FLOOD PLAIN TOPOGRAPHY AFFECTS ESTABLISHMENT SUCCESS OF DIRECT-SEEDED BOTTOMLAND OAKS

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Abstract—Five bottomland oak species were direct seeded along a topographical gradient in a flood plain to determine if environmental factors related to relative position in the flood plain influenced seedling establishment and survival. Two years after installation of the plantation, seedling establishment rates ranged from 12±1.6 (mean ± standard error) percent for overcup oak (*Quercus lyrata* Walt.) to 33±2.3 percent for Nuttall oak (*Q. nuttallii* Palmer). Germination and survival of swamp laurel oak (*Q. laurifolia* Michx.), willow oak (*Q. phellos* L.), and water oak (*Q. nigra* L.) ranked intermediate and averaged 21 percent. Nuttall oak seedlings averaged about 18.6±0.7 inches tall after two growing seasons, while shoot length of swamp laurel oak and water oak averaged 8.8±0.6 inches. Species rankings for growth of root-collar diameter tracked those for height growth. For a given species, logistic function models indicated that site factors associated with relative elevation in the flood plain strongly influenced seedling establishment and survival. Establishment and survival of all species responded positively to elevation. We summarize implications of our findings to afforestation and reforestation of alluvial flood plain sites within the context of site delineation and species assignments.

INTRODUCTION

Bottomland hardwood forests currently occupy about 29.8 million acres within alluvial flood plains of rivers and streams in the Southern United States (Hodges 1995). Regenerating bottomland hardwood stands classically involves natural regeneration methods (Hodges 1995). But more intensive management regimes are being instituted on alluvial flood plains as forest acreage declines and as consumers place greater demands on these forest resources. This shift to more intensive management appears in the increase in artificial regeneration activities on bottomland hardwood sites throughout the South. Enrichment planting in natural stands understocked with desirable reproduction and afforestation of marginal agricultural land are the primary practices spurring the expansion of artificial regeneration on alluvial flood plains. For example, about 447,000 acres of economically marginal agricultural land in Louisiana, Mississippi, and Arkansas are scheduled for afforestation by 2005 (Stanturf and others 1998).

Bottomland oak species (*Quercus* spp.) are favored for their commercially valuable wood and their desirable hard mast and, thus, are commonly used in afforestation and reforestation. Early research on oak plantation establishment in the Mississippi Alluvial Plain led to current direct seeding and seedling planting techniques (Kennedy 1993). Though these advances have provided sound procedures for establishing bottomland oak regeneration, plantation establishment on alluvial flood plain sites is still problematic. For example, oak seedlings often exhibit very slow growth that causes them to remain under herbaceous competition for several years before making significant gains in height increment (Kennedy 1993). Heavy herbaceous cover provides habitat for rodents that can destroy young plantations or retard seedling growth for several years by clipping shoots (Johnson 1981). Furthermore, the composite of site types typical of alluvial flood plains complicates the task of species assignments, often leading to deployment of inappropriate species on afforestation and reforestation sites.

Erosional and depositional processes in alluvial flood plains of the South can create heterogeneous site conditions over a relatively small area (Hodges and Switzer 1979, Putnam and others 1960). Several site types are recognized in alluvial flood plains, and these sites are delineated as topographic features or landforms. Fronts and ridges, which are the highest landforms in alluvial flood plains, experience infrequent flooding of short duration and are characterized by relatively coarse-textured, well-drained soils. Sloughs and swamps, the lowest landforms in flood plains, are frequently flooded for long durations and have heavily textured, very poorly drained soils. Flooding regime, soil texture, and drainage of flats are intermediate between those of ridges and sloughs (Hodges 1995).

