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Long-term effects of a lock and dam and greentree reservoir management on a bottomland hardwood forest

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Abstract

We investigated the long-term effects of a lock and dam and greentree reservoir management on a riparian bottomland hardwood forest in southern Arkansas, USA, by monitoring stress, mortality, and regeneration of bottomland hardwood trees in 53 permanent sampling plots from 1987–1995. The lock and dam and greentree reservoir management have altered the timing, depth, and duration of flooding within the wetland forest. Evaluation of daily river stage data indicates that November overbank flooding (i.e. 0.3 m above normal pool) of 1 week duration occurred only 10 times from 1950 to 1995 and four of these occurrences were the result of artificial flooding of the greentree reservoir. Results of the vegetation study indicate that the five most common dominant and co-dominant species were overcup oak, water hickory, Nuttall oak, willow oak, and sweetgum. Mortality of willow oak exceeded that of all other species except Nuttall oak. Nuttall oak, willow oak, and water hickory had much higher percentages of dead trees concentrated within the dominant and co-dominant crown classes. Probit analysis indicated that differences in stress and mortality were due to a combination of flooding and stand competition. Overcup oak appears to exhibit very little stress regardless of crown class and elevation and, with few exceptions, had a significantly greater probability of occurring within lower stress classes than any other species. Only 22 new stems were recruited into the 5 cm diameter-at-breast height size class between 1990–1995 and of these, three were Nuttall oak, three were water hickory, and one was sweetgum. No recruitment into the 5 cm diameter-at-breast height size class occurred for overcup oak or willow oak. The results of the study suggest that the forest is progressing to a more water-tolerant community dominated by overcup oak. A conservative flooding strategy would minimize tree stress and maintain quality wildlife habitat within the forested wetland.

Keywords: Wetland; Forested wetland; Riparian wetland; Dam; Greentree reservoir; Succession; Non-metric multidimensional scaling

1. Introduction

Riparian wetlands are characterized by their linear distribution along river and stream floodplains and by the large fluxes of energy and material inputs received from upstream systems (Mitsch and Gosselink, 1993). These wetlands occur globally within an array of

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environmental conditions (Wharton et al., 1982; Hughes, 1990; Bren, 1991; Johnson, 1992; Toth et al., 1993; Schnitzler, 1995); the critical common component is the linkage between riparian zone, river, and adjacent upland (Mitsch and Gosselink, 1993).

Bottomland hardwood forests (BLH) are riparian wetlands that occur along rivers and streams throughout the central and southern United States (Huffman and Forsythe, 1981; Mitsch and Gosselink, 1993). The timing, depth, and duration of flooding are the major determinants of plant species composition in these forested wetlands (Wharton et al., 1982). In general, plant species are distributed along a growing season flood gradient according to their flood tolerance; any alteration in flooding patterns can result in shifts in plant species composition (Franz and Bazzaz, 1977; Klimas, 1988).

The effects of dams on riparian forests vary depending upon the location of the forest relative to the dam. Forests located immediately upstream of dams are often completely inundated and may experience total tree mortality (Yeager, 1949; Harms et al., 1980). Downstream of dams, reduced peak flows and altered timing of flows associated with dam operations can result in subtle shifts in plant species composition because of their effect on seed dispersal, seedling establishment, and tree growth (Klimas, 1988; Schneider et al., 1989; Johnson, 1994).

Greentree reservoirs (GTRs) are a habitat management strategy of bottomland hardwoods that may also affect plant species composition. First constructed in Arkansas in the 1930s, greentree reservoirs now exist in over 20 states (Rudolph and Hunter, 1964; Wigley and Filer, 1989). Greentree reservoirs are typically developed by impounding a stand of bottomland hardwood forest with a levee system and water control structures (Rudolph and Hunter, 1964; Fredrickson and Batema, 1993). The impoundment is artificially and/or naturally flooded during fall and winter to allow foraging opportunities for wintering waterfowl on mast and invertebrates. Since the primary objective of GTRs is to provide quality habitat for wintering waterfowl, certain tree species are deemed more desirable because their mast is more heavily used by waterfowl. For instance, acorns of willow oak (*Ouercus phellos*) (plant names from Godfrey and Wooten, 1981) and Nuttall oak (*Q. nuttallii*) are preferred by wood ducks (*Aix sponsa*) and mallards (*Anas platyrynchos*) over acorns of the more water-tolerant overcup oak (*Q. lyrata*) because they are smaller and more palatable (Barras, 1993). Although early studies indicated that GTR management increased tree growth and had no effect on mast production (Minckler and McDermott, 1960; Merz and Brakhage, 1964; Broadfoot, 1967), more recent studies indicate that shifts in plant communities from less water-tolerant (e.g. willow oak) to more water-tolerant species (e.g. overcup oak) can occur as a result of GTR management (Malecki et al., 1983; King, 1995; Young et al., 1995).

Several studies have reported the effects of complete inundation and/or continuous flooding of BLH associated with dam construction (Green, 1947; Yeager, 1949; Harms et al., 1980); however, few studies (Klimas, 1988; Schneider et al., 1989) have reported on the more subtle impacts of dam operations such as alteration of timing and flood duration on these forests and none have reported on the combined effects of lock and dams and GTRs on BLH communities. The objective of this paper is to evaluate the combined effects of a lock and dam and GTR management on bottomland hardwood tree stress, survival, and recruitment.

