Relationship of Oak Seedling Height and Diameter with Bottomland Elevation

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Abstract: Hardwood bottomland restoration is an expanding conservation practice in the southeastern United States. Understanding relative flood tolerance of bottomland seedlings is important to restoration success. Thus, we related height and diameter of *Quercus phellos*, *Q. nuttallii*, and *Q. lyrata* to elevation gradient in a 6-ha west Tennessee bottomland. We planted 3,771 seedlings from January–March 2004 in a randomized design such that all species had spatial representation across elevation gradients. Seedling height and root-collar diameter were measured in October and November 2004, and related to bottomland elevation using linear regression. Heights of *Q. phellos* and *Q. nuttallii* seedlings were positively related with elevation; no linear relationship was apparent for *Q. lyrata*. Root-collar diameter also positively correlated with elevation for *Q. nuttallii*. Our results suggest that *Q. lyrata* seedlings may be most flood tolerant among these species. Managers may consider planting *Q. lyrata* in bottomlands at lower elevations, and *Q. nuttallii* and *Q. phellos* at intermediate to higher elevations.

Key words: Q. lyrata, *Q. nuttallii*, *Q. phellos*, flood tolerance, hardwood bottomland, oak seedlings, restoration, wetlands

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Hardwood bottomland ecosystems are forested wetlands adjacent to riverine systems (Messina and Conner 1998) and are important for timber production and habitat for fish and wildlife (e.g., Wharton et al. 1981, Kaminski et al. 1993, Young et al. 1995). They also are critical areas for floodwater storage and nutrient cycling and improve water quality by naturally filtering sediments and contaminants from runoff (Gosselink and Lee 1989). Trees in hardwood bottomlands also help stabilize river and stream banks and reduce erosion (Welsch 1991).

Approximately 30% of the hardwood bottomlands in the contiguous United States have been drained or deforested (Abernathy and Turner 1987, Tulloch 1994). Within the lower Mississippi Alluvial Valley, only 25% of the original hardwood bottomland acreage remains. Tennessee has lost almost 60% of its wetlands (Dahl 1990), most of which were hardwood bottomlands. Drainage of forested and other wetlands was encouraged by various legislative acts through the 1970s for agriculture and other human land-use developments (Mitsch and Gosselink 2000).

Protection of hardwood bottomlands and other wetlands was authorized by the Clean Water Act of 1977 (Mitsch and Gosselink 2000). In addition, the Swampbuster Provision of the Food Security Act of 1985 disqualified farmers from receiving federal subsidies if wetland areas were cultivated (Glaser 1986). This legislation, along with the creation of federal conservation programs (e.g., conservation reserve program, CRP; wetland reserve program, WRP), has decreased the rate of wetland loss and increased interest in hardwood bottomland restoration (Stanturf et al. 2001, Haynes 2004). These programs pay landowners to restore erodible agricultural lands and wetlands to native vegetation.

In Tennessee, most wetland restoration efforts have focused on forested wetlands. For example, 89.8% (3,605 ha) of wetlands restored by the Natural Resources Conservation Service (NRCS) in Tennessee prior to 2005 were forested (M. Zeman, NRCS, personal communication). Similarly as of 2004, Tennessee Wildlife Resources Agency (TWRA) acquired almost 21,050 ha of wetlands via the Tennessee Wetlands Acquisition Act, most of which were hardwood bottomlands (J. Hopper, TWRA, unpublished data). Often, these areas are replanted with oak seedlings (e.g., ca. 70% of Tennessee NRCS easements) to restore native communities. Interestingly though, very little information exists on suitable oak species to plant given elevation contours in a candidate bottomland (Stanturf et al. 2004).

Therefore, our objective was to relate height and diameter of three oak seedling species (willow oak, *Quercus phellos;* Nuttall oak, *Q. nuttallii;* overcup oak, *Q. lyrata*) to relative elevation in a west Tennessee hardwood bottomland that was previously farmed then reforested in 2004. Because elevation is related to flood depth and frequency in hardwood bottomlands (Williams 1988, Rosgen 1994), relating seedling height and diameter with elevation provides wildlife managers and foresters an indication of relative flood tolerance for these species.

