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# ABSTRACT

GREGORY B. EIBAND. Impacts of Past Sewage Exposure on the Growth of Bottomland Hardwood Trees. (Under the Direction of Dr. EDWARD J. KUENZLER)

A series of permanent vegetation plots was established under the direction of Drs. Edward J. Kuenzler and Curtis Richardson. From 1985 to 1990, diameter at breast height measurements were made on all tagged trees. In 1990, cores were taken from randomly selected trees and the growth rings were examined to detect differences between the sewage-impacted and non-impacted years. The results of ANOVA models showed statistically significant growth differences among plots. Regression analysis revealed a pattern of increased tree growth immediately downstream of the sewage sprayfield. Black gum (Nyssa sylvatica var. biflora) showed the greatest increase in growth due to municipal sewage loading. Tupelo gum (Nyssa aquatica) and baldcypress (Taxodium distichum) showed considerably less growth changes due to municipal sewage loading. Brown Marsh Swamp downstream of the sewage sprayfield seems to function normally after the sewage has ceased flowing through this area.

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# INTRODUCTION

## Wetlands Used in Treating Wastewater

The use of freshwater wetland systems for the further treatment of secondarily treated municipal wastewater is becoming more common in the southeastern part of the United States. Although many different types of wetlands are used to accept this wastewater, in North Carolina most of these wastewater discharges are to river swamps or bottomland hardwood forests (Kuenzler, 1987, 1988). Wetlands tend to occur in depositional environments that accumulate sediments from adjacent ecosystems (Brinson, 1985). The soils in the wetland system are usually a mixture of clay and silt and have a high organic content (Kuenzler, 1989).

Wetlands are often viewed as a nuisance to farmers and developers because they are unable to use these systems productively. However, wetlands have many functions and values to the immediate adjacent natural systems. Included in these functions and values are hydrologic values, organic productivity and biotic values. Perhaps the most important value attributed to a freshwater wetland is the ability to improve surface water quality by removing sediments, excess nutrients and toxic chemicals (Kuenzler, 1989). The wastewater treatment function of a wetland is an attempt to capitalize on the capacity for material accumulation beyond the natural levels of the system (Brinson, 1985).

The characteristics of swamps dominated by flood-tolerant trees give them potential for further treatment of secondary wastewater (Boyt *et al*., 1977, Lemlich and Ewel, 1984). The dispersion of the nutrient-rich water over a large area increases the surface contact with sediments and vegetation (Boyt *et al*., 1977, Richardson, 1988). The vegetation is adapted for filtering and settling the nutrient load for use in growth (Boyt *et al*., 1977, Nichols, 1983). Wetlands vegetation can readily assimilate organic and inorganic constituents from water (Guntenspergen *et al*., 1989). The increased nutrients and particulates also provide an efficient substrate for microorganisms (Nichols, 1983). In general, nutrient removal efficiencies in swamp systems are high depending upon the particular swamp system. Variations in removal efficiencies occur because of different redox states in the system, the amount of organics already present in the system, and the sediment type (Richardson, 1988, Kuenzler, 1989). This generalization is applicable to point and non-point sources of pollution.

## Characteristics of Bottomland Hardwood Forests

Bottomland hardwood forests are forests that occur on river floodplains in the southeastern portion of the United

States. The habitat is inundated or saturated by surface or groundwater periodically during the growing season. The water color is naturally dark, acidic, low in nutrients and low in conductivity (Kuenzler, 1987). The prevalent woody species associated with this habitat demonstrate the ability to survive, achieve maturity, and reproduce in a habitat where soils in the root zone may become anaerobic for various periods during the growing season (Odum, 1984, Mitsch and Gosselink, 1986). Southern deepwater swamps are defined as freshwater, woody communities with water throughout most or all of the growing season (Mitsch and Gosselink, 1986). Groundwater in these systems enters the swamp in sufficient amounts to sustain flow through non-storm periods. In the southeast, these communities are generally dominated by cypress and tupelo gum (Mitsch and Gosselink, 1986).

