pm 0.08$  in]) and Shumard Oak ( $7.59 \pm 0.61$  cm [ $3.0 \pm 0.24$  in]) displayed the smallest mean dbh (Fig. 5). Results of the Kruskal–Wallis test determined a significant difference in 2018 median dbh data between oak species grown in poorly drained soil ( $\chi^2 = 152$ ,  $df = 7$ ,  $P < 0.001$ ). The post-hoc analysis indicated 3 significantly distinct groupings of oak species: the 1<sup>st</sup> group included Willow Oak, Pin Oak, Nuttall Oak, Overcup Oak, and Swamp Chestnut Oak; the 2<sup>nd</sup> group included Water Oak and Swamp White Oak; and the 3<sup>rd</sup> group included Shumard Oak by itself. As a group, Willow, Pin, Nuttall, Overcup, and Swamp Chestnut oaks had the largest mean dbh measures compared with the other species in poorly drained soil after 14 growing seasons. Interestingly, Overcup Oak was the only species where the dbh was larger in poorly drained soil than in somewhat poorly drained soil, a finding consistent with both measurement periods (Figs. 4, 5).

### Comparing the change in mean dbh across species and soil saturation levels

Over the 8 growing seasons since the first measurements, the mean change in dbh was greater for all species in somewhat poorly drained than in poorly drained soils, with Overcup Oak the exception (Fig. 6). Regarding the Scheirer–Ray–Hare analysis, there was a significant difference in the mean change between species ( $H = 107$ ,  $df = 7$ ,  $P < 0.001$ ). However, there was no significant difference between soil saturation levels ( $H = 4$ ,  $df = 1$ ,  $P = 0.056$ ) and no significant interaction between species and saturation level ( $H = 9$ ,  $df = 7$ ,  $P = 0.262$ ). Post-hoc analyses revealed 3 distinct groupings across soil saturation levels, with Willow Oak and Swamp Chestnut Oak having the largest mean change ( $9.70 \pm 0.53$  cm [ $3.82 \pm 0.21$  in]); Water, Pin, Nuttall, and Overcup oaks having the middle range of mean change ( $8.38 \pm 0.30$  cm [ $3.30 \pm 0.12$  in]); and Shumard and Swamp White oaks having the lowest mean change ( $7.04 \pm 0.51$  cm [ $2.77 \pm 0.20$  in]). The mean dbh change across all species over 8 growing seasons in poorly drained soil was  $8.20 \pm 0.28$  cm ( $3.23 \pm 0.11$  in), with a minimum of 6.17 cm (2.43 in; Shumard Oak) to a maximum of 9.73 cm (3.83 in; Willow Oak). With somewhat poorly drained soil, the mean dbh change across all species was  $8.56 \pm 0.53$  cm ( $3.37 \pm 0.21$  in) with a minimum of

7.09 cm (2.79 in; Shumard Oak) to a maximum of 10.08 cm (3.97 in; Willow Oak) (Fig. 6). If extrapolated, Willow Oak could attain a notable 12.70 cm (5.00 in) dbh increase in 10 years.

### Discussion

Overall, when survival and dbh are considered together, 2010 data suggest that Overcup Oak, Nuttall Oak, and Pin Oak performed the best in the poorly drained category. Based on 2018 findings, Willow Oak should be added to this list (Fig. 5). The findings are consistent with literature stating that these species grow better than most species in heavy, poorly drained, loamy soil on alluvial sites and are moderately flood tolerant (Allen et al. 2001, Burns and Honkala 1990). The study site is an ideal location for these species because it contains Waverly and Falaya soils which are deep, poorly drained, and silty-loess. Although there was no significant difference in the dbh of Swamp Chestnut Oak with the recommended 4 species, the noticeable decline in survival (Fig. 2) over the period recommends against including this species with those 4 species on the most hydric sites. Perhaps this result suggests that the gain in dbh growth is more a factor of lower density which results in larger crowns, than with site adaptation, at least for Swamp Chestnut Oak.