2. Study area and methods

2.1. Study area

Felsenthal National Wildlife Refuge is located in southern Arkansas at the confluence of the Ouachita and Saline rivers (Fig. 1). Baldcypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) are dominant in sloughs and other semi-permanently flooded areas. Backwater basins and poorly drained flats are occupied by overcup oak and water hickory (*Carya aquatica*) while on better drained sites, sweetgum (*Liquidambar styraciflua*), Nuttall oak, and willow oak predominate. The goal of BLH forest management at Felsenthal National Wildlife Refuge is to maintain and even increase the abundance of Nuttall oak and willow oak because of their high quality mast for wintering waterfowl (U.S. Fish and Wildlife Service, 1979).

The 26 300 ha refuge was established in 1975 to partially offset the impacts of the United States Army Corps of Engineers' Ouachita–Black Rivers Navigational Project. This project resulted in the construction

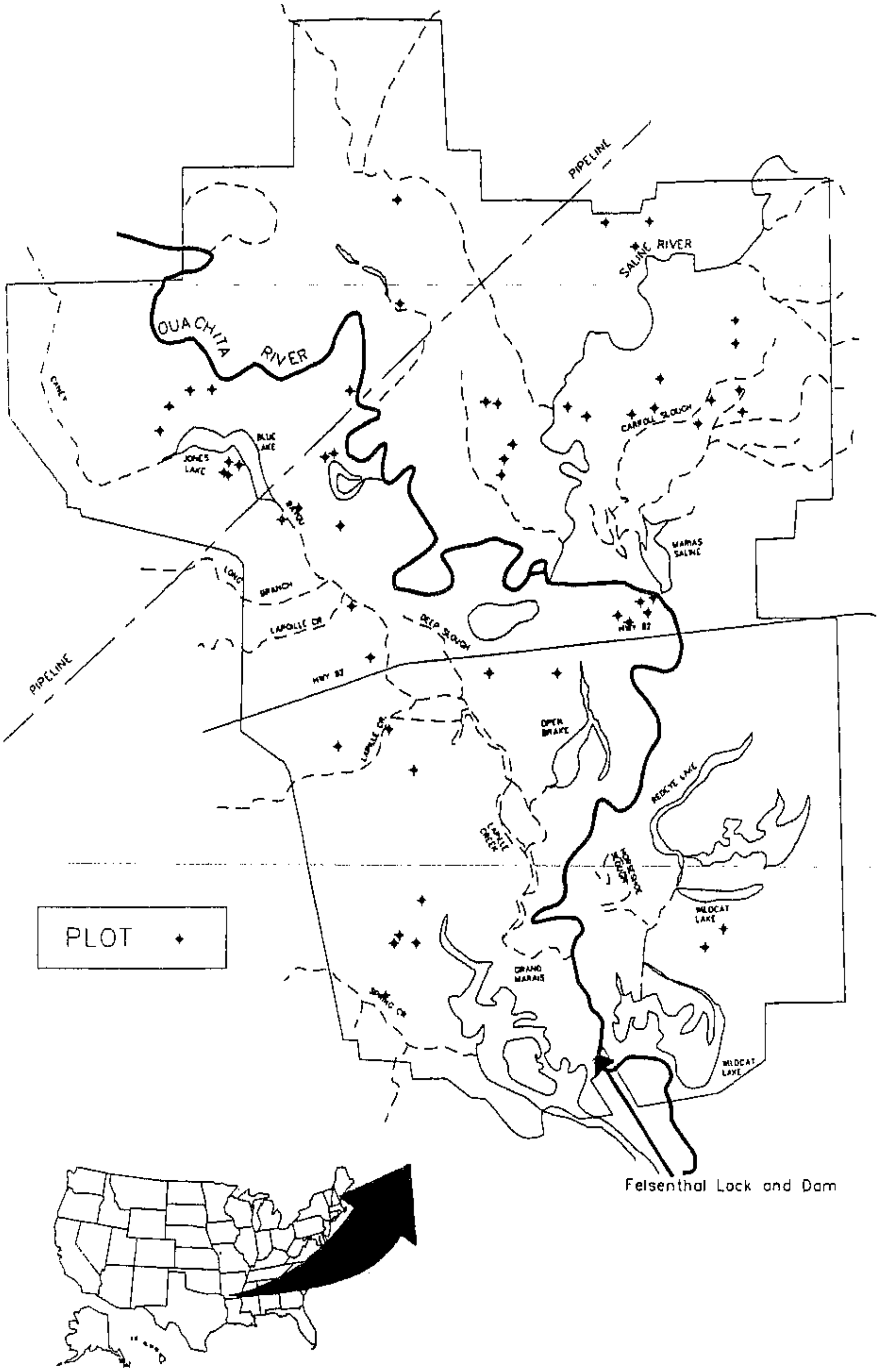

Fig. 1. Map of Felsenthal National Wildlife Refuge near Crossett, AR.

of two lock and dam structures. The first lock and dam was built in 1925 about 5.6 km downstream of the refuge's southern boundary and inundated about 2000 ha of forest within the refuge boundaries. The Felsenthal lock and dam, located on the southern boundary of the refuge, was completed in 1985 and permanently inundated another 4450 ha of forest in the refuge. The purpose of the Felsenthal lock and dam was to raise the permanent pool created by the first lock an additional 1 m to 19.8 m above mean sea level (MSL) for navigational purposes. However, the Felsenthal lock and dam was also designed so that the pool could be managed as a GTR between 19.8 and 21.3 m above MSL. At maximum pool, an additional 8500 ha of BLH are flooded to varying depths.

The water management plan for the first 2 years of operation (1985–1986) specified gradual raising of the GTR pool from 19.8 m above MSL on 1 November to 21.3 m above MSL on or about 1 January; the 21.3 m above MSL level was maintained for 1–2 weeks and then gradually lowered to 19.8 m above MSL on or about 1 March. Since 1986, the GTR has been managed on a more variable schedule which occasionally included extended spring flooding to allow more area for fish spawning. In several years, the GTR was not deliberately flooded but experienced extensive natural flooding (Fig. 2).

