THE GREENTREE RESERVOIR MANAGEMENT DILEMMA: A LITERATURE REVIEW

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Introduction

Greentree reservoir (GTR) management is a strategy that typically consists of impounding a bottomland hardwood stand with levees and seasonally flooding the living hardwood trees within to provide waterfowl habitat (Wigley and Filer 1989) and to enhance timber production (Newling 1981). Landowners near Stuttgart, Arkansas, initiated the practice during the 1930's solely for the purpose of enhancing waterfowl hunting opportunities on their property (Hunter 1978).

An estimated 80% of Mississippi Alluvial Valley forested wetland acreage has been lost to agriculture and human development (Baldassare and Bolen 1994); hence, GTR's play an increasingly priceless role in migrating and wintering habitat for waterfowl, particularly mallards (Anas platyrhynchos) and wood ducks (Aix sponsa). Waterfowl obtain carbohydrate- and protein-rich forage from these habitats (Heitmeyer 1985, Wehrle et al. 1995). Forested wetland structure also affords waterfowl sites for cover, refuge, and behavioral activities (Heitmeyer 1985).

Most GTR's are flooded only during the fall and winter dormant season and increased woody stem growth has been demonstrated. Recent studies of GTR's have shown, however, that consistent flooding during the dormant season for many years may decrease mast production, and adversely affect growth rates, vigor, and regeneration of timber. There is convincing evidence that current GTR management practices promote a shift in vegetation towards more water-tolerant species (Newling 1981, Young et al. 1995) and increase problems with water stress in red oaks (King 1995, Young et al. 1995) and therein lies the GTR management dilemma: both a diminishing waterfowl habitat quality and decreasing productivity of commercially-valuable hardwood timber may be an end result of well-intended management efforts.

Discussion

Wigley and Filer (1989) conducted a survey of GTR managers and found that GTR management is confined primarily to the southeastern United States. Most GTR's are <254 acres, <25 years old, and located on clay or silt loam soil. GTR timber stands are characterized as uneven-aged and dominated by oak or oak associations, but timber harvesting is uncommon - timber has been thinned or harvested in only 21% of GTR's. Herbicides, utilized for tree injection or vegetation removal around levees, has been used in 5% of GTR's. Flooding typically occurs between October through mid-March on an annual basis, the water source most often being a river diversion or runoff from agricultural irrigation. A particularly noteworthy characteristic is that oftentimes GTR managers are unable to adhere to this schedule due to the confounding ingenuity of beavers (<u>Castor canadensis</u>) and to natural flooding.

Broadfoot (1967) addressed the effects of GTR management on tree growth and reported that, following an annual February-July inundation of two shallow-water impoundment areas for 4 consecutive years each, there were no adverse affects to tree growth or vigor. It was reported that impounded water actually increased radial growth of pole- and sawtimber-sized trees by increasing soil moisture. Oaks had the best growth of all species without impounded water, but exhibited significant radial growth following inundation. New regeneration, such as Nuttall oak (*Quercus nuttallii*), always appeared within ten days immediately following the release of water from the impounded area. Furthermore, established seedlings that had recently been submerged grew as much as 15 cm.

Short-term studies on a particular greentree reservoir in Missouri indicated improved acorn production (Minkler and McDermott 1960, Minkler and Janes 1965). There is a plethora of documented research, however, which supports the assertion that GTR management is not a universally beneficial management strategy.

The most common problems reported by GTR managers to Wigley and Filer (1989) were poor regeneration of timber and loss of trees through mortality. Reports of problems were most common in GTR's >20 years old, in GTR's with timber >60 years old, and in GTR's where draining was delayed in >2 of 10 consecutive years. Managers generally perceived that acorn production and growth were similar in GTR's and naturally flooded stands.

Perceived shifts in composition towards more flood-tolerant species such as overcup oak (Q. lyrata) have spawned the concern of wildlife and forest managers. Overcup oaks produce large acorns that are rarely consumed by waterfowl. Other oak species commonly found in GTR's, such as cherrybark oak (Q. pagoda), produce acorns which are highly favored by waterfowl, as well as lumber which is more valuable than overcup oak.

Young and others (1995) evaluated the effect of GTR management on overstory, sapling and seedling composition and density in a minor stream bottom in Mississippi. Changes in seedling composition were reported to have occurred in two GTR's subjected to 2-year winter flooding regimes and natural flooding during the spring and summer months. While the relative contribution of overcup oak, red maple (Acre rubrum), and American hornbeam (Carpinus caroliniana) was similar between years, the presence of other flood-tolerant species (ie., water elm [Planera aquatica] and common buttonbush [Cephalanthus occidentalis]) increased.

The control site, which was subjected only to natural overflows of the Noxubee River, exhibited a shift in species composition as well, but species were less flood-tolerant. Mean number of saplings/ha was 2 to 3 times greater in the control area than in the GTR's, and overcup oak accounted for between 54% and 71% of seedlings in the GTR's; for only 4% to 5% in the control site. It was noted, however, that overcup oak was confined to approximately 25% of the land area; to poorly-drained sites on which overcup oak would normally occur.