The chemistry of these systems fluctuates between aerobic and anaerobic conditions, depending on the severity of flooding. In comparison to other systems, there is an intermediate organic content of the alluvial soils. Productivity is determined by the degree of flooding and the supply of nutrients provided by floodwaters (Messina et al., 1983). Flooding provides adequate water and continual nutrient replenishment. During anoxic periods, the nutrients may be mobilized from the sediments to the water making assimilation by plants more difficult (Mitsch and

Gosselink, 1986). The nutrient cycles are generally open in these wetlands, but they can serve as effective nutrient sinks. The general pattern is a net import of inorganics to the wetland and a net export of organics from the wetland (Mitsch and Gosselink, 1986).

Trees that grow in these environments have developed adaptations that enhance their survival during extremely wet periods. The flooded anaerobic environment reduces oxygen for respiration and mineral nutrient availability for metabolism (Guntenspergen et al., 1989). Both cypress and gum trees produce knees or arched roots that generally extend above the high water mark of the swamp. Although the functions of these knees and arched roots are speculative, they are thought to aid in gas exchange and tree stability (Odum, 1984, Mitsch and Gosselink, 1986, Guntenspergen et al., 1989). Trees that are found in flooded areas have swollen buttresses which also aid in gas exchange and tree stability (Mitsch and Gosselink, 1986, Guntenspergen et al.,1989). The roots of these trees have adapted to obtain nutrients from the interstitial water in the sediments (Guntenspergen et al., 1989). During anoxic conditions, cypress and gum trees are capable of circulating oxygen to the root systems to ease stress (Guntenspergen et al., 1989).

<u>Primary Productivity in Bottomland Hardwood Forests</u>

Many studies have shown that primary productivity in bottomland hardwood forests and other similar riparian systems is influenced primarily by hydrologic and nutrient conditions with other factors influencing the system as well. It has been established that primary productivity in riparian systems is higher than that of terrestrial systems (Ewel, 1975, Brown, 1981, Brinson <u>et al</u>., 1984, Mitsch and Gosselink, 1986 Guntenspergen <u>et al</u>., 1989). Within the different types of forested wetlands, there is much variation in the primary productivity. Ewel (1975) found that the growth of cypress trees in pure cypress stands was low while the growth of cypress trees in cypress-tupelo stands characterized by moderately wet conditions was high. These findings were confirmed by Mitsch and Ewel (1979). Brinson, <u>et al</u>., (1981) showed the range of primary productivity of U.S. riparian wetlands in to be 800-1600 g dry weight/$m^2$ yr.

The hydrologic conditions of a forested wetland have an important impact on the productivity of the system. Flowing water swamps are generally more productive than slow-moving water swamps, which are more productive than still-water swamps. (Brown, 1981). Fluctuating water levels are essential for growth and seed germination of trees in these systems (Ewel, 1975, Mitsch and Gosselink, 1986). Water flowing through the swamps functions in several capacities;

the water brings nutrients to the vegetation, washes away waste products from the vegetation and brings oxygen to the root systems (Mitsch and Gosselink, 1986, Guntenspergen et al., 1989). Water in a forested wetland can have negative effects as well. At extremely high water levels, anoxic conditions from slow-moving or standing water can damage or kill vegetation. The depth of the water in a forested wetland will also effect species distribution as some species are more flood-tolerant than others (Keeley, 1979, Guntenspergen et al., 1989). The flow rate of water through the system will also have an effect on oxygen and nutrient availability and plant development. With increased flow rate comes increased oxygen and nutrients for plant growth, and reduced residence time and effects of toxic substances (Guntenspergen et al., 1989).

As mentioned above, nutrient availability is closely related to the hydrology of a forested wetland and this in turn affects the growth of trees in the system. Nutrient inputs to a forested wetland from point or non-point sources are mainly removed from the water by sorption onto sediments (Brown, 1981, Richardson, 1988,). The accumulation into vegetation is relatively small in comparison (Brinson et al., 1984). Increasing tree wood increments account for 3.6% of nitrogen inputs and 0.3% of phosphorus inputs (Brinson et al., 1984). A large portion of the nitrogen inputs into the system is also removed through the nitrification-denitrification pathway (Brinson et al., 1984). The mean rates of net daytime photosynthesis, growth and wood production are related to the phosphorus inputs into the forested wetland (Brown, 1981).

