New Forests **15:** 69–76, 1998.

Effects of flood duration and season on germination of black, cherrybark, northern red, and water oak acorns

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Accepted 15 March 1997

Key words: acorns, bottomlands, germination ecology, *Quercus*, species-site relationships

Application. Species-site relationships are critical in establishing oak reproduction, and the process begins with the environmental factors affecting acorns after their dispersal. Seasonal flooding, which is a common site feature in the southern U.S., may damage acorns from natural sources or direct seeding, and thus, may limit the successful establishment of some species on bottomland sites.

Abstract. Effects of flood duration (0, 10, 20, and 30 days) and season (winter and spring) on acorn germination were tested for two upland oaks [black and northern red oak (*Quercus velutina* Lam. and *Q. rubra* L.)] and two bottomland oaks [cherrybark and water oak (*Q. pagoda* Raf. and *Q. nigra* L.)]. Acorns were stratified for 30 days before flooding at a depth of 15 cm along the edge of a small pond. After flooding, acorns were sowed in sand-filled plastic cups and germinated for 40 days. Flood duration and season strongly affected radicle and epicotyl emergence of the upland oaks, but effects were generally limited to spring flooding. Embryo axes of the upland oak acorns were severely damaged with as little as 10 days of spring flooding. Almost no epicotyls developed, but radicles developed from the connective tissues between embryo axes and the cotyledons of many acorns. Spring flooding also significantly increased the percentage of decayed acorns for the upland oaks. In contrast, germination of the bottomland oaks was slightly improved by flooding during both seasons. Results demonstrated that the effects of flooding on the distribution of species within bottomlands can begin with seed storage and germination.

Introduction

In the southern United States, seasonal flooding frequently occurs in river bottoms and is a principal factor in determining tree species distribution (Hodges and Switzer 1979). Flooding may affect tree growth by displacing soil air and limiting root respiration along with other effects, and extended flooding can kill flood-intolerant trees (Kramer and Kozlowski 1979). Flood tolerance of the major bottomland hardwood species, including many of the oaks, has been summarized (Hook 1984; Allen and Kennedy 1989), but little is known about the flood tolerance of tree seeds. The response of plants and seeds to flooding may differ. Some plants can develop aerenchymatous tissue when flooded to facilitate transport of oxygen to the roots, but this is not possible for seeds (Norton 1986). For the oaks, germination probably occurs after flood water retreats, but acorns of some species may be damaged. There is some indication that acorns of the bottomland oaks are able to tolerate more flooding than upland species. For instance, 15 days of flooding severely reduced acorn germination of white oak (*Quercus alba* L.), an upland species (Bell 1975), but acorns of Nuttall oak (*Q. nuttallii* Palmer), a bottomland species, were not affected by 34 days of flooding (Briscoe 1961). To further understand the germination ecology of the oaks, we designed a study to test the effects of flood duration and season on acorn germination of four species common to the southern United States. Bottomland species were water oak (*Q. nigra* L.) and cherrybark oak (*Q. pagoda* Raf.), and upland species were black oak (*Q. velutina* Lam.) and northern red oak (*Q. rubra* L.).

Methods

During November and December 1994, acorns from an individual tree of black, cherrybark, and water oaks were collected in Fayette County, TN, and acorns of a northern red oak were collected in Conway County, AR. All trees were growing on terraces of minor streams. After conducting a float test, acorns were air dried for 12 hours and stored in polyethylene bags at 4 °C. Before the start of each flooding treatment, acorns were stratified in moist sand for 30 days at 4 °C to assure a uniform state of dormancy. Northern red oak acorns were not stratified for the spring flooding treatment because radicles had already emerged.

A silt loam soil (fine-silty, siliceous, thermic, Typic Ochraquults) was collected from a terrace site in Drew County, AR. The soil was air dried and hand-processed to pass a 5-mm sieve. Plastic cups (0.5 l) with drainage holes were filled with 0.4 l of soil. Ten stratified acorns were buried 2 cm below the soil surface of each cup, except for northern red oak where there were five acorns per cup and two cups per replicate. Acorns were buried in soil because small mammals commonly bury acorns and survival of acorns on the forest floor is generally low (Bowersox 1993). After sowing, the soil was saturated with distilled water.

A split-plot design was used for data analysis because the seasonal flooding treatment could not be randomized and repeated. There were four flood durations: 0 (control), 10, 20, and 30 days. Winter flooding was from January 17 to February 16, 1995, and spring flooding was from March 17 to April 16, 1995. Each treatment combination was replicated four times with 10 acorns per replicate.