Study Area

We conducted our study in a 6-ha bottomland at the University of Tennessee West Tennessee Research and Education Center (WTREC) located in Jackson, Tennessee (35˚37'37"N, 88˚51'36"W, 120 m mean elevation). This bottomland contained six 1-ha impoundments (numbered 2–7) with 1-m high levees, which contained dropboard water control structures at their lower end that connected to a drainage channel (Fig. 1). The impoundments differed predictably in elevation, with the gradient sloping upward from 2 to 7 and northeast to southwest. Existing surface and groundwater hydrology were a consequence of localized rainfall, runoff, and water levels in the

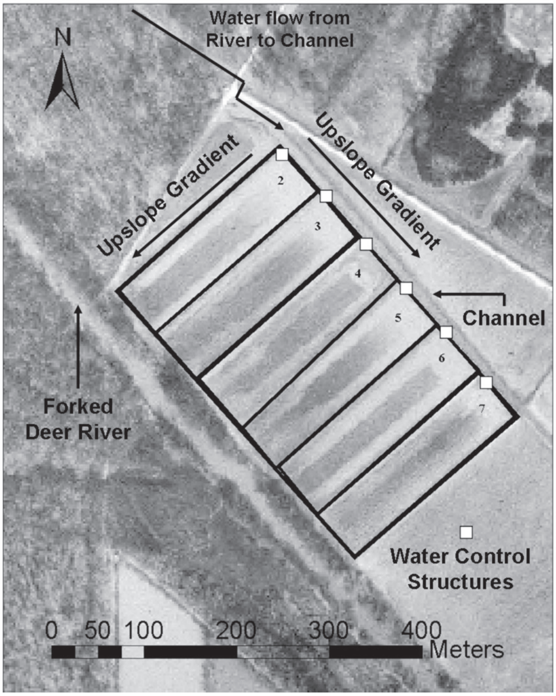

Figure 1. Impoundments (2–7), elevation gradient and water flow from the South Fork of the Forked Deer River in a west Tennessee bottomland, 2004.

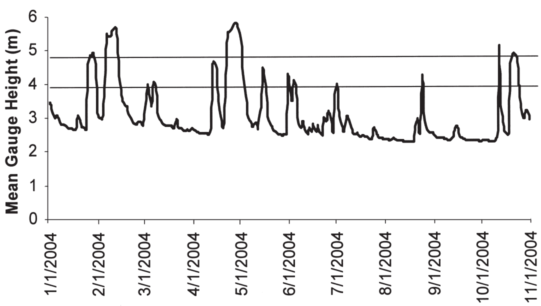

Figure 2. U.S. Geological Survey gage (#07027720) levels for the South Fork of the Forked Deer River, January–October 2004. Lower and higher elevations in study impoundments at the West Tennessee Research and Education Center were flooded when water levels exceeded 3.9 and 4.9 m, bottom and top line, respectively.

channelized South Fork of the Forked Deer River. When water levels in the Forked Deer River exceeded 3.9 m at USGS gage #07027720, the river backed into the bottomland via the drainage channel and subsequently through the water control structures, flooding lower elevations in the impoundments. This occurred 13 times for a total duration of 48 days from January through October 2004 (Fig. 2). All elevations in impoundments were flooded when water exceeded 4.9 m at the gage, which occurred six times for a total duration of 23 days. Thus, the elevation gradient in our bottomland resulted in greater frequency and duration of flooding in all impoundments near the channel, with probability of inundation decreasing from impoundments 2–7 (Fig. 1).