2.2. Plant community analysis

A series of 0.1 ha (31.6×31.6 m^2) permanent plots was established within selected forest stands between 1985 and 1987 to monitor plant communities (Teaford, 1989). A total of 53 plots was monitored in 1987, 1990, and 1995. Plot elevations were measured from benchmarks to the nearest 0.003 m with a stadia rod and transit.

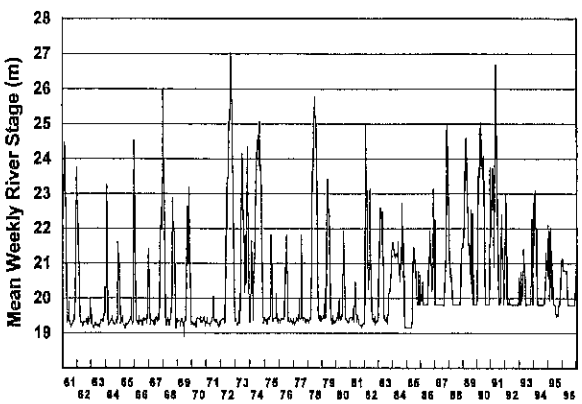

Fig. 2. Mean weekly river levels recorded at Felsenthal lock and dam from 1961–1995.

In 1987, diameter-at-breast height (dbh) and species identification of all trees $\geq$15.2 cm dbh were recorded. In 1990 and 1995, the minimum dbh for overstory trees was lowered to 5.1 cm and all trees $\geq$5.1 cm dbh were tagged and dbh and species identification were recorded. In addition, species identification and dbh of all saplings and shrubs (>1.4 m tall and <15.2 cm dbh in 1987; >1.4 m tall and <5.1 cm dbh in 1990) within a square 0.004 ha subplot located in the center of each 0.1 ha plot were recorded.

In 1990, each overstory tree was assigned to one of four crown classes (Smith, 1986): dominant, co-dominant, intermediate, or suppressed. To provide an estimate of tree stress in 1990 and 1995, each tree was assigned an index value of relative stress based on the estimated mortality of branches within the crown as follows: 0–5% crown dieback; 6–50% crown dieback; 51–95% crown dieback; or 96–100% crown dieback.

2.3. Data analysis

All statistical analyses were conducted on SAS Statistical Software, Version 6.11 (SAS Institute, Cary, NC). For all relevant analyses, plot elevations were classified into one of three categories: low (<20.7 m above MSL; n=23), mid ($\geq$20.7 and <21.3 m above MSL; n=16), or high ($\geq$21.3 m above MSL; n=14).

We used a two-factor analysis of variance (ANOVA) to examine the main effects of elevation and species and their interaction on basal area changes between 1987 and 1995 among the five most common dominant and co-dominant species. Means of main effects were tested at α=0.05 using Duncan's multiple range test for multiple comparisons. For a given species, a paired t-test was used to determine if mean basal area differed between 1987 and 1995.

The main effects of species, elevation, and sampling period (i.e. 1987–1990 and 1990–1995) and the interaction of species and sampling period on mortality of trees were analyzed with a three-factor ANOVA. One-factor ANOVA was used to determine the effects of species on size of dead trees in 1990 and 1995.

Duncan's multiple range tests were used to compare means of main effects in both of the preceding tests.

We used Probit analysis to determine the effects of the lock and dam, GTR water management, and natural stand development processes on tree stress between 1990 and 1995 for the five most common dominant and co-dominant species. Probit analysis is used to determine if the probability of an event is statistically more or less likely to occur based upon the relationship of the independent variables to the dependent variable (SAS Institute, 1992). The model was as follows:

$$vc95 = plotba90 + stemd90 + cclass90 + elevation$$

where:

vc95	tree stress class
plotba90	plot basal area for 1990
stemd90	plot stem density for 1990
cclass90	crown class for 1990
elevation	plot elevation

For the purpose of this analysis, plot basal area in 1990, plot stem density in 1990, and canopy class were used as measures of plant competition. Plot basal area and stem density values for 1990 were used because they represent the conditions present at the beginning of the study period (i.e. 1990–1995). Data from 1987 were excluded from this analysis because trees were not tagged or assigned crown classes until 1990.

To evaluate patterns of growth and mortality over the entire 8-year study period, diameter distribution charts (Conner et al., 1981; Parker, 1988) were constructed for each of the five most common dominant and co-dominant species. Current and past dominance and regeneration patterns were determined from each graph (Johnson and Bell, 1975; Conner et al., 1981; Parker, 1988).

To explore plot-level successional changes, tree importance values (relative dominance+relative density/200; Dollar et al., 1992) of the five most common dominant and co-dominant species were calculated for each plot for 1987 and 1995. Successional vectors for each plot were constructed by ordinating species importance values with non-metric multidimensional scaling (PC-ORD Version 2.0, Kruskal, 1964; Mather, 1976). The number of dimensions used in the final ordination was determined by evaluating final mathematical stress versus the number of dimensions and choosing the number of axes beyond which reductions in stress were small (McCune and Mefford, 1995). To avoid local minima, multiple starting configurations were utilized, including coordinates obtained from preliminary runs of detrended correspondence analysis (McCune, 1996). Solutions from several runs were compared to ensure that the ordination was converging on the best solution. Two matrices from the same data set were used to construct a joint plot to evaluate the direction and strength of successional changes. Joint plots are similar to biplots but do not necessarily follow the strict set of rules necessary for a true biplot (Jongman et al., 1987; McCune and Mefford, 1995). The lines of a joint plot radiate from the centroid of the ordination scores and the angle and length of the line indicate the direction and strength of the relationship between main and secondary matrices (McCune and Mefford, 1995). Similarly, the direction and length of the vectors represent the direction and magnitude of successional change within a given plot.

