RESPONSE OF TREE GROWTH TO CHANGES IN FLOODING REGIME IN A MIXED HARDWOOD BOTTOMLAND FOREST IN SOUTHERN ILLINOIS[1]

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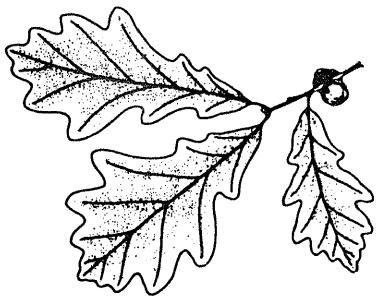

ABSTRACT.--To assess the impact of altered lake hydrology on an adjacent mixed hardwood bottomland forest, average annual tree growth (basal area increments) and seasonal patterns of growth were determined for a range of size classes of the most important species. Seasonal growth patterns were also determined for trees in an adjacent mixed hardwood upland forest for comparison. Significant reductions in annual basal area increments between the pre- and post-altered flooding conditions occurred for the four most important bottomland species. Cypress, however, a highly flood tolerant species, was not affected. No clear relationship between the seasonal pattern of tree growth for bottomland species and flooding was observed. The seasonal pattern included periods of rapid growth and no growth, and was similar for all size classes. In contrast, upland species accumulated basal area throughout the growing season.

INTRODUCTION

The impact of altered flooding regimes on bottomland forests has been documented for several forest types of the eastern U.S. (Yeager 1949, Broadfoot 1967, Broadfoot and Williston 1973, Bell and Johnson 1974, Harms et al. 1980, Conner et al.1981, Malecki et al. 1983). In general these studies showed that an increase in the depth and duration of flooding, particularly into the growing season, resulted in decreased growth rates of trees and increased tree mortality. If, however, flooding is restricted to the dormant season, tree growth in the subsequent growing season may increase because of improved soil moisture (Broadfoot 1967).

The major effect of flooding is the creation of anaerobic conditions in the soil especially when the floodwaters are stagnant or slowly moving as is often the case when flooding regimes are altered. Anaerobic soils generally result in death of roots produced under aerobic conditions (Broadfoot and Williston 1973, Hook and Brown 1973). Species tolerant to flooding will produce new, secondary roots in a relatively short time period, whereas intolerant species are incapable of producing new roots. However, even for tolerant species few water roots are produced if flooding is seasonal; more or less continuously saturated soils are needed for abundant production of these secondary roots (Hook et al. 1970). Altered flooding regimes that result in the presence of standing water well into the growing season will affect the growth of bottomland trees over the long term through reduced root activity (e.g., nutrient and water uptake) and the resulting reduction in photosynthesis and thus stem growth.

The objectives of this study are (1) to investigate if the altered hydrology of Horseshoe Lake in southern Illinois is having an effect on the growth of the most important species in a mixed hardwood bottomland forest that is flooded by the lake, and (2) if tree growth is affected, to determine during what part of the growing season the most important species are affected. Evidence suggests that Horseshoe Lake has undergone several changes in recent years due to an increase in sediment input from the surrounding watershed. As a result the hydrology of the lake has changed. I suggest that this change in lake hydrology has altered the depth and duration of flooding in the bottomland forest so that flooding tends to extend longer into the growing season.

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DESCRIPTION OF STUDY SITES

The study site is located in an old-growth forest on the southern end of an island in Horseshoe lake, Alexander Co., southern Illinois (37 12' N, 84 19' W), about 19 km NW of the confluence of the Mississippi and Ohio Rivers. Horseshoe Lake was once part of the Mississippi River and was formed when the river abandoned the Horseshoe Lake channels (US Mississippi River Commission 1945). The channels now drain nearby upland areas, but they are subject to backwater flooding from the Mississippi and Ohio Rivers. The watershed of the Lake has undergone many land use changes in recent years, particularly conversion to row-crop agriculture. In 1929 a stop-log spillway was installed across the major outlet; this was replaced by a fixed concrete spillway in 1939 (K. A. West, personal communication). This fixed spillway reduced the zone of intermittant flooding from as much as 1.8 to 2.4 m in elevation to approximately 0.6 m.

Horseshoe Lake island has gently undulating topography with a total relief of about 3 m which resulted from previous river action depositing alluvial materials on top of thick deposits of glacial outwash clays (Robertson et al. 1978). As a result the soils on the island vary from sandy to extremely clayey. Soils subject to flooding are Okaw and Jacob silt loams, poorly drained Typic Albaqualf and Vertic Haplaquept, respectively. The ridges are composed of a Bloomfield loamy fine sand (Psammentic Hapludalf) (Parks and Fehrenbacher 1968, Robertson et al. 1978).