Sewage Impacts on Vegetation

Recent concern of sewage introduction into wetlands has spurred much research on this subject. The introduction of a large amount of nutrients into a system may cause stress to the system, and these stresses are the subject of much of this research (Odum, 1984, Mitsch and Gosselink, 1986, Kuenzler, 1987). The studies can be divided into those concerning the community structure and those concerning plant uptake. The results are discussed below.

Every study that has been concerned with tree growth as a result of the addition of sewage found that the experimental plots (sewage added) grew at a higher rate than the control plots. The results of one study were at variance. Lemlich and Ewel (1984) found that the addition of raw or primary sewage to trees in cypress strands had a negative effect on growth while secondary sewage enhanced growth, possibly due to less extensive reducing conditions and less impact or formation of toxic compounds. Brown (1981) reported that photosynthesis and respiration in wetland vegetation increase with increasing phosphorus inputs, but leaf and fruit production decrease. Even in cypress domes, which are characterized by long hydroperiods, the addition of sewage increased productivity in the trees by 2-3 times. Ewel and Odum (1978) discovered a 2.5-fold increase in basal area increments and greater seedling survival after the addition of sewage to a Florida cypress dome for more than 50 years. Nessel and Bayley (1984) reported that mean basal area increments in a cypress strand receiving wastewater increased 1.7-2.3-fold. Phosphorus uptake by cypress was also higher in the experimental sections, and there was a 2.6-fold increase in leaf phosphorus concentrations.

Litterfall was also higher in the sewage-impacted trees. Boyt et al., (1977) reported higher tree growth in swamps that receive sewage as a result of increased nutrient uptake. Nessel et al., (1982) reported an increase in basal area increments in black gum and cypress after sewage addition.

It was also discovered that even mature trees can respond to an increase in nutrients to the system. Dierberg and Ewel (1984) found that wastewater increased the nutrient content of leaves and fruit in a cypress dome and that litterfall was also increased. Deghi (1984) reported that addition of sewage to tupelo gum and bald cypress seedlings increased mortality and decreased the growth rate of the survivors. Ewel (1975) reported that trees grow slightly faster when exposed to sewage, but the difference was not statistically different. Dierberg and Brezonik (1984) found that the nutrient content of aboveground cypress tree components increased because of wastewater addition. In general, the addition of wastewater to forested wetlands enhances the nutrient uptake and growth of the trees in these systems.

Sewage Impacts on Community Structure

The community structure of a forested wetland is also affected by the introduction of a large amount of nutrients, but these changes are not irreversible (Ewel, 1984). The current total biomass is representative of past disturbances and past productivity rates (Brown, 1981). In terrestrial systems, the addition of a large amount of nutrients often results in a change in species composition and invasion by non-native plants, but in wetland systems, the change in speciation is not significant (Ewel, 1984). An important change to the community is the appearance of a thick cover of small floating plants (Ewel, 1975, Ewel and Odum, 1978, Ewel, 1984). These small floating plants can rapidly process sewage nutrients in the water and transfer them to sediments where plants have access to them. However, these plants can also reduce the oxygen content of the water thereby killing fish, amphibians, insects and some emergent plants (Ewel and Odum, 1978). The biomass and species turnover rates are also increased with the addition of sewage to the wetland (Ewel, 1975, Brown, 1981). With regards to the effects on species diversity in sewage-impacted wetlands, there are conflicting results. Ewel (1975) reported a decrease in species diversity while James and Bogaert (1989) reported an increase in species diversity.