3. Results

3.1. Basal area

The mean plot basal area for stems $\geq$15.2 cm dbh in 1987, 1990, and 1995 was 27.8$\pm$0.8 m^2/ha (mean$\pm$1 s.e.), 30.3$\pm$0.8 m^2/ha, and 29.3$\pm$0.9 m^2/ha, respectively. For stems $\geq$2.5 cm dbh, the mean plot basal area was almost identical in 1990 (28.6$\pm$0.8 m^2/ha) and 1995 (28.4$\pm$0.8 m^2/ha). The range in basal area changes during 1990–1995 was from a net gain of 7.1 m^2/ha to a loss of 12.4 m^2/ha.

Among species, the amount of basal area change during 1987–1995 differed (F=3.06; P=0.0184) with Nuttall oak (−0.49$\pm$0.54 m^2/ha) and willow oak (−0.93$\pm$0.63 m^2/ha) differing from overcup oak (1.37$\pm$0.39 m^2/ha) (Fig. 3). Within a species, however, total basal area in 1987 did not differ from total basal area in 1995 ($t\leq$0.44; $P\geq$0.43).

3.2. Mortality

Mortality differed among species (F=4.05; P=0.0164) and elevations (F=9.01; P=0.0019) (Table 1). For all species combined, mortality was

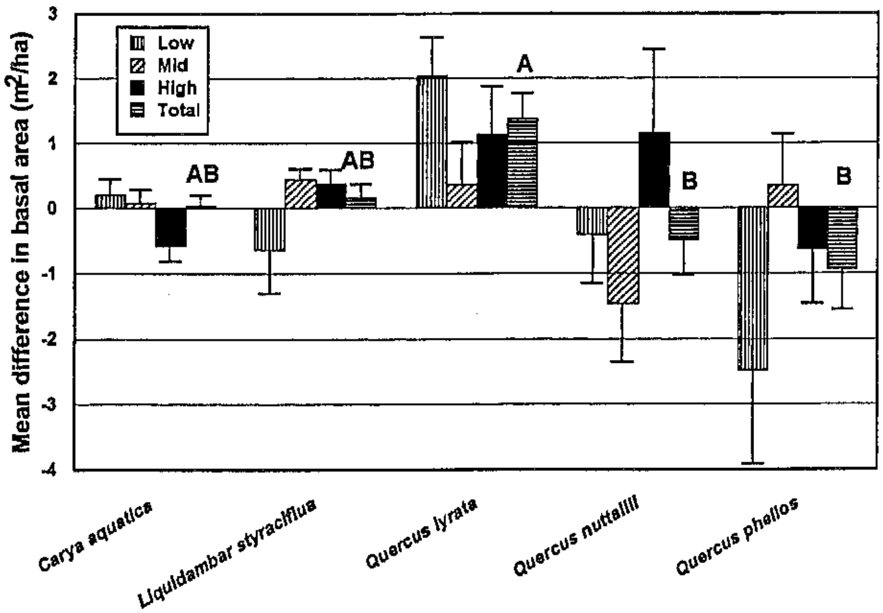

Fig. 3. Mean basal area changes (m^2/ha) during 1987–1995 for the five most common dominant and co-dominant species located within 53 sampling plots at Felsenthal National Wildlife Refuge. Mean basal area changes were calculated only for plots containing a given species in 1987. Means of total basal area changes sharing similar letters do not differ ($P \geq 0.05$).

Table 1
Percent mortality (total number of dead trees) of five most common dominant and co-dominant tree species at Felsenthal National Wildlife Refuge

Species	Elevation	1987–1990	1990–1995
Carya aquatica	Low	16.3 (24)	17.7 (20)
	Mid	11.2 (11)	4.8 (4)
	High	0	0
Liquidambar styraciflua	Low	0	22.2 (2)
	Mid	8.8 (5)	8.3 (4)
	High	5.9 (7)	3.6 (4)
Quercus lyrata	Low	13.4 (110)	10.5 (71)
	Mid	15.2 (39)	5.3 (9)
	High	9.2 (6)	3.5 (2)
Quercus nuttallii	Low	8.4 (19)	21.7 (41)
	Mid	12.4 (12)	18.9 (14)
	High	9.1 (2)	10.5 (2)
Quercus phellos	Low	20.8 (47)	26.5 (43)
	Mid	15.0 (31)	14.0 (23)
	High	13.3 (20)	12.8 (16)

Mortality estimates were for stems $\geq$5.0 cm dbh. In 1987, trees <15.24 cm dbh were not recorded; therefore, mortality estimates for the 1987–1990 period are conservative estimates that are based upon the number of living trees $\geq$15.24 cm dbh present for a given species in the plots during 1987 and 1990.

greatest at the lower- and mid-elevations. Mortality of willow oak exceeded that of all other species except Nuttall oak. Both Nuttall oak and willow oak mortality was greater than that of water hickory and sweetgum. The crown class (see Section 3.3) and size of trees killed also varied among species. Nuttall oak, willow oak, and water hickory had much higher percentages of dead trees concentrated within the dominant and co-dominant classes than overcup oak. Over 50% of dead willow oak and water hickory stems and 26.3% of Nuttall oak stems occurred in the dominant and co-dominant classes whereas 93.9% of dead overcup oak stems were in the suppressed canopy class. In 1990 (F=46.20; $P\leq0.0001$), average stem size of dead trees for willow oak (25.5±1.2) was larger than that of all other species; average stem size of dead trees for Nuttall oak (19.4±1.1) was greater than that of sweetgum (14.9±1.7), water hickory (12.9±1.1) and overcup oak (11.3±0.5). In 1995 (F=38.71; $P\leq0.001$), average stem sizes of dead willow oak (31.7±1.3), sweetgum (31.7±1.6), and Nuttall oak (27.2±1.5) were larger (P<0.05) than those of overcup oak (13.1±1.0) and water hickory (12.1±1.4).