Site factors, including moisture availability, flooding regime, and soil drainage, interact with the physiological functions of flood plain trees, resulting in species associations unique to each site type. For example, ridges are occupied by flood-intolerant species that require well-drained soils; e.g. American sycamore (*Platanus occidentalis* L.) and water oak (*Q. nigra* L.). Flood-tolerant species such as baldcypress [*Taxodium distichum* (L.) LC Rich.] and water tupelo (*Nyssa aquatica* L.) typically grow on the poorly drained soils of sloughs and swamps where they endure extended flooding (Hodges and Switzer 1979, Putnam and others 1960). Thus, topographic features in flood plains have various edaphic and hydrologic conditions manifested through vegetation associations. Field observations indicate bottomland oak species are stratified among sites in mature forests of alluvial flood plains (Tanner 1986). To

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investigate the importance of seedling establishment on the distribution of bottomland oaks, we installed a plantation of five oak species along a topographical gradient in an alluvial flood plain. Our aim was to determine if microsite factors associated with flood plain relief influenced bottomland oak seedling establishment.

METHODS

Study Area

The study is located near the confluence of the Tombigbee and Alabama Rivers in Clarke County, AL (31°19' N., 87°51' W.) on an area previously abandoned as an American sycamore plantation. The surface of the field decreased in elevation from a ridge to a slough on about a 1-percent grade; i.e., there was a 4-foot decrease in elevation over 400 feet of surface. Soil cores were extracted along the elevational gradient on the study site to identify physical characteristics. An Urbo-Mantachie-Una soil complex predominated the site. Soil on the lowest portion of our study area (the slough or return channel) was typical of the Una series. Una is a poorly drained soil with very slow runoff and permeability. Una soils are classified as fine, mixed, active, acid, thermic Typic Epiaquept with a thin clay surface overlying a clay subsoil. Soil characteristic of intermediate positions on our study area belonged to the Urbo series. Urbo is somewhat poorly drained with slow runoff and very slow permeability. It is classified as fine, mixed, active, acid, thermic Vertic Epiaquept with a clay surface overlying a clay subsoil. The Mantachie series was typical of the highest portion of our study area and is typically found on high flats and low ridges. Mantachie is somewhat poorly drained with slow runoff and moderate permeability. This series is classified as fine-loamy, siliceous, active, acid, thermic Aeric Endoaquept with a fine sandy loam surface overlying a clay loam subsoil. All three soils on the study site experience annual flooding for brief (ridge and high flat) to long duration (low flat and return channel). Cover on the study area was primarily herbaceous species including sugar cane plume grass [*Erianthus giganteus* (Walter) Muhl.], panic grass (*Panicum rigidulum* Bosc ex Nees), beak rush [*Rhynchospora corniculata* (Lam.) A. Gray], and marsh mallow (*Hibiscus laevis* Allioni). We mowed the area in preparation for planting, but practiced no further weed control during the study.

Experimental Design

Five oak species were systematically direct seeded along the topographical gradient in April 1993. Overcup oak (*Q. lyrata* Walt.), Nuttall oak (*Q. nuttallii* Palmer), swamp laurel oak (*Q. laurifolia* Michx.), willow oak (*Q. phellos* L.), and water oak were selected for this study, because these species are native to the region and exhibit different site preferences in natural stands. Acorns were collected under at least five different parent trees growing in alluvial bottoms of east-central Mississippi and west-central Alabama. These acorns were float tested (except for overcup oak) to eliminate those damaged by insects, then they were stored in polyethylene bags under refrigeration until sowing (Bonner and Vozzo 1987). Three replications of plots were established as a grid along the topographical gradient. In each plot, 70 rows were delineated at 6-foot intervals perpendicular to the slope. In each row, five planting spots were flagged 2 feet apart, and two acorns for each species were seeded at a randomly chosen spot in each row. Thus, 420 acorns were seeded 3 to 4 inches deep for each species along the topographical gradient.

Table 1—Model coefficients[a] for predicting seedling establishment for direct seeded acorns in an alluvial floodplain, Alabama

Species	b_1	b_2	b_3
Overcup oak	1.0000	2.9196	-0.4088
Nuttall oak	0.5286	0.7392	-0.6051
Swamp laurel oak	0.3183	1.5895	-0.8304
Willow oak	1.0000	3.2266	-0.8113
Water oak	0.4176	9.1738	-4.5961

[a] Logistic model for establishment = $b_1/(1+e^n)$, where n = (b_2 + b_3 * elevation).

