PRODUCTION OF WILLOW OAK ACORNS IN AN ARKANSAS GREENTREE RESERVOIR: AN EVALUATION OF REGENERATION AND WATERFOWL FORAGE POTENTIAL

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Abstract—Greentree reservoirs (GTRs) provide critical habitat for a broad suite of species. Unfortunately, many GTRs are mismanaged, leading to undesirable successional changes and possible habitat degradation. This study evaluates willow oak acorn production in terms of the potential for natural regeneration and waterfowl forage. During the fall and winter of 2004 and 2005, acorns were collected biweekly from 40 overstory willow oaks distributed throughout the study site. Once collected, acorns were subjected to a float test and counted. During both years of the study, production of sound acorns was well above the generally accepted giving-up density of 50 kg/ha of forage for waterfowl. Further, comparing germination rates observed at the study site to those predicted in the literature indicates that willow oak acorns are germinating at a higher rate than expected. This study further emphasizes the importance of gaining a better understanding of artificially flooded hardwood systems.

INTRODUCTION

The practice of managing bottomland hardwood stands as greentree reservoirs (GTRs) began in the late 1930s in the area around Stuttgart, AR (Rudolph and Hunter 1964). The primary objective of GTR management is to replace the natural flooding regime of a bottomland hardwood stand with a more reliable flooding regime in order to consistently provide habitat for migrating waterfowl and subsequently provide waterfowl hunting opportunities (Fredrickson 2005, Fredrickson and Batema 1992, Hertlein and Gates 2005, King and Allen 1996). Following the initiation of the practice in AR, GTR management spread throughout numerous states in the Southeastern and Northeastern United States with most states within the Mississippi Alluvial Valley having GTRs by 1963 (Fredrickson and Batema 1992). The basis for this popularity was likely the perception that GTR management benefited waterfowl and waterfowl hunters without any adverse effects on the timber (Fredrickson and Batema 1992, Rudolph and Hunter 1964). Some early studies found beneficial effects related to annual flooding and GTR management (Merz and Brakhage 1964, Broadfoot and Williston 1973). However, more recent studies have documented numerous detrimental effects attributable to GTR management (Hertlein and Gates 2005, King 1995, Malecki and others 1983, Schlaegel 1984, Wigley and Filer 1989).

In their survey of GTR managers, Wigley and Filer (1989) found that 95 percent of GTRs, both publicly and privately owned, were flooded every year. From their survey, the authors were able to identify several common problems associated with GTR management. These problems included low regeneration of seedlings and saplings of desirable species, increased overstory tree mortality, wind-throw, crown dieback, basal swelling, scarring by beaver, and excessive sedimentation. Problems occurred most often in GTRs with dominant timber at least 60 years old.

According to Fredrickson and Batema (1992), waterfowl readily consume fully developed acorns with little insect damage; however, waterfowl rarely consume damaged, deformed, or aborted acorns. McQuilkin and Musbach (1977) found no difference in the production of sound pin oak (*Quercus palustris*) acorns in GTRs compared to nonflooded areas. They did, however, find fewer acorns were damaged by insects in GTRs. Reduced acorn damage in GTRs is attributed to the fact that nut weevils (*Curculio* spp.) overwinter in the soil (Brezner 1960) and are thereby killed by long-term dormant season flooding. Karr and others (1990) found a slight increase in cherrybark oak (*Quercus pagoda*) acorn production in GTRs. Similar to the results of McQuilkin and Musbach (1977), Karr and others (1990) found decreased acorn damage by weevils in GTRs.

Merz and Brakhage (1964) found total pin oak acorn production did not differ between naturally and artificially flooded areas. However, they did find trees in the flooded area produced more sound acorns than did trees in unflooded plots. Despite more sound acorns having been produced in flooded areas, Merz and Brakhage (1964) found that in flooded areas, only 1 seedling became established for every 2,100 acorns, compared to 1 established seedling for every 26 acorns in unflooded areas. The authors state that increased consumption by waterfowl largely accounted for the difference in seedling establishment. In contrast to other studies, Francis (1983) found Nuttall oak (*Quercus nuttallii*) in unflooded areas produced approximately twice as many acorns as Nuttall oaks in a GTR.