Flooding treatments were applied by submerging cups 15 cm below the surface of a 0.2-ha pond located in Drew County, AR. Cups were randomly distributed in an area that was protected with a wire screen (1.2 cm mesh) to keep out seed-consuming animals. A maximum-minimum thermometer was submerged with the cups, and water temperature was recorded every 10 days. Flooding of replicates of the 10- and 20-day treatments was staggered in time so that environmental gradients occurring over the 30-day period could affect all treatment levels. Cups awaiting flooding and those with completed flooding treatments were free-drained and stored at 4 °C until day 30 when cups were collected. The same procedures were followed for winter and spring flooding treatments. Minimum temperatures during winter flooding were 4, 7, and 9 °C for each 10-day period, respectively, and 16, 12, and 14 °C during the spring flooding. Maximum temperatures during the winter flooding were 20, 24, and 24 °C and 27, 26, and 29 °C during the spring flooding. According to U.S. Department of Commerce (1995), air temperature averaged 5.9 and 16.5 °C over the winter and spring flooding periods, respectively; these means were 0.2 and 2.2 °C above the respective normal temperatures.

For germination tests, acorns were sown in 0.2-l cups filled with sand. Cups were irrigated with distilled water and placed in a germinator with six 30-W fluorescent lights and a 12/12 hour dark/light photoperiod. Temperature ranged from 20 °C during the dark period to 25 °C for the light period. Radicle and epicotyl emergence of each acorn was recorded weekly over a 6-week period when the respective length exceeded 2 cm. Radicles were visible because of the sloping sides of cups. At the termination of the germination test, the number of decayed and ungerminated acorns were recorded.

Data were analyzed by GLM of SAS (SAS Institute Inc., 1986). Normality and equal variance were not violated. Within each flooding season, means for a flood duration were compared using a t'-test ($p = 0.05$) by computing a t' value and standard error of difference (Steel and Torrie 1980).

Results

During the winter, flood duration did not affect radicle and epicotyl emergence of black oak but influenced those of northern red oak moderately. However, flood duration affected radicle and epicotyl emergence of the upland oaks dramatically in the spring (Figure 1). Spring flooding of 10 and 20 days reduced epicotyl emergence of the upland oaks to less than 10% as compared to a 95% emergence in the control, and 30-day flooding totally inhibited epicotyl emergence. Radicle emergence of the upland species was also reduced, although more than 80% for northern red oak and 60 and 40% for black oak developed in the 10- and 20-day treatments, respectively.