3.3. Tree stress

A total of 1621 stems was used in the probit analysis of stress class values. The Pearson and L.R. Chi-Square tests indicated that the cumulative distribution function of the model follows a Gompertz distribution (P=0.3633). Overall, the results confirmed that a combination of elevation ($P\leq0.05$–0.0001) and crown class ($P\leq0.0001$) affected the probability of a tree occurring within a given stress class (Fig. 4). Although crown class accounted for a significant amount of variation within the data, plot basal area (P=0.3943) and plot stem density (P=0.6131) did not affect stress class.

Regardless of species, suppressed stems had a lower probability of occurring in stress classes 1–3 than stems in the dominant, co-dominant, or intermediate crown classes ($P\leq0.0002$). Furthermore, trees in both the dominant (P=0.0056) and co-dominant (P=0.0002) crown classes had a greater probability of occurring in stress classes 1–3 than intermediate stems. No difference was observed between dominant and co-dominant crown classes (P=0.6439).

Overcup oak appears to be exhibiting very little stress regardless of crown class and elevation and, with few exceptions, had a significantly greater probability of occurring in stress classes 1–3 than any other species. At the lowest elevation, willow oak had lower probability of occurring in stress classes 1–3 than virtually all other species/elevation combinations. The only exceptions were Nuttall oak (P=0.3045) and water hickory (P=0.0557) at the highest elevation and sweetgum (P=0.8334) at the lowest elevation. The lack of a difference between willow oak populations and the high elevation Nuttall oak (n=22) and water hickory (n=8) and low elevation sweetgum (n=8) may be due to small sample sizes for these species/elevation combinations. The probability of mid- and high-elevation willow oak populations occurring within stress classes 1–3 did not differ from each other nor did either population differ from any of the Nuttall oak populations. At the mid- and high-elevations, mean stress class of willow oak decreased as the canopy position improved.

No differences were observed among Nuttall oak populations. The low- and mid-elevation populations of Nuttall oak did, however, have a lower probability of occurring in stress class 1–3 than all populations of overcup oak. The high elevation Nuttall oak had a lower probability of occurring in classes 1–3 than the lower and mid elevation overcup, but did not differ (P=0.0703) from the low elevation overcup. These relationships could have been affected, however, by the low numbers of Nuttall oak occurring in the high elevation plots.

3.4. Recruitment

Despite the increased sunlight on the forest floor as a result of dead and stressed trees, only 22 new stems were recruited into the 5 cm size class since 1990. Of these, three were Nuttall oak, three were water hickory, and one was sweetgum. No recruitment into the 5 cm size class occurred for overcup oak or willow oak.

With the exception of the three newly recruited Nuttall oak stems, analysis of the diameter distribution charts indicates that the abundance of Nuttall oak and willow oak stems declined in all size classes below 30 cm during the 1990–1995 period (Fig. 5). Some recruitment into larger size classes occurred for both species. Overcup oak experienced successful recruit-