Seedling survival, height, and diameter data were collected after the first 2 growing seasons for each of the 420 acorns sown for each species. Also, relative elevation at each planting spot was measured with a transit and leveling rod in an attempt to relate seedling survival and establishment success to flood plain relief. Analysis of variance according to a completely random design tested for a species effect on survival and height growth ($\alpha = 0.05$). A logistic function modeled seedling establishment from direct-seeded acorns and planted seedling survival along the topographical gradient (Hamilton 1986, Monserud 1976). Model coefficients for each species and stock type are presented in table 1.

RESULTS AND DISCUSSION

Establishment and Growth

Two years after sowing, seedling establishment from direct-seeded acorns ranged from 33 percent for Nuttall oak to 12 percent for overcup oak ($P < 0.0001$) (table 2). Establishment rates for swamp laurel oak, willow oak, and water oak were intermediate and averaged about 21 percent following the second growing season. Nuttall oak germinants were the tallest after two growing seasons, with an average height of 18.7 inches ($P < 0.0001$) (table 2). Swamp laurel oak and water oak germinants grew the least with an average shoot height < 10 inches after two growing seasons. Overcup and willow oak germinants grew more than 4 inches taller than those of swamp laurel oak and water oak. Results for root-collar diameter growth were similar to those for height growth (table 2). Nuttall oak seedlings developed the largest root-collar diameters, followed by overcup oak and willow oak, then swamp laurel oak and water oak.

In this study, direct-seeded Nuttall oak showed the highest germination rate and also the greatest height and diameter growth. The superior germination and early height growth of this species is consistent with other research on direct-seeded bottomland oaks and undoubtedly leads to its popularity in direct seeding operations (Johnson 1981). Direct seeding Nuttall oak has yielded first-year establishment rates as high as 55 to 71 percent in the Mississippi Alluvial Plain, but 35 percent is a reasonable estimate of the establishment rate for direct-seeded Nuttall oak (Johnson and Krinard 1985, Kennedy 1993, Miwa and others 1993). In contrast, we observed poor establishment

Table 2—First- and second-year survival, seedling height, and root-collar diameter of five bottomland oak species direct seeded along a topographic gradient in an alluvial floodplain, Alabama[a]

	Survival		Height		Diameter	
Species	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
	- - - - - - - percent - - - - - - - -		*- - - - - - - - inches - - - - - - - -*		*- - - - - - - - 0.1 inch - - - - - - -*	
Overcup oak	43.5 ± 2.4 c	12.4 ± 1.6 c	6.8 ± 0.24 b	15.9 ± 1.02 b	0.83 ± 0.02 b	1.77 ± 0.11 b
Nuttall oak	58.8 ± 2.4 a	33.0 ± 2.3 a	9.4 ± 0.31 a	18.7 ± 0.71 a	1.29 ± 0.03 a	2.36 ± 0.11 a
Swamp laurel oak	47.8 ± 2.4 bc	18.7 ± 1.9 b	5.3 ± 0.19 c	9.7 ± 0.63 c	0.83 ± 0.02 b	1.29 ± 0.06 c
Willow oak	58.8 ± 2.4 a	22.0 ± 2.0 b	6.3 ± 0.19 b	14.2 ± 0.83 b	0.75 ± 0.02 c	1.42 ± 0.07 b
Water oak	52.4 ± 2.4 ab	22.2 ± 2.0 b	4.5 ± 0.16 d	7.9 ± 0.55 c	0.63 ± 0.02 d	0.98 ± 0.05 c

[a] Values presented are means ± standard error of the mean. Entries in a column followed by the same letter do not differ at the 0.05 probability level.

for direct-seeded overcup oak. A twofold to threefold increase in sowing rate would have been required to establish an overcup oak seedling density similar to that observed for Nuttall oak. Low acorn viability may partially explain the poor establishment rate for overcup oak. Prior to direct seeding, a standard float test separated sound acorns from insect-damaged acorns. However, this test is not appropriate for overcup oak acorns, which have a corky layer around the cotyledons that causes the seed to float. Thus, we were not able to remove insect-damaged overcup oak acorns from the lot.