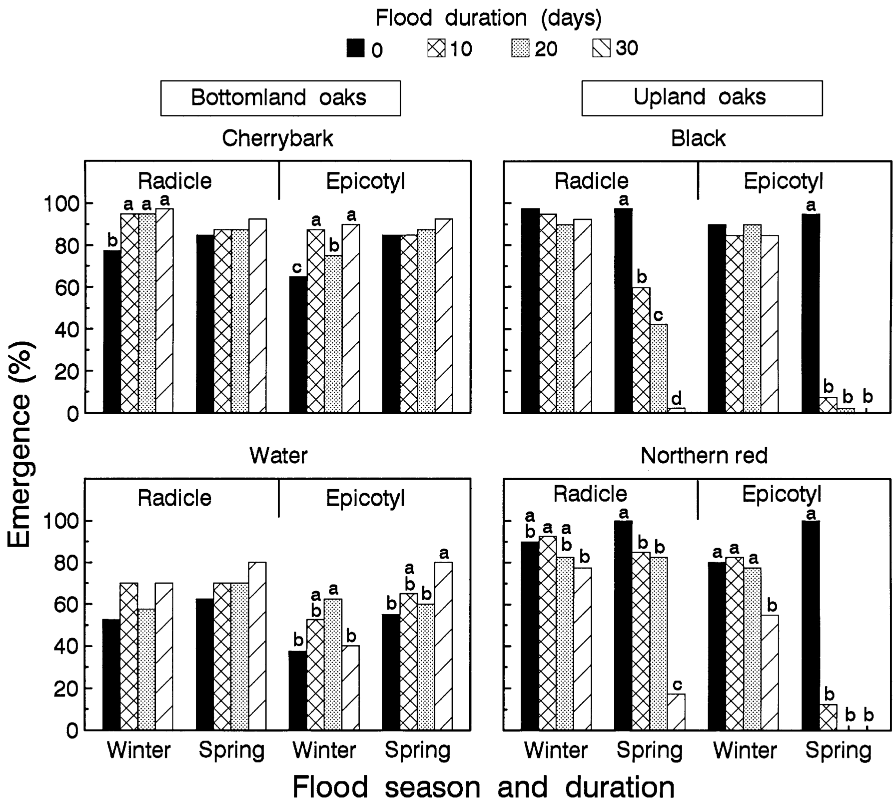

Figure 1. Effects of flood duration and season on radicle and epicotyl emergence of black, northern red, cherrybark, and water oak acorns. Bars of a cluster with different letters differ at p = 0.05.

Radicle emergence of cherrybark oak in the winter flooding was affected by flood duration but was not affected in the spring flooding. Winter flooding, regardless of duration, promoted emergence over the control. Spring flooding for water oak did not significantly affect radicle emergence. For spring flooding, epicotyl emergence of water oak was increased by 30-day flooding, while the epicotyl emergence of cherrybark oak was not affected. Although variable, winter flooding seemed to increase epicotyl emergence of cherrybark oak.

Percentage of decayed acorns for the upland oaks was strongly affected by flood duration and season, and significant interactions occurred between flood duration and season (Figure 2). The percentage of decayed acorns of cherrybark oak was influenced by flood season, but no significant differences occurred for water oak. In spring flooding, the percentage of decayed black oak acorns increased significantly as flood duration increased, while

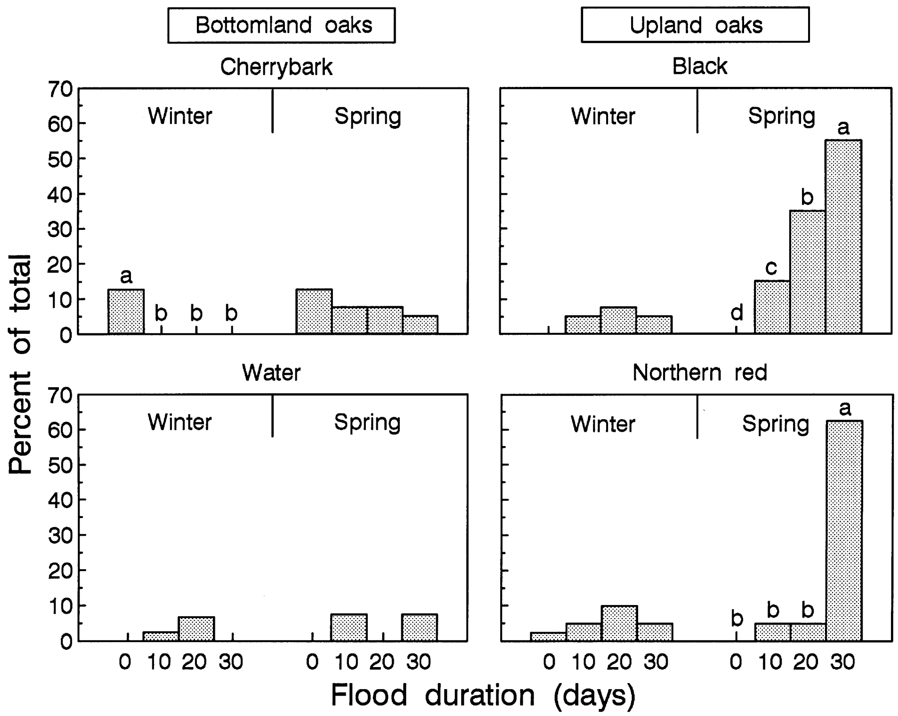

Figure 2. Effects of flood duration and season on the percentage of decayed acorns of black, northern red, cherrybark, and water oaks. Bars of a cluster with different letters differ at p = 0.05.

30 days of flooding substantially increased the percentage of decayed acorns for northern red oak. For the bottomland oaks, winter flooding did not result in decayed acorns for cherrybark oak, but 12.5% of the acorns were decayed for the control. In spring flooding, a similar percentage of decayed acorns occurred in the control, but some decayed acorns also occurred for the flooding treatments. However, these differences were not significant.