Results of this study reiterate that when recommending oak seedlings in bottomland sites that were previously in row crop agriculture, practitioners should examine the soil mottling to discover at what depth the >50% gleyed matrix occurs (Mercker et al. 2012b). Internal drainage is known to greatly affect tree survival and growth, highlighting the importance of matching species to site in bottomland planting designs. When comparing 2018 mean dbh and percent survival data between soil saturation levels, some interesting patterns emerge (Fig. 7). Most oak species' diameters in this study were consistent with acceptable published growth

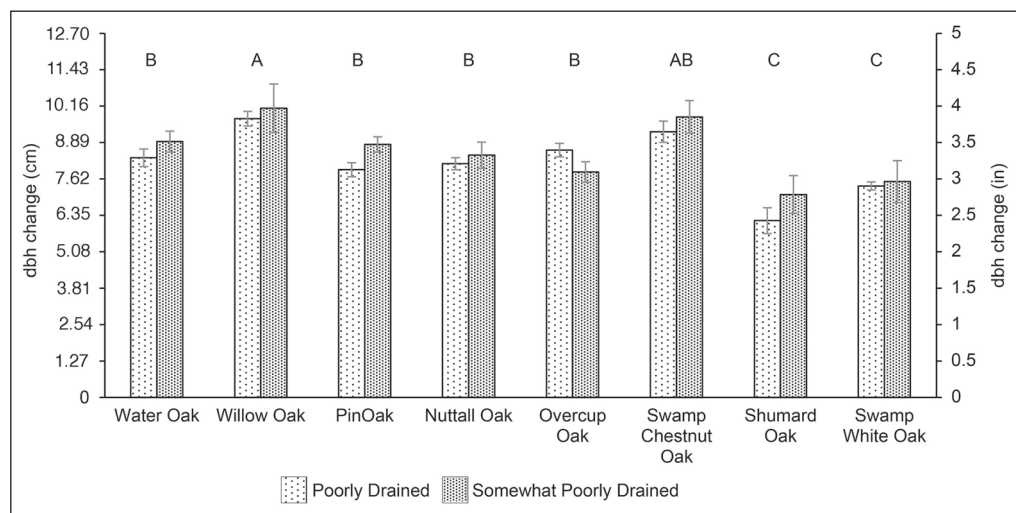


Figure 6. Mean change in dbh (in cm and inches) from 2010 to 2018 across oak species for both somewhat poorly drained and poorly drained soils. Letters indicate significant differences in growth between species since 2010. Error bars represent standard error.