Site Characterization

Brown Marsh Swamp is a forested wetland in Bladen County, North Carolina, located southeast of the town of Clarkton. Beginning in May 1985, sewage from the town of Clarkton was introduced into one tributary to the swamp. Raw sewage from the town first passed through a one-celled oxidation pond which supported a dense phytoplankton population. The sewage was then pumped to the swamp and distributed by rotating sprayers over an area of 0.4 hectares (Kuenzler, 1987). Within 18 months after the introduction of sewage into this area, 98% of the trees in the spray field were dead due to unknown causes. There was a clear demarcation within which the trees were killed. This line appeared at the limit of the solid spray

(Kuenzler, 1987). The bark of the trees was peeled off 1-3 meters above the ground which indicates damage by physical force. The trunks of these trees were constantly saturated by effluent and a sludge blanket 0.4 meters thick composed of dead algae sometimes covered part of the area (Kuenzler, 1987). Sewage introduction into this portion of the swamp was discontinued late in 1987 in reaction to the tree mortality.

The wetlands below the spray field are a floodplain forest clearly dominated by tupelo gum (Nyssa aquatica). Other important species in this area are black gum (Nyssa sylvatica v. biflora), baldcypress (Taxodium distichum), swamp cottonwood (Populus heterophylla), ash (Fraxinus spp.), elm (Ulmus spp.), laurel oak (Quercus laurifolia), and red maple (Acer rubrum) (Table 1). Brown Marsh Swamp has characteristics of bottomland hardwood forests and southern deepwater swamps. Portions of this swamp were continuously flooded during the growing season while other parts on slightly higher ground were only periodically flooded. The water in this floodplain forest flows through many pathways. No distinct banks or levees have been formed by the water flow. At times of low flooding, the water is mainly confined to many intermediate courses but at the extreme flood stages, water moves over the entire floodplain. The total watershed of this swamp is 235 $km^2$ (Kuenzler, 1987).

Study Objectives

A series of permanent plots (0.10 ha.) was established below the outfall of the spray field in 1985 by Drs. Edward J. Kuenzler and Curtis Richardson (Figure 1). The spray field was divided into 4 0.05 ha. plots. Plots 5-10 were situated downstream of the spray field along the main tributary. Plot 5 was located 91 meters downstream of the outfall, Plot 6 was located 103 meters downstream, Plot 8 was located 213 meters downstream, and Plot 9 was located 221 meters downstream. Measurements of the diameter at breast height (d.b.h.) of approximately 1000 tagged trees commenced in order to study the preliminary effects of the addition of sewage to this swamp. Measurements of d.b.h. were continued on the trees in the permanent plots. In addition to the d.b.h. measurements, cores were taken from randomly selected trees in the study area to provide another method of assessing tree growth. There were two reasons for conducting this study. The first was to examine growth patterns before and after the trees were exposed to municipal sewage, and the second was to compare growth patterns between trees in the upstream and downstream plots. The hypothesis being examined by this study is that sewage introduction into forested wetlands will not disturb the growth of the affected trees.

In temperate zones of the world, trees produce rings that are very straightforward to enumerate (Schweingruber, 1984). The wood tissue forms clearly defined boundaries between wood formed early in the growing season (earlywood), and wood formed late in the growing season (latewood). Every change in environmental conditions is reflected in some way in the annual ring width in trees (Schweingruber, 1984). For example, environmental changes such as changes in the tree's position, light, water, temperature of the ecosystem, damage to the tree's crown, and chemical changes in the environment will all have some measurable effect on the width of the annual rings of the affected tree. These changes affect the size of the cells and the thickness of the cell walls when the tree is growing. Through examination of cores taken from an environmentally stressed area, the beginning and ending points of these stresses can be determined. This information can be valuable in determination of pollution events and its effects on tree growth rate.

## MATERIALS AND METHODS

### D.B.H. Measurement

Measurement of the diameter at breast height (d.b.h.) (approximately 1.37 meters above the soil) have been made periodically. Only the final two measurement dates are incorporated in this study. Each living tree in each plot had been tagged at the beginning of the study when the first d.b.h. measurements were made. Trees which died between measuring periods were dropped from the study. Similarly, if a tagged tree could not be located again or if the tag was missing, the tree was deleted.