Southern Illinois has a continental climate with warm summers and cold winters. Mean annual precipitation for Cairo, about 19 km southeast of Horseshoe Lake, is 1149 mm (10-yr average, Denmark 1974). The rainiest months are March to June (103-122 mm/mo) with the precipitation fairly evenly distributed for the remainder of the year. Mean monthly temperatures range from 3-27.3°C, with the lowest and highest temperatures recorded in January and July, respectively (Denmark 1974). The frost-free period extends from about late February or early March to early November, or about 230 days (Denmark 1974).

The forest (about 63 ha) on the island is composed of upland and bottomland areas. The bottomland forest is the northern terminus of the Southern Floodplain Forest (Robertson et al. 1978). The dominant canopy tree in this forest in Horseshoe Lake is sweet gum (Liquidambar styraciflua L.), and the major subdominant species are American elm (Ulmus americana L.), red maple (Acer rubrum L.), green ash (Fraxinus pennsylvanica Marsh.), black gum (Nyssa sylvatica L.), and sycamore (Platanus occidentalis L.). Small individuals of these species dominate the sparse understory. The forest had a total stem density and basal area of 459 trees/ha and 41 m^2/ha, respectively (for trees with a dbh > 2.5 cm), and a mean canopy height of 34 m (Brown and Peterson 1983).

A description of the vegetation of Horseshoe Lake forest is given in Robertson et al. (1978), but indices of forest structure for the uplands are not distinguished from those of the bottomlands. Species typical of the upland forest on Horseshoe Lake island are American beech (Fagus grandifolia), white oak (Quercus alba), swamp oak (Q. michauxii), sweet gum, sugar maple (Acer saccharum), American elm, and black walnut (Juglans nigra).

Hydroperiod

Typically, bottomland hardwood forests of the Southern Floodplain Forest region are flooded in winter and spring. However, in recent years I hypothesize that the hydroperiod of Horseshoe Lake bottomland forest has changed as a result of both the construction of the fixed spillway at the outlet of the lake and changes in land use of the lake watershed. During recent years (about the last 15 yr) the Horseshoe Lake basin has become shallower as a result of increased sedimentation due to conversion of much of the land in the watershed to row crop agriculture (D. M. Garver, personal communication, 1984). Although the data are sparse, the evidence suggests that standing waters are present in the forest well into the growing season. Out of the 260-day period from March 1 to November 15, 1973, the bottomland area of Horseshoe Lake island was flooded 145 days to an average depth of 38 cm (Robertson et al. 1978). From November 1977 to June 1978 and from December 1978 until August 1979, standing water was present in the forest area (Brown and Peterson 1983). During the present study flood waters were above the soil surface until early August during both 1983 and 1984.

METHODS

The first objective of the study was to determine if the growth of bottomland hardwood trees was being impacted by the change in lake hydrology. Annual rings of the major bottomland species were used to estimate growth rates, expressed as basal area increment. An increment borer was used to collect cores at approximately breast height from a wide range of diameter classes of five species. A total of 78 trees were sampled in the fall of 1978, including the following species: sweet gum, American elm, green ash, red maple (these four species were the most important ones in the forest); and cypress (Taxodium distichum). The latter species was not very important, but it was selected because it is one of the most flood tolerant species.

The cores were mounted in grooved blocks of wood and sanded smooth enough so that individual cells could be seen with the aid of a dissecting stereomicroscope. The cores were visually divided into two 20 yr periods: 1938-1957 and 1958-1977. The width of the first 20 yr period (1938-1957) was measured with an ocular micrometer and the average annual basal area increment calculated for the interval; this was designated the control

period. On close inspection of the cores it was observed that the width of the annual rings during the last 7-8 yr period appeared to be much narrower than in past years, thus the most recent 5 yr period (1973-1977) was designated the treatment period. The width of this interval was measured and average annual basal area increments were calculated. As the magnitude of the basal area increment is a function of the tree's diameter, least squares regression techniques were used to develop equations of dbh vs. basal area increments for the individual species for the two time intervals. To determine if the tree growth rates for the treatment period were different from those for the control period, the slopes of the resulting regression equations were compared using a t-test (Steel and Torrie 1960).