In this experiment, newly established oak seedlings showed slow juvenile growth rates in comparison to other shade-intolerant bottomland species. Typically they favor root growth over shoot growth in high light environments and defer significant height growth until several years after establishment (Gardiner and Hodges 1998, Hodges and Gardiner 1993, Wittwer 1991). Swamp laurel oak and water oak showed the poorest height growth of new germinants in this study. This characteristic may be detrimental to these species on bottomland sites with rank competition or on sites with frequent or extended floodwater inundations.

Influence of Topography on Seedling Establishment

The primary objective of this study was to determine if seedling establishment or survival was controlled by factors associated with flood plain topography. Seedling establishment from direct-seeded acorns of bottomland oaks appeared to vary with elevation (fig. 1). All species generally exhibited a positive establishment slope along the topographic gradient; i.e., seedling establishment increased with increasing elevation (fig. 1). But oak species had differing establishment patterns along the elevational gradient. For example, Nuttall oak showed the best predicted establishment (about 20 percent) on the lowest end of the study area (fig. 1). For this species, predicted establishment increased about 28 percent to a maximum rate of 45 percent on the highest portion of the study area. Seedling establishment from overcup oak and swamp laurel oak acorns appeared least responsive to the gradient, increasing only 15 and 22 percent, respectively, with elevation. Establishment of seedlings from direct-seeded water and willow oak acorns was highly responsive to the gradient. For water oak, virtually no establishment was recorded on the lowest quarter of the plantation. But, establishment for this species quickly increased above that point to a maximum near 41 percent. Predicted establishment of reproduction from willow oak acorns increased from about 4 percent on the lowest end of the study area to > 54 percent on the highest end (fig. 1). It appears that factors associated with topographical gradient greatly influenced success of seedling establishment from direct-seeded water and willow oak acorns.

Though edaphic and hydrologic factors drive productivity of bottomland hardwoods (Baker and Broadfoot 1979, Broadfoot 1976), we are aware of only one other study which has attempted to relate germination and establishment of direct-seeded bottomland oaks to edaphic or hydrologic factors in the field. Miwa and others (1993), who studied bottomland oak afforestation methods in the Mississippi Alluvial Valley, were unable to detect effects of three different soil series on first-year germination and growth of four bottomland oak species. This finding was consistent through 5 years after plantation establishment (Ozalp and others 1998). They attributed this lack of a soil series effect on oak germination and survival to the absence of seasonal flooding during the 5-year study period. Their field conditions were in sharp contrast to those on our study site, which received spring flooding each of the 2 sample years.

CONCLUSIONS

In an alluvial flood plain, establishment success and growth of five bottomland oak species varied by species. Of the species we examined, direct-seeded Nuttall oak showed superior establishment and growth. Overcup oak showed poor establishment success across the entire study area, but height and diameter growth of this species exceeded that of swamp laurel oak and water oak. Interestingly, for a given species, microsite factors associated to flood plain topography influenced topography. This finding is particularly noteworthy as there was only a 1-percent grade across the study area.

This research illustrates that microsite factors drive bottomland oak seedling establishment on alluvial flood plains, emphasizing important considerations for artificial regeneration of bottomland hardwood sites. First, accurate identification of site conditions prior to afforestation or reforestation is absolutely critical. Sensible species assignments for regeneration projects can be made only after identifying