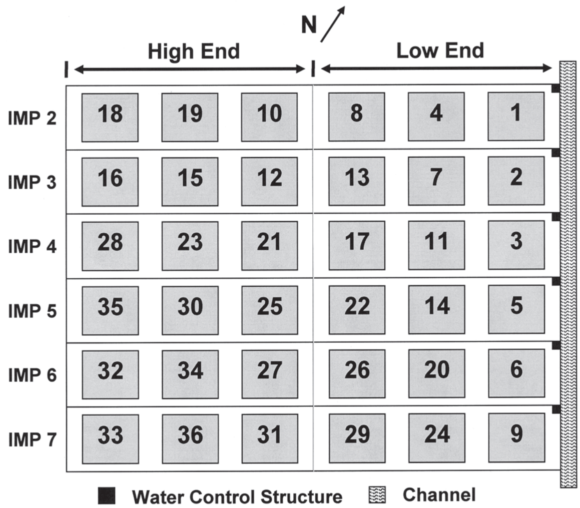

Figure 3. Planting and elevation schematic of hardwood bottomland seedlings in six impoundments (IMP 2–7) in a west Tennessee bottomland, 2004. Species were randomly assigned to numbered elevation blocks within impoundments and ends. Elevation increased with ordinal ranking of blocks. Willow oak *(Quercus phellos)* were planted in blocks 2, 6, 8, 9, 12, 14, 17, 18, 23, 25, 34, and 36. Nuttall oak *(Q. nuttallii)* were planted in blocks 1, 3, 7, 15, 19, 20, 21, 22, 29, 31, 32, and 35. Overcup oak *(Q. lyrata)* were planted in blocks 4, 5, 10, 11, 13, 16, 28, and 30.

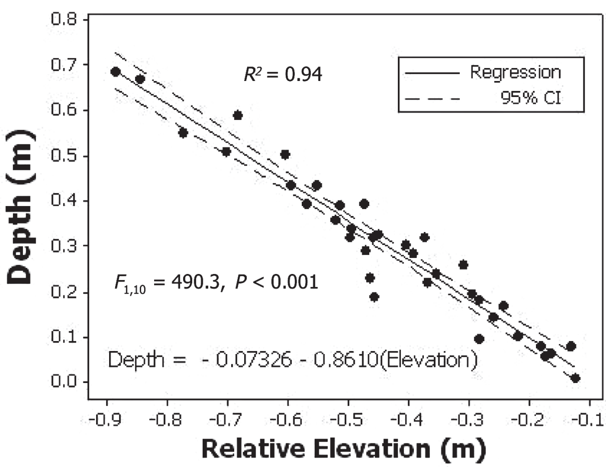

Figure 4. Linear regression statistics and 95% confidence bands relating water depth and relative elevation in a west Tennessee bottomland, 2004.

Methods

We planted seedlings in monospecific plots with 3 × 3-m spacing in six 36 × 36-m elevation blocks per impoundment (Fig. 3). We measured relative elevation in blocks using a Topcon® electronic total station (Topcon Corporation, Paramus, New Jersey), and ordinally ranked elevations from 1–36. Block elevations followed the bottomland gradient (Fig. 1), with blocks 1 and 36 lowest and highest, respectively (Fig. 3). Water depth in blocks when the Forked Deer River gage exceeded 4.9 m (i.e., when all impoundments were flooded) was strongly correlated with elevation, and ranged from 0.01 to 0.69 m from the highest to lowest block (Fig. 4).

Impoundments were experimentally divided into low and high ends to randomly assign species to elevation blocks (Fig. 3). Within each impoundment and end, we randomly assigned a seedling species without replacement to each elevation block. This ensured that a species was not clustered at low or high elevations within impoundments. We planted approximately 144 seedlings per elevation block, although portions of some blocks in impoundments 5, 6, and 7 could not be planted because of a pre-existing gas line. Thus, there were less than 144 seedlings per block in these impoundments. Also, we planted water oak (*Q. nigra*) instead of overcup oak in impoundments 6 and 7; however, the former was not included in analyses because of limited spatial distribution in the bottomland, and sample size was small ($N = 4$ elevation blocks). We included overcup oak in the analyses, because $N = 8$ elevation blocks and it was spatially represented throughout the bottomland (Fig. 3).

We acquired all seedlings (1-0 stock) from the Tennessee Division of Forestry State Nursery, and maintained them at 4 C in a walk-in cooler at WTREC until planted. To standardize planting conditions, we sub-soiled 1-m width rows at 36 cm depth along planting locations. We planted seedlings during January–March 2004 using a Whitfield Tree Planter (R.A. Whitfield Manufacturing, Mableton, Georgia), which is specifically designed for hardwood seedlings. At the time of planting, all seedlings within species appeared in similar physical condition, and individuals for a species were planted randomly within elevation blocks. Due to this designed randomization, we assumed that height and diameter of seedlings were not correlated with elevation at planting. We applied Oust XP (sulfometuron methyl, DuPont, Wilmington, Delaware) prior to bud break and Roundup (glyphosate, Monsanto, St. Louis, Missouri) in June 2004 uniformly around all seedlings to limit potential herbaceous plant competition and ensure uniformity in growth responses among impoundments and elevations. Other environmental factors that may influence seedling growth, such as soil type and ambient conditions, likely were similar across the bottom due to its small size and relative flatness (Brown et al. 1978).