In general, acorn production for most oak species is highly variable within and among years and species (Dey 1995, Greenberg 2000, Koenig and others 1994). Numerous studies have investigated the role of biotic and abiotic factors on acorn production (Cecich and Sullivan 1999, Francis 1983, Goodrum and others 1971, Greenberg 2000, Perry and others 2004, Stelzer and others 2004); however, the

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full range of mechanisms influencing acorn production are still not fully understood. Perry and others (2004) found a significant linear relationship between mast production and basal area for two white oak (Leucobalanus) species. However, the authors found no linear relationship existed between acorn production and basal area for red oak (Erythrobalanus) species in the Ouachita Mountains, AR. Francis (1983) found thinning did not affect acorn production, but flooding and tree size did. On average, trees in flooded areas produced fewer acorns than trees on nonflooded areas, and larger trees typically produced more acorns than smaller trees. Cecich and Sullivan (1999) found relative humidity contributed significantly to the variation in white oak (*Quercus alba*) acorn production but not to black oak (*Quercus velutina*). Rain positively affected black oak flower survival but had no effect on white oak. Fog had a positive effect on flower survival for both species.

The production of acorns varies greatly by species (Dey 1995). Species such as sessile oak (*Quercus petraea*) may not begin to produce acorns until trees are 40 years old; whereas, Nuttall oak and sawtooth oak (*Quercus acutissima*) may produce an acorn crop as early as age five. Further, numerous species of oak can be expected to produce acorn crops on a 1 to 2 year interval, while other species may have intervals of up to 5 to 7 years or even 4 to 10 years (Young and Young 1992). According to Young and Young (1992), willow oaks (*Quercus phellos* L.) may produce their first acorn crop around age 20, and on average, produce on a 1-year interval. Several studies have found the average weight of a fresh willow oak acorn to be approximately 1 gram (Goodrum and others 1971, Young and Young 1992).

McQuilkin and Musbach (1977) found the number of underdeveloped acorns and insect-infected acorns varied little between years for pin oaks growing in a GTR. Further, the authors estimated that waterfowl only consume sound, fully developed acorns in significant numbers. It is estimated that a minimum of 50 kg/ha of acorns is required for waterfowl to forage efficiently (pers. comm., R.M. Kaminski, Mississippi State University, Department of Wildlife and Fisheries). Below this threshold, the energetic expenses related with foraging outweigh the benefits and waterfowl will cease to forage on an area. Many acorns never become available for waterfowl forage or natural regeneration due to being consumed prior to falling. Cypert and Webster (1948) estimated that canopy-dwelling birds consumed approximately 13 percent of the acorns from willow oak and water oak (*Quercus nigra* L.) trees. Similarly, Korschgen (1954) estimated arboreal feeders consumed 14 percent of mature acorns.

STUDY AREA

This study was conducted in a 291-ha GTR located in Arkansas County, AR, approximately 8 km south of Stuttgart, AR. The dominant soil on the area is Perry clay (approximately 83 percent of the area). Other soils found on the area are Dewitt silt loam (13.2 percent) and Stuttgart silt loam (3.7 percent). Soil pH ranged from 5.3 for the Dewitt silt loam to 5.8 for the Perry clay (NRCS web soil survey, http://websoilsurvey.nrcs.usda.gov/app/).

The management practices applied to the GTR currently, and historically, were to flood the entire area annually. The primary objective of managing this GTR was to provide opportunities to hunt migrating waterfowl. The average flooding depth across the area was 34.6 cm. Flooding was typically initiated in mid-October to ensure that there was an adequate amount of aboveground water in the GTR by the time migrating waterfowl began moving through the area. The actual initiation date varied considerably from year to year due to climatic conditions. In the fall of 2004, flooding was initiated between September 20 and November 20 for the various compartments within the stand. Similarly, flooding initiation occurred between September 20 and December 9 for the fall of 2005.

METHODS

Field Methods

In September 2004, 40 acorn traps were established throughout the GTR. Acorn collection traps consisted of four 1.52 m pieces of metal conduit for legs, a square frame (area = 1 m^2) constructed from treated lumber, a catchment area made of plastic netting, and a plastic collection bottle. Trap locations were selected using sample points from an earlier vegetation analysis study (Guttery and Ezell 2005). Points were selected such that the entire GTR was sampled relatively evenly. At each point, an acorn trap was erected under the overstory willow oak nearest to plot center. Traps were placed in a random direction halfway between the bole and the edge of the canopy of selected trees. At each selected tree, the diameter at breast height (d.b.h.) and the crown radius in each cardinal direction was recorded. Once traps were established, acorns were collected approximately every 14 days during the time acorns were falling for 2004 and 2005. In 2004, acorns were collected six times between October 2 and December 11. In 2005, acorns were collected seven times between October 1, 2005 and January 14, 2006. For the 2005 collection, acorns were only collected from 38 of the original 40 traps because one sample tree died and one trap suffered irreparable damage. Collected acorns were subjected to a float test to determine the number of sound and “bad” acorns per trap. “Bad” acorns were the result of insect infestation, being aborted by the tree, and damage by arboreal feeders.