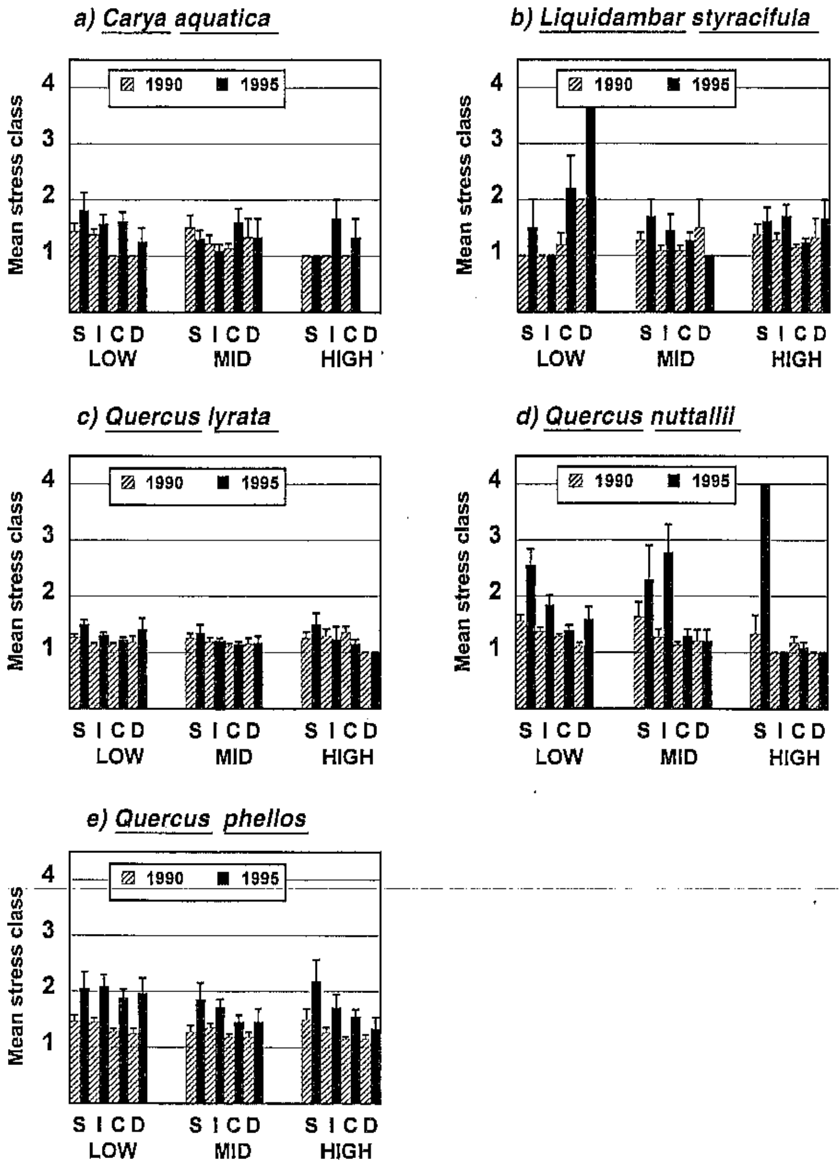

Fig. 4. Mean stress class values (±1 SE) by elevation and canopy class for the five most common dominant and co-dominant species located within a GTR at Felsenthal National Wildlife Refuge. Stress class values were derived for trees ≥5.0 cm dbh based upon subjective assessments of branch mortality within the crown as follows: (1) 0–5% crown dieback; (2) 6–50% crown dieback; (3) 51–95% crown dieback; and (4) 96–100% crown dieback. Plot elevations were divided into three categories: low – <20.7 m MSL; mid – ≥20.7 <21.3 m MSL; and high – ≥21.3 m MSL. Crown class designations are derived from Smith (1986) and were assigned the following abbreviations: (1) suppressed (S); (2) Intermediate (I); (3) Co-dominant (C); and (4) Dominant (D).

ment into several size classes, although declines were observed in the four smallest size classes during 1990–1995. Similar declines in the smaller size classes were observed for water hickory and sweetgum. Outside of the smaller size classes, the changes in the size class distribution of water hickory were not definitively positive or negative. Similarly, for sweetgum, the changes in diameter distribution classes were very small and were not obviously positive or negative overall.

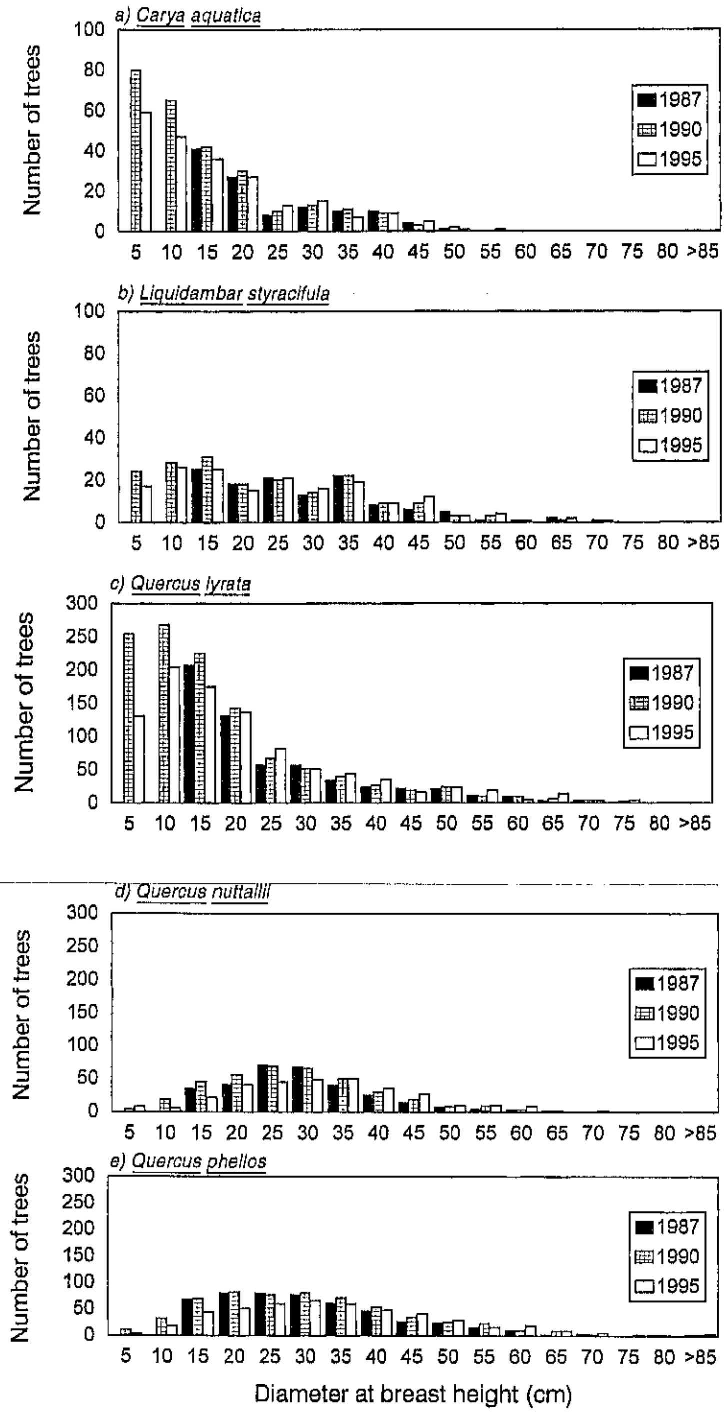

Fig. 5. Diameter distribution charts for the five most common dominant and co-dominant tree species at Felsenthal National Wildlife Refuge from 1987–1995. In 1987, the minimum tree size measured was 15.24 cm dbh. In 1990 and 1995, the minimum diameter size was lowered to 5 cm dbh.