We measured height and root-collar diameter of all seedlings ($N = 3,771$) in October and November 2004. Seedling height was measured to the nearest 0.5 cm from the ground to the terminal bud using a meter stick. We measured root-collar diameter to the nearest 0.5 mm at ground-level using calipers. Height and diameter were averaged per elevation block and regressed linearly against relative ordinal ranking of elevation in the bottomland (Fig. 3). Because mean height and diameter were calculated from least 1,171 individuals, it was reasonable to assume that mean responses approximately followed a normal distribution and linear model assumptions were satisfied (Hogg and Craig 1995). We used the SAS system to test ($\alpha = 0.05$) for statistical significance in all relationships (Littell et al. 1991).

Results

Height was positively related to elevation for willow and Nuttall oak seedlings ($P \leqq 0.002$); no relationship was detected for overcup oak ($P = 0.27$, Fig. 5). Approximately 65% and 70% of the variation in height was explained by elevation for Nuttall and willow oak seedlings, respectively. Root-collar diameter also was positively

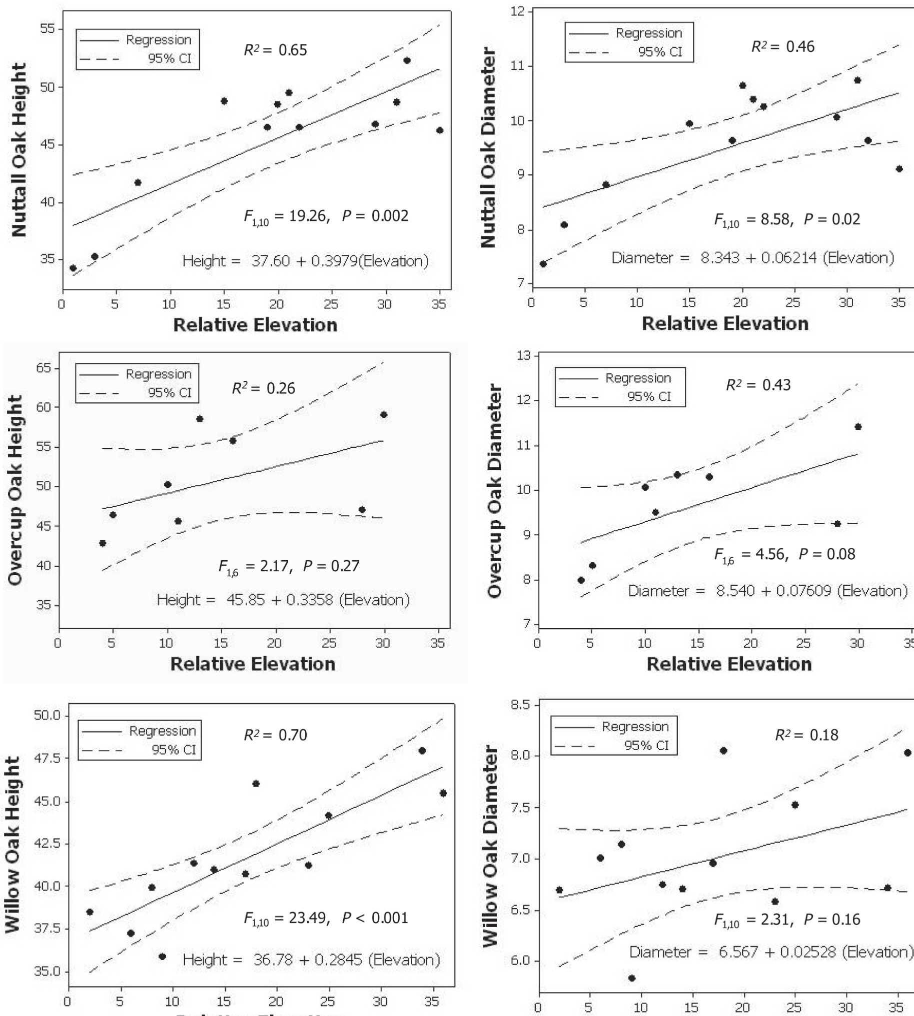

Figure 5. Linear regression statistics and 95% confidence bands relating seedling height (cm) and diameter (mm) of willow oak *(Quercus phellos),* Nuttall oak *(Q. nuttallii)* and overcup oak *(Q. lyrata)* to relative elevation in a west Tennessee bottomland, 2004.

related to elevation for Nuttall oak seedlings ($P = 0.02$, Fig. 5). Approximately 46% of the variation in diameter was explained by elevation for Nuttall oak seedlings.