The second objective of the study (still in progress) is to measure the seasonal patterns of tree growth to determine if there is a relationship between these patterns and the position of the water table. In the spring of 1983 two transects (300 m long for each) were established in the bottomland area. Using the point-quarter method, two trees were selected and tagged at 15 m intervals along the transects for a total of 40 trees per transect. The study was extended into the upland area where a 150 m transect was established and 20 trees selected and tagged in the same manner as in the bottomland.

Seasonal growth rates were determined from measurements of the tree's circumference (rather than diameter because larger changes would be expected in the circumference thus improving the accuracy in the measurements) at three fixed points (5 cm above and below and at breast height) at roughly monthly intervals throughout the growing season. Changes in the circumference were converted to average change in basal area per tree for different size classes (Winget and Kozlowski 1965, Conner et al. 1981). Although measurements were initiated in 1983, data for a complete growing season are available for 1984 only. Seasonal growth rates were obtained for 73 bottomland and 16 upland trees; missing values are due to tree mortality since the study started and incorrect field measurements.

RESULTS AND DISCUSSION

Tree Core Data

The relationships between average basal area increment and dbh (at the end of the time interval) for the two time periods are shown in figure 1. All the equations were significant at $p < 0.01$. Linear equations gave the best fit (highest r^2) for sweet gum (fig. 1a) and red maple (fig. 1d), whereas curvilinear equations gave the best fit for green ash (fig. 1b), American elm (fig. 1c) and cypress (fig. 1e). Because the age of a tree is generally related to its diameter, the relationships shown in figure 1 may be viewed as growth curves. The linear relationships for sweet gum and red maple suggest that these trees accumulate the same amount of basal area over their life span. The curvilinear relationships for the other species suggest that the small young trees grow slowly at first, but as they mature and reach the canopy their growth rate becomes increasingly faster.

The slopes of the equations for the treatment period were significantly smaller ($p < 0.05$) than those for the control period for the four hardwood species (fig. 1a-d). These results provide strong evidence that the important hardwood species in Horseshoe Lake bottomland forest were growing slower in 1973-1977 than during earlier times, most likely due to increases in flooding in the forest. Average reductions in growth vary from as little as 8% for red maple to 38% for sweet gum, 47% for green ash, and 59% for American elm. On the other hand, cypress, the most flood tolerant species, appears to be unaffected because neither the slope nor the intercept of the two equations were significantly different ($p < 0.05$). This lack of difference in growth rates of cypress for the two periods is further evidence that changes in the flooding regime are causing the reduction in growth rates of the hardwoods rather than climatic changes which would affect all species.

Another trend exhibited by the data is that large diameter trees were affected more by the flooding than small ones (fig. 1). There also appear to be other factors affecting the relationship between basal area growth and diameter during 1973-1977 because less of the variation in the data was explained by the regression (the errors associated with measurements of the 5-yr ring widths are considered negligible). This was particularly the case for sweet gum and green ash. This greater variability in the data may be due to the interaction of microtopography and the water table resulting in a patchy distribution of flooded and non-flooded areas well into the growing season.

Using the equations in figure 1, estimates of the total basal area increment for the stand for the two time periods were made (dbh in 1977 was used with the equations for 1938-57 to estimate the potential growth rate without the effects of altered flooding). The basal area increment for the current conditions was 0.71 m^2/ha compared to a potential increment of 1.1 m^2/ha. It appears, therefore, that the altered flooding regime has reduced the forest production by about 36%.

Seasonal Growth Patterns

The seasonal growth of trees is expressed as basal area increments, accumulated for each time interval, and plotted at the end of the corresponding time interval (the first measurements were made on June 14, 1984). Time intervals were approximately 1 mo duration. The pattern of seasonal growth for the bottomland trees was fairly similar among size classes but the magnitude of growth was significantly different (fig. 2a and b).