3.5. Successional analysis

Coordinates obtained from ordinations of the data using detrended correspondence analysis resulted in the most stable solution. Two dimensions provided the best overall solution; axes 1 (58.1%) and 2 (33.7%) accounted for 91.8% of the variance in the BLH forest. The joint plot suggests that overcup oak, willow oak, and Nuttall oak accounted for the greatest amount of variation in the data (Fig. 6). The length and direction of the successional vectors indicated that a large number of plots were moving towards overcup oak and in several instances, the shifts were quite strong. Plots dominated by overcup oak in 1987 tended to exhibit very little change between 1987 and 1995.

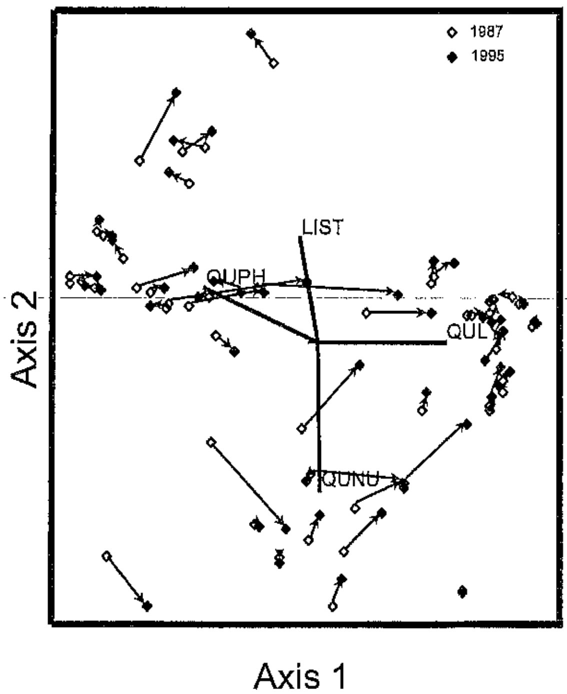

Fig. 6. Non-metric multidimensional scaling ordination diagram of basal area changes in 53 sampling plots for the five most common dominant and co-dominant trees at Felsenthal National Wildlife Refuge. The length and direction of each vector represents the strength and direction of successional changes within a given sampling plot for the period 1987–1995. Abbreviations are as follows: CAAQ, *Carya aquatica*; LIST, *Liquidambar styraciflua*; QULY, *Quercus lyrata*; and QUNU, *Quercus nuttallii*; QUPH, *Quercus phellos*.

4. Discussion

The results of this study suggest that the combined effects of the lock and dam, GTR water management, and natural stand development processes are having significant effects on forest vigor and composition. During 1987–1995, the basal area of the more water-tolerant overcup oak increased at a significantly greater rate than the basal area of the less water-tolerant willow oak and Nuttall oak. Although these changes have occurred throughout the GTR, they are especially pronounced at lower elevations. In the lowest 0.5 m of the GTR, the changes may be a direct effect of the permanent pool. Over 43% of willow oaks and nearly 30% of the Nuttall oaks $\geq$15.2 cm dbh present in 1987 at elevations $\leq$20.3 m above MSL died by 1995. Even at the mid- and high-elevations of the GTR, the basal area of overcup oak is increasing at a rate greater than or equal to that of willow oak and Nuttall oak.

Tree stress and mortality patterns are due to a combination of plant competition and hydroperiod. The large number of dead dominant and co-dominant stems of willow oak, however, suggests that hydroperiod is having a greater impact on this species than it has on the more water-tolerant overcup oak. King (1995) noted that flood-induced mortality of willow oak in an east Texas GTR was also more prevalent among larger diameter trees. In this study, all three plots with greater than 6 m^2 losses in basal area during 1990–1995 were concentrated among dominant and co-dominant stems of Nuttall oak and willow oak. One of these plots was located adjacent to the permanent pool and likely experienced permanent to semi-permanent subsurface and surface flooding. Somewhat surprisingly, however, the other two plots were 0.7 (low-elevation category) and 1.1 m (mid-elevation category) above the fringe of the permanent pool. Yeager (1949) noted that the effects of the permanent pool on tree mortality in his study were negligible at $\geq$0.6 m above permanent pool; however, neither willow oak nor Nuttall oak were present on his study site. The two plots in our study were either in localized depressions or near systems of sloughs that may have experienced a greater amount of ponding of water and higher water tables than occurred prior to construction of the lock and dam and GTR. Assuming that the features of these two plots are not totally unique, there may be numerous scattered pockets of high mortality of willow oak and Nuttall oak in the low and mid-range of elevations within the GTR.

It is doubtful that the current water-level management practices will result in the development of a 'dead-tree reservoir,' such as has occurred throughout the permanent pool and on some of the earliest GTRs (Rudolph and Hunter, 1964). Similarly, it is not likely that in the near future Nuttall oak and willow oak are going to be completely replaced by overcup oak and other more flood-tolerant species, at least at the highest elevations. However, for Nuttall oak and willow oak, the high mortality rate of dominant and co-dominant trees, the relatively high stress levels of the remaining trees, and the lack of significant advanced regeneration indicate that these species are declining and will likely continue to decline for the next several years. As the primary objective of the refuge is to 'provide high-quality wintering and resident waterfowl habitat' (U.S. Fish and Wildlife Service, 1979), these changes could be viewed as a negative development.