It was concluded that winter flooding of GTR's, in conjunction with the random impoundment of overflows during the spring and summer growing season was responsible for both the shift in seedling species composition and increased sapling mortality, particularly in lower elevations. Topographic areas not normally flooded extensively and lower elevations, which were flooded longer and had saturated soil conditions, were most heavily effected by GTR management.

The effects of alternative flooding regimes on desirable oak seedling survival within the same GTR's was investigated several years later. The flooding regimes compared were periodic flooding (ie., subjected to overflow from the Noxubee River which occurrs 4 times/year and floods the GTR for ≤1 week) and continuous (ie, flooded when inundated during bank overflow in addition to winter flooding from late-November to mid-March). Survival, height, and density of cherrybark oak, willow oak (Q. phellos), and overcup oak seedlings were measured in each of the two GTR's.

Survival of cherrybark oak and willow oak seedlings was greater in the periodically flooded GTR after one winter. After 2 consecutive winters of flooding, seedling survival and densities were greater for all oak species in periodically flooded areas. Despite lower survival, however, mean seedling height of all species was greater in the continuously flooded GTR. These data could debatably imply that continuous flooding of GTR's reduces seedling survival and density but may actually increase seedling height (M. J. Gray and R. M. Kaminski, unpubl. paper).

King (1995) analyzed regeneration patterns, stand structure, and overstory stress and mortality within 2 overcup - willow oak stands in Texas. An impoundment with levees and an impoundment without levees were chosen based upon their similar composition and potentially different flooding patterns. Both impoundments were managed as GTR's and annually flooded artificially and/ or naturally from November to February. While the study did not effectively provide quantitative contrasts between overcup oak and willow oak regeneration, it did provide some valuable information on the dynamics of overcup oak in GTR environments.

Record rainfall resulted in growing-season flooding in both impoundments, but the levee system and the topographic relief of the impoundment with levees impeded drainage of surface water and prolonged growing-season flooding. Overcup oak was the most abundant seedling in both impoundments. Limited regeneration of all other species except overcup was observed in both impoundments.

Strong statistical relationships between flooding regimes in the impoundment with levees and (1) the density of overcup oak seedlings at the time of peak establishment, (2) overcup seedling mortality, and (3) stress levels of willow oak trees, indicate that modification of drainage patterns, intentional flooding, and extreme flood years can have substantial impacts on bottomland hardwood communities in a relatively short period of time.

An ecological investigation of a GTR in the Delta National Forest, Mississippi, indicates that long-term GTR management promotes a shift to a wetter forest community. The extreme conditions created by 18 years of GTR management were evident in decreased stem densities of seedlings and sprouts, reduced species diversity, and significantly higher stem densities of water hickory (Carya aquatica), overcup oak, and buttonbush in the GTR than in a referenced hardwood bottomland subjected only to infrequent, natural inundations (Newling 1981).

These documented compositional shifts in GTR's pivot around species-site-hydroperiod relationships. This is consistent with the silvicultural understanding of the interaction between floodwater and topographic position and its ultimate influence on species composition.

Cherrybark oak is a relatively flood intolerant species which naturally occurs on relatively well-drained soils or ridges that only periodically flood (Pezeshki and Chambers 1985) and may be subject to induced mortality with inundation or saturated soil conditions which last for 5 and 15 days, respectively (Hosner 1960, Hosner and Boyce 1962). Hosner and Boyce (1962) reported no mortality of willow oak seedlings exposed to saturated soil conditions for 60 days. Willow oak typically occurs on low flats, is considered moderately tolerant of flooding and flooded trees have exhibited increased radial growth (Broadfoot 1967). Overcup oak seedlings are likely more flood-tolerant than either cherrybark oak or willow oak due to such physiological adaptations as hypertrophied lenticels (Kozlowski 1984, King 1985) and commonly occurs on poorly drained sites.

Flood-tolerance reflects particular physiological adaptations to anaerobic conditions (Kozlowski 1984, Pezeshki and Chambers 1985). The timing, depth, and duration of flooding are the major factors affecting species composition and are manifest in the topographical distribution of species throughout a floodplain (Wharton et al. 1982).

Figuratively speaking, the documented shifts in species composition are indicative of a downward lateral movement along relief gradients in response, not to the winter flooding regimes of GTR management alone, but GTR management in conjunction with the natural overflows which are an inherent quality of the hardwood bottomlands in which GTR's are located. Inherent properties of GTR's - levee systems and low topographic relief - impede drainage of surface water and prolong growing season flooding. Current GTR management practices seemingly equate to the creation and management of ephemeral pools!

Suffice it is to say that excessive soil moisture and growing-season flooding are apparently the decisive factor in decreased production of red oaks in GTR's. But what about light? As mentioned earlier, only about one-quarter of all GTR's are subject to harvesting practices and chemical injection of mid-story occurs in only 5% or less.