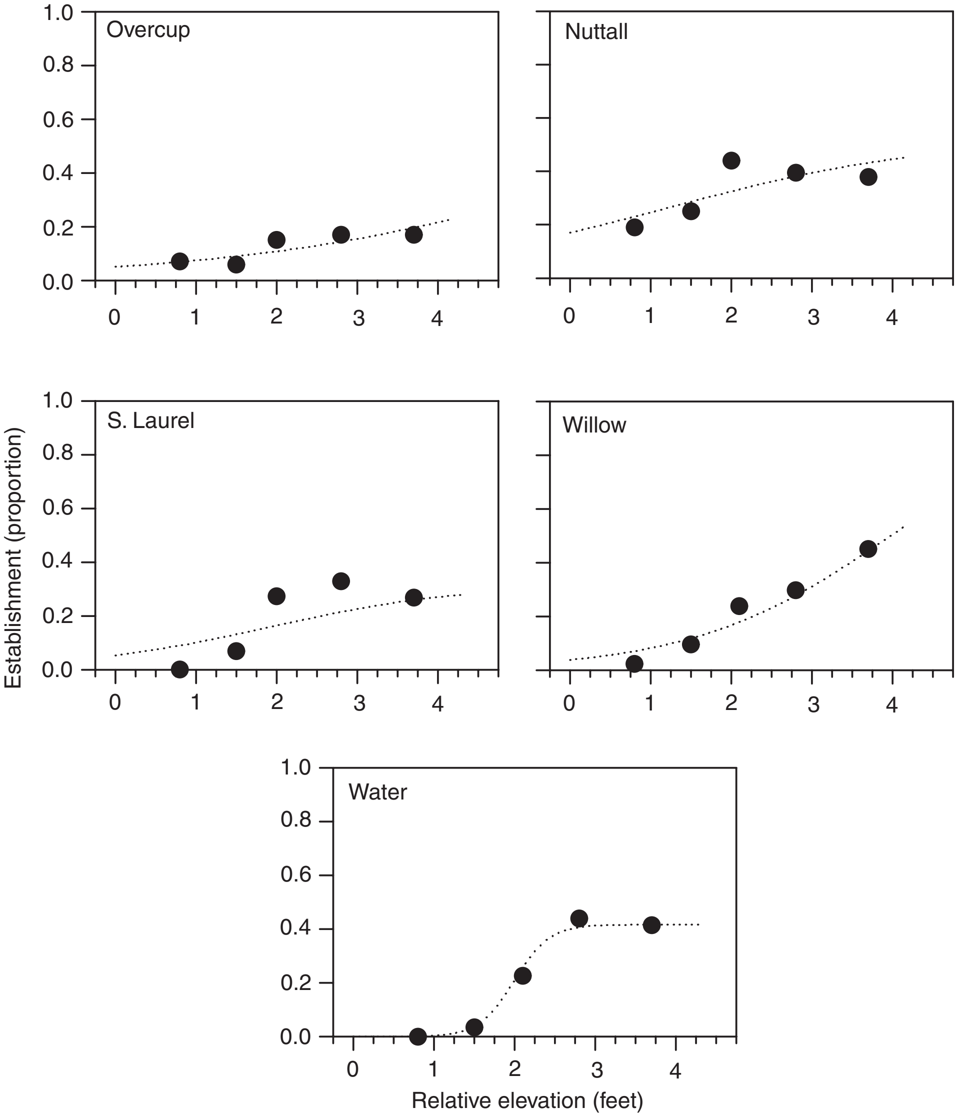

Figure 1—Establishment proportions as predicted with a logistic function 2 years after direct seeding along an elevational gradient on an alluvial flood plain near the confluence of the Alabama and Tombigbee Rivers, AL. Data points represent the mean establishment observed at elevational quintiles on the gradient. These points are projected for reference only and were not the data points used to model predicted establishment.

and delineating site conditions on the ground. Second, bottomland sites should be regenerated with species mixtures to improve establishment success. Even after identifying site conditions and assigning appropriate species, uncontrollable problems of plant phenology or weather may reduce establishment success of certain species. Next, species mixtures should be intergraded along margins of topographic features in alluvial flood plains. These features are often subtle, leading to a gradual shifting of site conditions and precluding assignment of absolute boundaries between site types. Finally, planting or sowing density should match site conditions that may potentially affect establishment. For example, oak establishment was difficult on the lowest portion of our study site, probably due to poor soil drainage or flooding intensity or duration. Anticipating such problems, the regeneration forester can modify sowing or planting rates accordingly.

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