Analyses

Prior to analysis, sample trees were grouped into 5-cm diameter classes. Sample trees ranged in d.b.h. from 35 to 85 cm, with the majority of stems falling between 45 and 65 cm. Then, using vegetation inventory data (Guttery and Ezell 2005), the average number of overstory willow oak trees/ha was calculated, as divided into 5-cm diameter classes. Willow oak diameters across the entire GTR ranged from 20 to 110 cm, with the majority (>75 percent) of stems ranging from 40 to 65 cm.

Using the average crown radius, the 2-dimensional area of each sample tree’s crown was estimated. Since each acorn trap was of a known area (1 m^2), it was possible to calculate a blow-up factor to extrapolate acorn production across the entire crown of each sample tree. In doing this, it is assumed that the area sampled was representative of the entire crown. Production of sound, bad, and total acorns for each tree was then calculated across both collection years. Finally, the average production of sound, bad, and total acorns for each diameter class was calculated. Using a random sample of sound acorns (n=585 acorns) collected during the 2005 collection period, the average weight of a single willow oak acorn was determined. This weight was used to calculate the number of sound acorns required to weigh 1 kg. This allowed for the average weight of sound acorns within each diameter class to be calculated. Finally, using trees/ha (Guttery and Ezell, 2005), the total production of sound, bad, and total acorns was estimated by diameter class across the entire GTR. In order to investigate the variability of acorn production, the average acorn production per tree as well as measures of variability were calculated (PROC MEANS, SAS Institute 2004). In performing all these calculations, it is assumed that the trees sampled were representative of overstory willow oak trees across the entire GTR.

RESULTS

Acorn production for both 2004 and 2005 varied considerably both for total production and among diameter classes. Results of the average total acorn production by diameter class are found in table 1. For both 2004 and 2005, the 35 and 85 cm diameter classes produced, on average, the fewest total acorns per ha. Low acorn production in these diameter classes could be a function of these diameter classes having the fewest number of trees/ha, low acorn production per tree, or both. In 2004, trees between 55 and 65 cm produced 60 percent of the acorns based on diameter classes sampled. In 2005, these three diameter classes produced only 45 percent of the total acorns based on diameter classes sampled. For both years, the 75 cm diameter class produced a considerable number of acorns (90,615 and 54,596, respectively), while both the 70 and 85 cm diameter classes produced far fewer in both years. For both total production and for 7 of the 10 diameter classes, total acorn production was greater in 2004 than in 2005.

Similar to total acorn production, the production of sound acorns varied greatly between years and diameter classes (table 2). With an average of 301,667 sound acorns per hectare for the 10 diameter classes sampled, production for 2004 was considerably better than 2005 (159,304 sound acorns per hectare). The diameter classes of 55 cm through 65 cm produced 58 percent of the sound acorns in 2004 and 61 percent of the sound acorns in 2005. For both years, sound acorn production was found to be least for the 35 and 85 cm diameter classes. This finding is not surprising since these diameter classes had the lowest total acorn production. As with the total acorn production, sound acorn production within the 75 cm diameter class was unusually high compared to adjacent diameter classes for both years. Data in table 2 also show the average weight (kg/ha) of sound acorns by diameter class. For both years, total average production far exceeded the minimum of 50 kg/ha needed to support waterfowl.

The production of bad acorns exhibited some of the same patterns as the total and sound acorn production (table 3). For bad acorns, average acorn production was lowest for the smallest and largest trees for both years (similar to total acorn production and sound acorn production). Also, the 75 cm diameter class produced considerably more bad acorns than adjacent diameter classes in both years. Data from 2004 sampling show 62 percent of the bad acorns were produced by trees in the 55 through 65 cm diameter classes. However, in 2005 these diameter classes only produced 32 percent

Table 1—Average total acorn production by diameter class, 2004 and 2005.

Year	Diameter (cm)	Trees Sampled	Trees/ha	Total Acorns / ha	Standard Error
2004					
	35	1	2.7	113	_
	40	2	5.2	10223	1462
	45	8	6.3	36974	2244
	50	5	6.4	32943	1235
	55	5	5.8	63973	4018
	60	6	4.5	135537	13362
	65	9	3.7	62398	6827
	70	2	1.8	6951	983
	75	1	1.5	90615	_
	85	1	0.4	1769	_
	Overall	40	41.4	555671	3088
2005					
	35	1	2.7	113	_
	40	2	5.2	58573	11119
	45	7	6.3	43779	3474
	50	5	6.4	25325	520
	55	5	5.8	59015	2369
	60	6	4.5	54054	5084
	65	8	3.7	51030	3263
	70	2	1.8	15487	2297
	75	1	1.5	54596	_
	85	1	0.4	1327	_