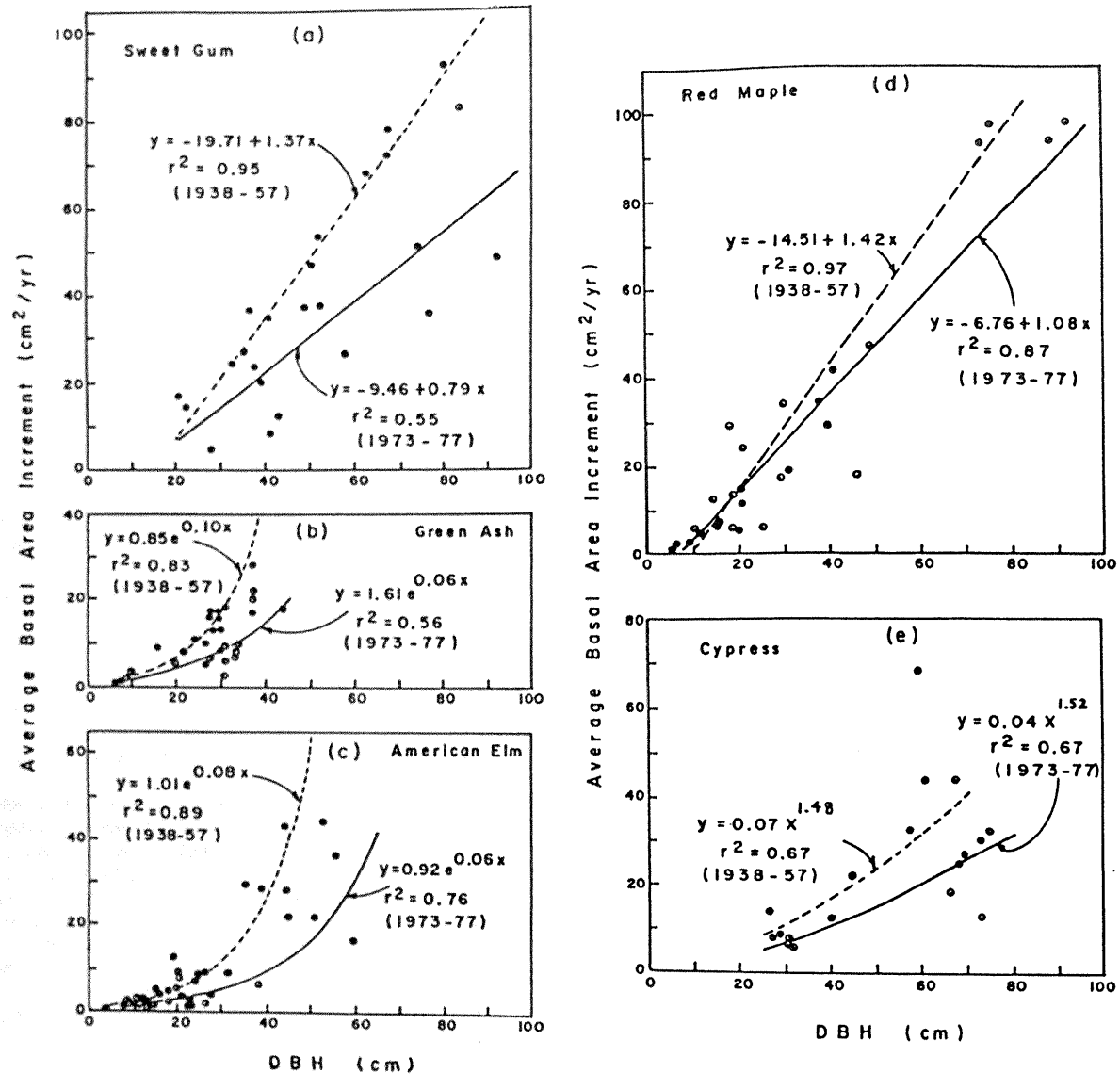

FIGURE 1.--Relationship between dbh and average annual basal area increment for major tree species in Horseshoe Lake bottomland forest for the periods 1938-57 and 1973-77. The number of sample trees for each species are: sweet gum - 12, red maple - 14, American elm - 20, green ash - 15, and cypress - 9.

Tree growth was observed until late August, followed by a period of relatively little growth until late September after which maximum growth appeared to occur. The exception to this pattern were the trees 40-60 cm dbh in transect 2 (only one tree greater than 60 cm was located on this transect) (fig. 2b) which appear to exhibit no growth during the last month. Comparison of the growth rates with the level of the water table (fig. 2c) suggests that minimum growth occurred when the water table was well below the ground surface (greater than 150 cm). As the water table rose again in the late fall most of the trees exhibited their maximum growth (steepest slope). For example, the basal area growth of all trees in transect 1 during the time interval 9/24 to 10/18 was greater than that for the accumulated growth during all the preceeding time intervals by an approximately two-fold factor. Unfortunately, data on tree growth for earlier time intervals, when the forest was flooded to its maximum depth, are not available because the forest was inaccessible at that time (floodwaters were > 1 m deep).

From the results available so far it is difficult to make firm conclusions about the relationship of seasonal tree growth of bottomland species to the level of the water table. It is clear, however, that very low water tables (greater than 150 cm deep) had a negative impact on tree growth which may be due to the shallow roots that bottomland species typically have. A higher water table appeared to result in faster growth rates, but as no data are available for the period of deepest flooding during the growing season the effect of this on tree growth remains to be determined.