Initial survival and early growth of oak seedlings beneath a dense canopy are primarily dependent on stored food reserves in acorns. Seedlings must survive on photosynthate produced by new leaves following the depletion of cotyledon reserves. Light then becomes a limiting factor (Crow 1988). Light intensity near the forest floor of hardwood stands may be below the compensation point for oaks, particularly in stands where dense mid-stories or multi-storied layers of tolerant vegetation exists. Photosynthetically active radiation levels in southern bottomlands are often inadequate for the maintenance of positive carbon balance (Hanson 1986), so carbohydrate reserves used in respiration exceed that produced by photosynthesis and the seedlings usually die.

Findings of GTR studies discussed herein demand that light as a limiting factor be given ample consideration. Gray and Kaminski (unpubl.) reported decreasing densities of oak seedlings in a continuously-flooded GTR. Mean seedling age of the seedlings in both of the GTR's, however, was later determined to be approximately 2.25 years (Kaminski, pers. commun.). King (1995) maintained that the lack of a significant relationship between light availability and seedling growth and survival was likely attributable to prolonged hydroperiod. That may very well be the case but light conditions for these stands was reported as ranging between 9.4% and 12% full sunlight, well below the 30% to 50% range of full sunlight in which photosynthetic saturation and maximum growth of oak seedlings is known to occur (Hodges 1987).

Management Implications

The literature discussed herein provide compelling evidence that hydroperiod in GTR's may result in the exclusion of red oaks in future stand composition, but bear in mind that by definition GTR management implies the flooding of hardwood bottomlands only during the dormant-season. Dormant season flooding is less detrimental to tree survival than growing season flooding (Hook 1984) though it is not uncommon, however, for seedling mortality to increase due to winter flooding (Jones et al. 1994). Temporary growing season flooding can prevent seedling growth or cause mortality by inhibiting internode elongation, leaf initiation, leaf expansion, and by inducing premature leaf senescence, injury, and abscission (Kozlowski 1984). Pezeshki and Chambers (1985) reported that flooding for as little as six days induced stomatal closure, reduced transpiration, and reduced net photosynthesis of cherrybark oak seedlings.

Growing-season flood control and efficient floodwater discharge are critical to seedling development and should be integrated into GTR management (Young et al. 1995). Sapling heights $\geq$1.4m are needed if trees are to develop into codominant and dominant positions in the future stand; sufficient height is needed to protect regeneration from periodic overflows. Because water management may be arresting sapling development, regeneration should be monitored closely (Hodges and Janzen 1986).

A 2-year flooding regime may allow for the aeration of soil and decrease the amount of windthrow (Hodges and Janzen 1986). Emulating natural flooding regimes, as advocated by Gray and Kaminski (unpubl.) would minimize flooding duration and alter the annual timing of floods. The proposed method involves winter flooding regime whereby a GTR is flooded for one month and then drained. An adjacent GTR is flooded the following month. Though repetitious flooding and draining of GTR's may prove to be cost prohibitive, it could mitigate any deleterious effects of soil water-saturation while supplying wintering habitat for migratory waterfowl. Furthermore, research conducted in Mississippi GTR's indicates invertebrate biomass, acorn availability, and waterfowl use is the greatest during the initial month of flooding (Wehrle et al. 1995). Flooding at one month intervals maximizes natural food availability peaks and waterfowl use trends.

If GTR water-management is successful in the creation of adequate amounts of advance oak regeneration, the next step is to ensure the growth and development of the regeneration. To ensure that red oaks play a prominent role in future stands, effective greentree reservoir management will entail timely thinnings, cuttings, and/or chemical injections to increase both the quality and quantity of light which reaches oak seedlings.

Future Research Needs

The optimal frequency and duration of winter flooding to maintain forest productivity, while also providing consistent waterfowl habitat is unknown. The GTR research discussed herein basically reflects periodic, year-round inundation - both winter flooding and natural overflows during the growing-season. It seems essential, then, to exclude the phenomena of growing-season flooding from the research design to saliently assess the true effects of winter flooding in greentree reservoirs, or at least to mitigate such experimental bias by ensuring adequate and immediate drainage prior to the growing-season.

The ecology of hardwood bottomlands, as expressed in terms of species distribution in relation to relief features, should be reflected in future experimental design by stratified sampling, the delineation of the hardwood bottomland by relief features. It may not be as important to know that red oak species X exhibited density and/or survival declines without knowing where exactly in the bottomland this phenomena was observed - knowing that cherrybark oak, for example, exhibited a decline in seedling density on high flats while overcup oak demonstrated increased seedling densities on these same areas may be of greater value to resource managers than simply knowing that such changes were observed, which might be attributable to cherrybark oak acorns having been deposited along a slough pursuant to water drawdown.

It is imperative to monitor resource variables prior to and following management strategies. Our current understanding of greentree reservoir management may be remiss without pre-impoundment vegetation and hydrologic data and one may conclude that we have only begun to scratch the surface.

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