Table 2—Average total sound acorn production by diameter class, 2004 and 2005

Year	Diameter (cm)	Trees Sampled	Trees/ha	Sound Acorns / ha	Standard Error	Percent of Total	Mass (kg/ha)
2004							
	35	1	2.7	113	_	100	0.1018
	40	2	5.2	1513	199	14.8	1.3631
	45	8	6.3	27522	1967	74.4	24.795
	50	5	6.4	19826	785	60.2	17.861
	55	5	5.8	50568	3348	79.0	45.557
	60	6	4.5	93846	11599	69.2	84.546
	65	9	3.7	31290	2489	50.1	28.189
	70	2	1.8	5963	434	85.8	5.3721
	75	1	1.5	70142	_	77.4	63.191
	85	1	0.4	884	_	50.0	0.7964
	Overall	40	41.4	363794	2250	65.5	327.74
2005							
	35	1	2.7	0	_	0.0	0
	40	2	5.2	7597	1232	13.0	6.8441
	45	7	6.3	8538	541	19.5	7.6919
	50	5	6.4	11223	668	44.3	10.111
	55	5	5.8	33917	1500	57.5	30.556
	60	6	4.5	28824	3258	53.3	25.968
	65	8	3.7	33929	2659	66.5	30.567
	70	2	1.8	7219	926	46.6	6.5036
	75	1	1.5	27299	_	50.0	24.594
	85	1	0.4	758	_	57.1	0.6829
	Overall	38	41.4	207352	971	49.6	186.8

of the bad acorns. Trees in the 40 through 50 cm diameter classes produced 50 percent of the bad acorns produced by trees in the diameter classes sampled for 2005.

DISCUSSION

Auchmoody and others (1993) classified northern red oak (*Quercus rubra*) acorn crops of between 309,000 and 618,000 acorns/ha to be "good" crops. Using this criterion, willow oaks in this GTR experienced "good" crops during both years of this study (table 1). However, the ecology and biology of northern red oak and willow oak differ considerably, and therefore these numbers may not be equally meaningful for willow oak acorn production. Overall average acorn production during this study was 486,885 acorns/ha. This finding is considerably higher than the 12 year average production of 356,700 pin oak acorns per hectare reported by McQuilkin and Musbach (1977).

These results show considerable variation in total acorn production, as well as production by diameter class and for individual trees, both within and between years. Numerous studies have documented the variation in acorn production (Beck 1977, Downs and McQuilkin 1944, Koenig and others 1994, Sork and others 1993). Young and Young (1992) state that willow oaks typically produce an acorn crop every year. Although this study only presents two years of data, the findings indicate that willow oak in this GTR may be consistently producing acorn crops. The fact that 33 of the 38 trees sampled in both years exhibited greater than a 20 percent difference in total acorns produced between the two years indicates that, for the most part, acorn production per tree varies considerably. However, the fact that total acorn production per hectare was high for both years indicates that while individual trees may not produce consistently, the willow oak population does seem to produce well each year. Again, these statements are based on two years data so long-term trends can only be speculated.

Overall, the production of sound acorns per tree in both 2004 and 2005 was less variable than was total acorn production per hectare. However, 32 sample trees had sound acorn production that varied by greater than 20 percent, compared to 33 trees for total acorn production. Table 2 shows that overall production of sound acorns per tree varied less in 2005 (SE=971) than in 2004 (SE=2 250). Although production was highly variable between years and among diameter classes, no obvious patterns in variability were observed, indicating that either no relationship exists between diameter and acorn production or more years of monitoring are needed to assess the relationship.

Approximately 35 percent of the acorns produced in 2004 were bad, compared to approximately 50 percent in 2005. Although there appears to be a considerable difference in the production of total bad acorns between 2004 and 2005, the difference was actually less than 20 000 acorns (table 3). For both years of the study, the overall variability in bad acorn production was considerably lower than the variability of total acorn production and equal to or less than the variability in sound acorn production. This seems to indicate that the overall production of bad acorns was relatively constant. Similarly, McQuilkin and Musbach (1977) report a smaller range in the number of underdeveloped/aborted acorns and insect infested acorns than for total acorn production. These authors concluded that regardless of crop size, a similar number of underdeveloped/aborted and insect infested acorns are produced each year.