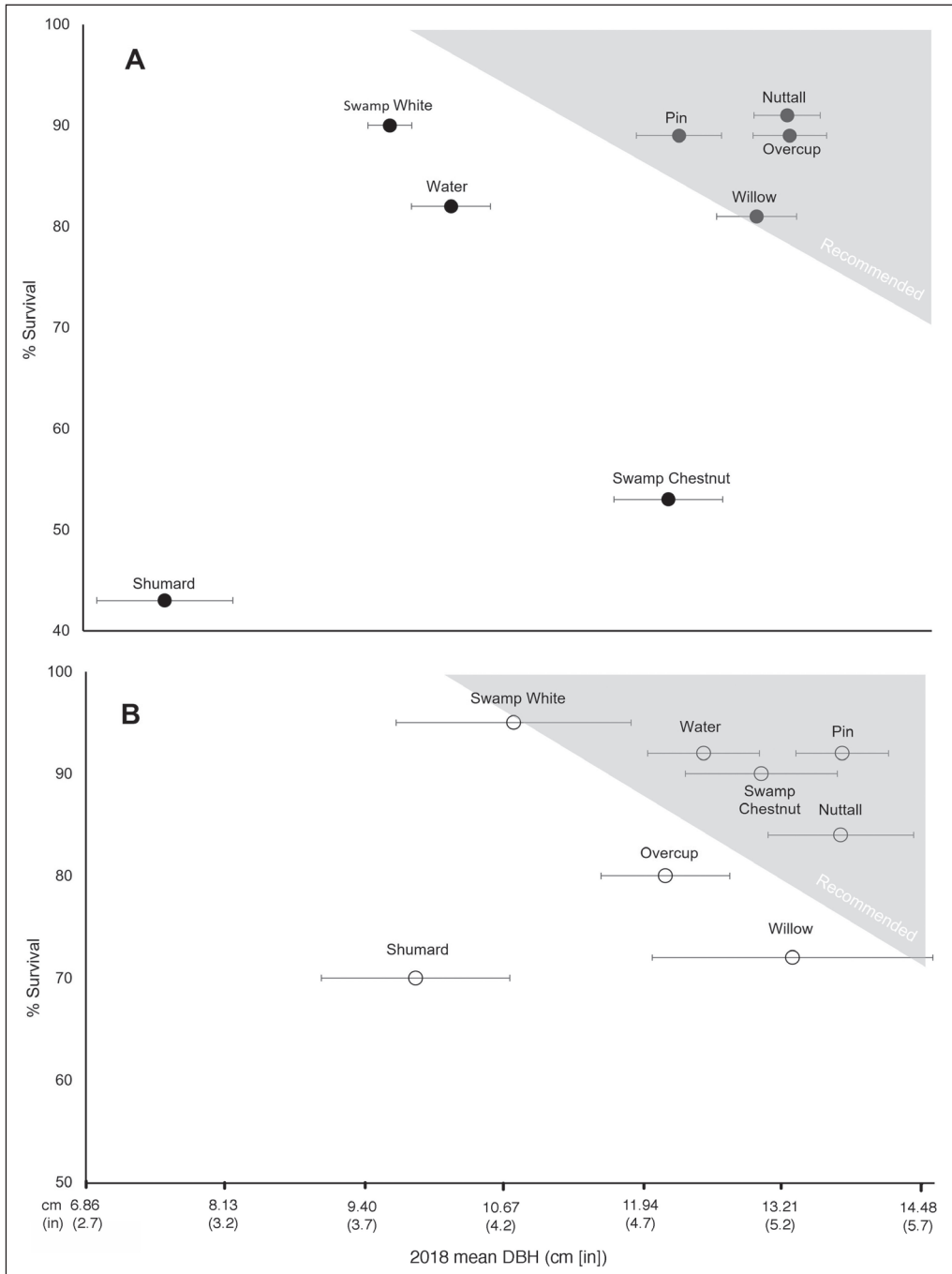


Figure 7. Percent survival and mean dbh ( $\pm$  standard error) for 2018 oaks grown in different soil saturation levels. Oak species grown in poorly drained soil are represented by graph (A) and those grown in somewhat poorly drained soil are represented by (B). Species occurring in the shaded area represent recommendations for that particular soil drainage type based on at least a 70% survival rate after 14 growing seasons and at least a 10.03 cm (3.95 in) mean dbh.

rates of bottomland oak species over 14 growing seasons (10.03–12.70 cm [3.95–5.00 in]; Mercker et al. 2012a, Rousseau 2008). The exceptions are Swamp White Oak, Water Oak, Swamp Chestnut Oak, and Shumard Oak on the poorly drained soils, and Shumard Oak (marginally) on the somewhat poorly drained soils.

Utilizing the USDA's conservation practice standard related to at least a 70% survivorship after 2 years (USDA, NRCS 2019) and the 10.03–12.70 cm (3.95–5.00 in) dbh benchmark referenced above, we recommend planting Nuttall Oak, Pin Oak, Overcup Oak, and Willow Oak in poorly drained soil (gleyed matrix occurring at a depth of 0–22.9 cm [0–9.0 in]) (Table 2). As drainage improves to somewhat poorly drained (gleyed matrix occurring at a depth of 22.9–45.7 cm [ $>9.1$ –18.0 in]), Water Oak, Swamp Chestnut Oak, and Swamp White Oak (marginally) can be added. Shumard Oak is questionable in any level of saturated soil. Cherrybark Oak and Bur Oak, though not included in this study, fall into the category of adapted to moderately drained soil (Adapted from Allen et al. 2001, Baker and Broadfoot 1979, and Ozalp et al. 1997). Tree species diversity can expand as the soil drainage improves.

Over the last 4 decades, many aspects of bottomland hardwood restoration have been explored (Allen et al. 2001, Baker and Broadfoot 1979, Hodges et al. 1979, King and Kein 2019, Ozalp et al. 1997, and Stanturf et al. 2004). This study supplements the knowledge base with more in-depth analyses of a specific soil property, soil mottling and the gleyed matrix. Unlike other soil-site properties such as texture, compaction, porosity and nutrients, soil mottling is a property that can be easily taught to, and assessed by, field practitioners, thereby allowing the best possible long-term match when establishing hardwoods on bottomland sites.

Table 2. Recommended oak species to plant according to soil drainage category from 2010 (Mercker et al. 2012a) and 2018 (current) studies.

Soil drainage	Recommended oak species	
	2010	2018
Poorly drained	Nuttall, Pin, Overcup	Nuttall, Pin, Overcup, Willow
Somewhat poorly drained	Willow	Swamp Chestnut, Swamp White, Water
Moderately drained	Swamp Chestnut, Water, Swamp White, Shumard	Shumard

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