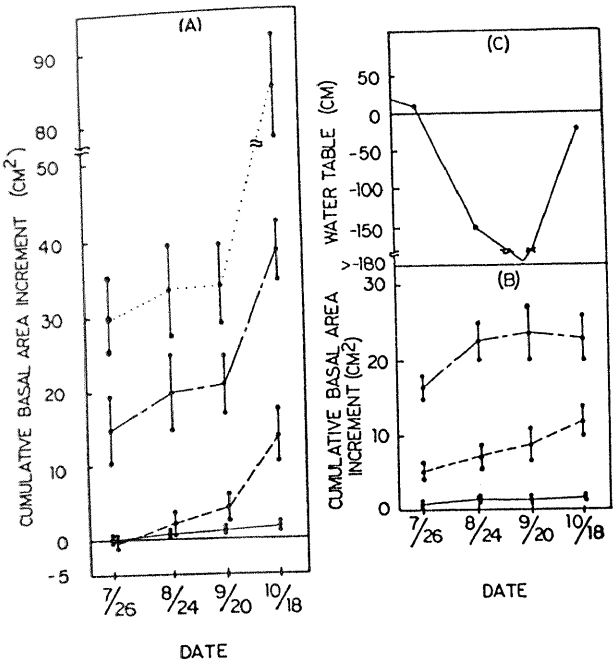

FIGURE 2.--(A and B) Basal area growth (mean ± 1 SE) curves for different size classes of trees on two transects in the Horseshoe Lake bottomland forest. Transect 2 (B) is closer to the lake than 1 (A). (——— = 0-20 cm, ----- = 20-40 cm, — — — — — — = 40-60 cm, ••••• = > 60 cm.)

The seasonal growth patterns for the upland trees not only differed among size classes but they were also different from those of the bottomland species (fig. 3). None of the upland size classes showed reduced growth rates during 8/24 to 9/20 as did the bottomland species. The largest upland trees exhibited an almost constant rate of growth throughout the study period. In contrast, the smallest upland trees appeared to stop accumulating basal area by late September. The intermediate size upland trees initially exhibited little to no growth followed by a period of rapid growth during late summer to early fall. In contrast to the bottomland species, fastest growth rates (steepest slope) of the upland species appeared to occur when the water table was at its lowest point.

Although the patterns of growth of the bottomland trees were different from those of the upland trees, the total amount of basal area accumulated by the trees throughout the growing season was similar in both areas (with the exception of 40-60 cm size class in transect 2). Total basal area increments for the bottomland species ranged from 1.4 to 85 cm^2 and for the upland species from 7.4 to 68 cm^2. These tree growth rates are within the range of values obtained from the tree core study for the period 1973-77 (fig. 1).

FUTURE RESEARCH

Growth rates of the hardwood species in the bottomland forest of Horseshoe Lake island have clearly changed during the period 1973-1977 compared to the control period. Changes in lake hydrology are implicated, but concrete evidence is lacking. The effect of flooding on seasonal growth rates remains to be clarified, particularly during the early stages of the growing season when flooding is most severe. Future research plans include measuring the seasonal growth as described above for another year ensuring that early growth rates, when the forest is flooded to greater depths, are measured. Also, another bottomland site has been located nearby in which the flooding regime is unaltered and similar measurements will be obtained there. Tree cores, encompassing the same time period used in this study, will be collected from this area. These additional data will enable conclusive statements to be made concerning the effects of altered lake hydrology on the bottomland forest.

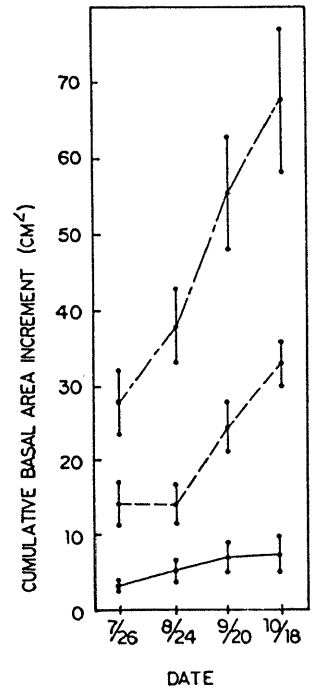

FIGURE 3.--Basal area growth curves (mean ± 1 SE) for different size classes of trees in the Horseshoe Lake upland forest. (——— = 0-30 cm, ----- = 30-60 cm, — — — — — — = > 60 cm.)

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