Discussion

Cherrybark and water oaks frequently occur on bottomland sites. Cherrybark oak is seldom abundant on wet or swampy soils, and it grows best on loamy sites on the first bottom ridges (Krinard 1990). Water oak, on the other hand, ranges from wet bottomlands to well-drained uplands, and the best development occurs on the better-drained silty clay or loamy soils (Vozzo 1990). Black and northern red oaks are both upland species. Black oak is widely distributed and grows best on silty clay to loam soils. Northern red oak grows best on soils similar to those best for black oak but on lower to middle slopes (Sander 1990).

The different responses of the tested species to flood duration and season suggest different adaptions to flooding. Although some treatment differences were statistically significant, neither winter nor spring flooding strongly affected germination of either of the bottomland oaks. In contrast, germination of the upland oak acorns was substantially reduced by spring flooding but was not strongly affected by winter flooding. Obviously, warm-temperature flooding (average maximum water temperature of 27 °C) severely damaged acorns after as little as 10 days of flooding. The damage of the upland oak acorns by the warm-temperature flooding may be due to increased anaerobic metabolism, which could damage seed through the buildup of toxic materials (Martin et al. 1991).

Few studies have evaluated the flood tolerance of tree seeds, including the oaks. Bell (1975) found that acorn germination of white oak was severely limited by 15 days of flooding, which was consistent with the results of this study for the associated upland species. Larsen (1963) tested the effects of water soaking for up to 8 weeks on acorn germination of four southern oaks [southern red oak (*Q. falcata* Michx.), willow oak (*Q. phellos* L.), laurel oak (*Q. laurifolia* Michx.), and overcup oak (*Q. lyrata* Walt.)], and found little difference in germination between upland and bottomland species. However, the highest temperature regime tested by Larsen was 12–18 °C, which was much lower than the average temperature range for the spring flooding in this study (14–27 °C). Obviously, there are sufficient differences in the tested temperature regimes and species to account for the different results from Larsen's and our study. Briscoe (1961) compared the tolerance of cherrybark and Nuttall oak acorns to spring flooding in Louisiana. Nuttall oak is a flood-tolerant species, while cherrybark oak is not. The germination of Nuttall oak acorns was not affected by 34 days of flooding. Germination of cherrybark oak acorns was not affected through 18 days of flooding but declined by one half from 18 to 34 days. Although Briscoe's results for cherrybark oak differ somewhat from those reported here, there were mitigating circumstances. The acorns in Briscoe's study were stratified for 4 months, and only 44% of the acorns of both species germinated in the unflooded controls. Bonner (1974) indicated that cherrybark oak acorns require only 30 to 60 days of stratification. Furthermore, Briscoe's reported water temperatures (averaging 4 °C) were considerably colder than those of this study. Obviously, the ability of acorns to withstand damage from flooding depends on many factors such as species, genetic variation, acorn properties (pretreatment, quality, and dormancy), and flood conditions (depth, duration, and water properties).

Examination of the flood-damaged acorns of the upland oaks showed that most of the embryo axes had decayed. However, radicles often developed from the connective tissue between the embryo axis and the cotyledons. Apparently, the embryo axis was the most sensitive tissue to flooding damage. Some cotyledons with 10- and 20-day flood treatments for both upland oaks appeared to be alive 40 days after initiation of germination, even though the embryo axes were apparently dead. In horticulture, tissue culture techniques frequently use cotyledons to produce plants, with most studies reporting successful shoot development from the cotyledon tissues under tissue cultural conditions (Dodds and Roberts 1995). In our study, radicles developed from flood-damaged acorns, but conditions were apparently unfavorable for shoot development.

Flood season and duration are critical factors that can affect the distribution of species on alluvial sites. This process begins with the storage and germination of seeds and continues through all stages of seedling establishment and subsequent development. Although limited in scale, results from our study indicate that some species may be excluded from alluvial sites because of flood damage to their seeds. Results suggest that cherrybark and water oak acorns can sustain shallow water flooding during the spring for periods of at least a month. In contrast, black and northern red oak acorns were severely damaged by as little as 10 days of spring flooding. Although the genetic material tested in this study represented a limited range of intraspecific variation, the half-sib acorns from the two upland oaks behaved in a similar manner as did those from the two bottomland oaks. However, further testing is needed to confirm the full extent of intraspecific variation for the species tested here in addition to other species.

Acknowledgment

The authors thank Drs. F.T. Bonner, J.D. Hodges, J.B. Murphy, J.A. Vozzo, and the anonymous reviewers for their helpful comments. Publication of this manuscript was approved by the Director, Arkansas Agricultural Experiment Station, manuscript #95144.

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