The changes in forest composition cannot be attributed solely to the effects of GTR management. Major natural flooding events, such as occurred in 1989–1991, would possibly have affected forest stress and composition in the absence of GTR management and the lock and dam. More importantly, several lock and dams have been constructed along the Ouachita River and its tributaries beginning in the early 1900s. These lock and dams have altered the hydrology of this system for a considerable length of time and vegetative communities are responding to the new hydrological regimes. For example, widespread mortality of nearly pure willow oak stands has been observed downstream of the GTR at the Upper Ouachita and D'Arbonne National Wildlife Refuges in an area that is impacted by the Columbia lock and dam (Kelby Ouchley, U.S. Fish and Wildlife Service, Pers. Commun.). The Felsenthal lock and dam has also affected the systems' hydrology. By maintaining water levels at a minimum of 19.8 m MSL, the Felsenthal lock and dam has created more constant and higher minimum flows than would have occurred historically on the Ouachita river. While the effects of complete inundation by the direct pool are clearly evident, it is unknown how subsurface hydrology has been affected by the new flow regimes. It is well established, however, that water table elevation and the timing, depth, and duration of flooding are the major determinants of plant species composition in floodplain forests (Wharton et al., 1982; Sharitz and Mitsch, 1993; Hodges, 1997).

GTR management has compounded the effects of the lock and dam and natural flooding events by directly influencing the timing, depth, and duration of flooding within the impoundment. Evaluation of daily river stage data indicates that November overbank flooding (i.e. 0.3 m above normal pool) of 1 week duration occurred only 10 times from 1950–1995 and four of these occurrences were the result of artificial flooding of the GTR. Alteration of the timing of flooding can impact BLH and other riparian systems by affecting seed dispersal, seed germination, and seedling survival and can initiate or accelerate successional changes (Klimas, 1988; Schneider et al., 1989; King and Allen, 1996).

It is also plausible that artificially maintaining high water levels during the winter period has exasperated the effects of late winter/early spring flooding and has resulted in floods lasting longer into the growing season than would have occurred had the impoundment not been artificially flooded during the winter (King and Allen, 1996). During the 10 years of operation, the impoundment has been lowered to the target levels by the target date only once (1994–1995). Flooding during the spring and summer of 1989–1991 was particularly intense. Although the target river levels were 19.8 m above MSL by 15 May of each year, river levels exceeded 19.8 m above MSL until 17 August 1989, 11 July 1990, and 9 July 1991.

Compositional changes within the GTR are clearly occurring and these changes are consistent with the effects of increased flooding (King, 1995; Young et al., 1995). The Felsenthal GTR is unique because of its large size and because it was created by damming a large river system rather than diverting water to an area impounded with levees. The problems associated with the GTR and lock and dam, however, are common to many GTRs throughout the region (e.g. King, 1995; Young et al., 1995). Improperly designed GTRs with inadequate water level control can override even the best conceived water management practices and result in widespread tree mortality (King, 1995; Young et al., 1995; King and Allen, 1996). Wigley and Filer (1989) noted in a survey of GTR managers that 81% of 179 GTRs were not drained on time in five of the previous 10 years and 42% were not drained on time in any of the previous 10 years. As a result, tree mortality and a lack of regeneration were common problems mentioned by GTR managers in their survey. Other studies have documented shifts in plant communities dominated by less water-tolerant oaks such as cherrybark oak (*Q. falcata* var. *pagodaefolia*), willow oak, and Nuttall oak to plant communities dominated by the more water-tolerant overcup oak.

The effects of improper GTR and water management can occur over a short period, but recovery, if possible, of structural and compositional features indicative of pre-impoundment forests may require ≥60 years (Weller, 1989) and will necessitate restoration of original surface and sub-surface hydrology. In essence, GTR management targets an average condition among months and years rather than the dynamic pattern of flooding that is indicative of short- and long-term fluctuations in natural systems (Fredrickson and Reid, 1990). GTR management, in usual practice, converts a dynamic hydroperiod into a relatively stable, predictable hydroperiod that is much more extreme than natural conditions (e.g. Heitmeyer et al., 1991; King, 1995). Furthermore, design and management schemes of GTRs seldom consider the short- and long-term precipitation fluctuations characteristic of these systems and as a result, flooding and tree stress are often intensified (Fredrickson and Reid, 1990; King and Allen, 1996). The goal of GTR management should be to emulate the natural hydroperiod including natural variability (Fredrickson and Reid, 1990). In some instances, emulation of natural hydroperiod may require no water management; in other instances, however, intensive water management may be necessary to restore or enhance composition and function of BLH communities (King and Allen, 1996).

The unique features of the Felsenthal GTR limit some management options, and managers are faced with balancing long-term habitat integrity against short-term resource needs. This dilemma is further complicated by intense pressure to maintain sufficient and often conflicting habitat requirements for a variety of species, as well as to provide public hunting and fishing opportunities. The primary objective of the Felsenthal lock and dam is to maintain water levels ≥19.8 m above MSL for navigational purposes. Any water over 19.8 m above MSL is a result of artificial and/or natural flooding. The large size of the river and GTR prevent rapid drawdown of the impoundment following a flooding event. Therefore, a pragmatic strategy for reducing stress of the trees would be to not artificially flood the impoundment during any year. In the 3 years that the GTR was not artificially flooded, natural flooding occurred for several days during each year providing valuable wintering and brooding habitat for waterfowl. This conservative approach would reduce flood stress more than any other flood management scheme. This strategy is not, however, politically feasible or necessarily biologically desirable. Artificial flooding of the impoundment during severe drought years could provide a vital regional resource need for wintering waterfowl. Yet, drought years, are believed to be necessary for regeneration of BLH forests (Putnam et al., 1960) and stand conditions should be assessed before artificial flooding is initiated. Stressed trees, as determined by canopy and leaf characteristics, should never be flooded. During non-drought years, minimal flooding that mimics the dynamic conditions typical of BLH forests could reduce tree stress, enhance regeneration, and provide greater flexibility in water management plans during drought years.

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