Table 3—Average total bad acorn production by diameter class, 2004 and 2005

Year	Diameter (cm)	Trees Sampled	Trees/ha	Bad Acorns / ha	Standard Error	Percent of Total
2004						
	35	1	2.7	0	_	0.0
	40	2	5.2	8710	1263	85.2
	45	8	6.3	9452	659	25.6
	50	5	6.4	13116	584	39.8
	55	5	5.8	13405	680	21.0
	60	6	4.5	41691	4063	30.8
	65	9	3.7	31108	5253	49.9
	70	2	1.8	987	549	14.2
	75	1	1.5	20474	_	22.6
	85	1	0.4	884	_	50.0
	Overall	40	41.4	191856	1405	34.5
2005						
	35	1	2.7	113	_	100
	40	2	5.2	56173	9887	87.0
	45	7	6.3	35242	3034	80.5
	50	5	6.4	14103	235	55.7
	55	5	5.8	25099	914	42.5
	60	6	4.5	25228	2341	46.7
	65	8	3.7	17101	984	33.5
	70	2	1.8	8267	3222	53.4
	75	1	1.5	27299	_	50.0
	85	1	0.4	569	_	42.9
	Overall	38	41.4	210188	917	50.4

In 2004, approximately 65.5 percent of the estimated total acorns per hectare were sound. This percentage equates to an estimated 328 kg/ha of sound acorns (table 2). Production of sound acorns in 2005 declined considerably to only 50 percent of the total production and an average of 207,352 sound acorns per hectare (187 kg/ha). Per hectare levels of production far exceed the minimum requirement of 50 kg/ha necessary to sustain waterfowl on an area. Given the average weight of a single willow oak acorn for this GTR, if it is assumed that waterfowl do reduce acorn abundance to 50 kg/ha then there should be approximately 55,000 sound acorns remaining that could potentially germinate. Applying the germination rate for acorns in artificially flooded areas reported by Merz and Brakhage (1964), an average of 26 established willow oak seedlings/ha would be expected. Guttery and Ezell (2005) found an average of 210 willow oak seedlings/ha that were less that 0.3 m tall in this GTR (one seedling for every 264 sound acorns), indicating that either waterfowl are not consuming large quantities of willow oak acorns or germination rates are unusually high.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study are similar to the findings of several other studies. Overall, acorn production could be considered "good" in both 2004 and 2005. It should be noted that the numbers reported here are likely to be below actual production levels, since calculations did not include a correction for acorns which may have been consumed by birds and rodents while in the trap or on the tree. The production of sound acorns appears to be sufficient to support waterfowl while still allowing for some willow oak regeneration. Acorn production was good despite the artificial flooding regime imposed upon this site, and damage to acorns by insects was likely reduced due to flooding. Although flooding does not appear to be negatively impacting acorn production, it is likely having a substantial affect on willow oak regeneration. King (1994) found that acorns submerged in water for 90 days exhibited significantly lower rates of germination compared to nonflooded acorns. This, along with seedlings often being flooded prior to dormancy, is likely limiting willow oak regeneration on this site. Therefore, an altered flooding regime could be beneficial in efforts to regenerate this GTR naturally. Since red oak acorns take two years to mature, good acorn crops can be anticipated as much as a year in advance through visual surveys (Gysel 1956). By flooding the GTR during the year preceding an anticipated good acorn crop, nut weevil populations can be greatly reduced, therefore limiting the amount of damage to sound acorns by weevils. Allowing the GTR, or areas in the GTR, to remain unflooded, or flooded only briefly during the dormant season, for two or more years thereafter it is likely that ample willow oak regeneration will be able to establish and grow to heights greater than mean flooding depth. Finally, controlling undesirable midstory species may create light conditions more conducive to oak regeneration (Guttery 2006).

The desire to regenerate oaks in artificially flooded areas while also managing for waterfowl gives rise to new questions and concerns for managers and researchers. First, studies have not conclusively shown that waterfowl select particular GTRs based on the availability of acorn forage. It is possible that the primary role of GTRs for waterfowl is to provide cover rather than to provide food (forage versus cover hypothesis). Second, many waterfowl species seem to prefer open park-like stands. Dense regeneration could make stands less desirable to waterfowl; however, studies have not been conducted to determine if this truly is the case. Therefore, until these questions can be resolved the issue of managing GTRs may be even more complex than previously thought. If acorn production is a major factor influencing waterfowl use of GTRs then it is necessary to ensure that mast producing trees continue to exist in these areas. However, management activities aimed at promoting oak regeneration may result in stands being less desirable for waterfowl. If in fact forage availability is of lesser importance than cover, then species composition may not matter for waterfowl, but decreased biodiversity resulting from a shift in composition to all highly flood tolerant tree species will likely be detrimental to many other faunal species.

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