Discussion

Seedling height was positively related to elevation for willow and Nuttall oaks. Willow oak seedling height had the strongest relationship with elevation, indicating its height changed greatest across elevation gradients. Root-collar diameter also was positively correlated with elevation for Nuttall oak. A trend between seedling height and diameter and elevation was not detected for overcup oak, suggesting that environmental factors associated with elevation may not influence its growth as much as willow and Nuttall oak seedlings.

Because elevation in the WTREC bottomland was directly related with flood frequency and depth (Figures 2, 4), it is reasonable to assume that seedlings at lower elevations experienced greater hydrologic stress than at higher elevations. Reduced growth is a common physiological response to hydrologic stress for seedlings, because anaerobic conditions thwart energy storage and metabolism (Kozlowski 1984, Kozlowski and Pallardy 1997). Species that experience greater cessation of growth generally are considered less flood tolerant (Kozlowski 1984). The strong correlations of seedling height with elevation for willow and Nuttall oaks and root-collar diameter for Nuttall oak seedlings suggest these species grew least at lower elevations during the first year. In contrast, overcup oak height and diameter did not appear to be influenced by elevation. Thus, our results suggest that overcup oak may be most flood tolerant among these species.

Previous research in greenhouses and Southeast bottomlands appear to support our conclusions regarding flood tolerance. Gray and Kaminski (2005) found that overcup oak had 10% greater survival than willow oak seedlings in a Mississippi hardwood bottomland that was continuously flooded during winter. Overcup oak seedlings also were 13% taller than willow oak seedlings in this bottomland (M. Gray, unpublished data). Soil saturation also can reduce growth and increase secondary root mortality in willow oak seedlings (Hosner and Boyce 1962). Physiology and growth of Nuttall oak seedlings also may be negatively influenced by flooding. In controlled experiments, flooding reduced stomatal conductance, net photosynthetic rate and height growth of Nuttall oak seedlings (Anderson and Pezeshki 1999, Farmer and Pezeshki 2004).

Management Implications

Our results suggest that wildlife managers and foresters should not replant hardwood bottomlands in a random species arrangement. Seedlings of bottomland species differ in flood tolerance, and flood frequency and depth are typically correlated with elevation. Overcup oak seedlings appeared to be most flood tolerant among our species. Thus, managers should consider planting overcup oak at low elevations and willow and Nuttall oak seedlings at intermediate to high elevations. Alternatively, wildlife biologists may consider managing low elevations in candidate bottomlands as moist-soil wetlands and only replanting intermediate to high elevations with willow and Nuttall oak seedlings. Moist-soil wetlands are highly productive (Gray et al. 1999), and important natural habitats for various species including waterfowl and amphibians (Baldassarre and Bolen 1994, Gray and Smith 2005). Also, overcup oak timber is less valuable and their acorns are less preferred by some wildlife than red oaks (Young et al. 1995, Barras et al. 1996), hence this species may not be ideal for bottomland restoration in the Southeast.

Our seedling results included first-year growth only. However, it is reasonable to assume that first-year growth responses will be magnified in subsequent years as opportunities for hydrologic stress accumulate and influence survival (King 1995, Gray and Kaminski 2005). First-year survival rates of our seedlings was >95% and was not correlated with elevation (J. McCurry, unpublished data). Nonetheless, shorter seedlings have a greater chance of being overtopped by floodwaters than taller seedlings, which can negatively influence growth and survival (Briscoe 1957, Hosner 1960). Shorter seedlings also may not be able to compete for light and other resources as well as taller seedlings of similar species (Kozlowski and Pallardy 1997). Therefore, planting unsuitable species at lower elevations in a hardwood bottomland may decrease success of a restoration project. In our bottomland, the median elevation was 0.75 m above the permanent water source. Thus, managers may consider planting less flood-tolerant oak seedlings above the 1-m contour to increase likelihood of restoration success.

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