The d.b.h. measurement was performed with the tape directly above the numbered tag. Any growths on the outside of the tree that interfered with the path of the tape were removed so as to obtain the diameter just outside of the bark. Trees with physical deformities that interfered with the measurement of d.b.h. were omitted at the discretion of the investigator. The following characteristics were calculated from the results of the d.b.h. measurements:

<u>Total Density</u> - Number of trees/area of plot
<u>Relative Density</u> - (100)(Density for species)/total density

Basal Area - Cross-sectional areas of tree trunk at breast height

Dominance - Total basal area for a species/area of plot

Relative Dominance - (100)(Dominance for species)/total dominance

Frequency - Number of plots containing species/total number plots

Relative Frequency - (100)(Frequency for species)/total frequency for all species

Importance Value - Relative Density + Relative Dominance + Relative Frequency

Growth - The increase in diameter from the beginning of the study to the end

(Mueller-Dombois and Ellenberg, 1974).

The species density of a plot in this study is the number of individuals of that species per unit area. The frequency value for a species is the chance of finding a species in a particular area in a particular trial sample. The advantage to these measurements is that they are quick and easy to record. However, they also have some shortcomings for descriptive vegetation analysis. These two parameters are dependent on plot size and therefore, these calculations are not considered absolute. Optimum plot size is also a consideration, but in this study, the plots were already established. The frequency value reflects the pattern of tree distribution as well as the density of these individuals. It yields information about two fundamental characteristics of vegetation (pattern and abundance) and therefore it may confuse these two important features (Goldsmith and Harrison, 1976).

Additional information concerning the Importance Value is helpful for a complete understanding of the calculations.

The permanent plot method of vegetational analysis can yield many quantitative parameters, any one of which can be interpreted as important depending on the investigator. The Importance Value is a parameter that gives equal weight to three relative values from the above calculations, and therefore comparisons among species in a plot can be obtained with relative ease. One shortcoming of a relative parameter is that it gives less information about vegetation than actual parameters. For example, densely and sparsely vegetated habitats may have the same relative density and Importance Values, but nothing is stated about species biomass or cover, and these are important ecological considerations (Mueller-Dombois and Ellenberg, 1974).

Random Core Sampling

Three species, tupelo gum, black gum and baldcypress were examined more closely because of their relative flood tolerance (Goldsmith and Harrison, 1976), their abundance throughout the swamp and their close association in the environment (Goldsmith and Harrison, 1976). Although ash was abundant as well, it was not chosen for this study because it is less tolerant of flooding (Goldsmith and Harrison, 1976) and the species could not be positively identified.

In addition to measuring the d.b.h. for the living trees in these permanent plots, cores were taken from a random sample of trees in these plots. A simple random sample of the trees to be cored was undertaken for two reasons. A complete sample of approximately 1000 trees was not logistically possible, and with fewer observations of these sample cores, more care could be taken in obtaining the samples (Freese, 1978).

In selecting trees to be cored, it is necessary to minimize bias. For example, the beginning of the coring process during this study was aimed at only obtaining cores from trees that showed positive growth over the entirety of the five year study. However, since there was a bias incurred in this sampling method, it was quickly abandoned. The adopted sampling method involved the calculation of a minimum number of cores to be taken from each plot and selection of the particular trees to be cored using a table of random numbers (Freese, 1978). The estimation formula was only used on the <u>Nyssa aquatica</u> trees in all vegetation plots and <u>Nyssa sylvatica</u> var. <u>biflora</u> trees in Plot 9. Because of the limited number of <u>Nyssa sylvatica</u> var. <u>biflora</u> and <u>Taxodium distichum</u> in the permanent plots, all individuals of these two species were cored.

Freese (1978) gives the following formula for estimating the sample size for a simple random sample of a continuous variable:

$$n = \frac{1}{\frac{E^2}{t^2 s^2} + \frac{1}{N}}$$

Where:
n = the number of random samples to be taken
E = the samples confidence limits; this is how close the sample estimate is to be to the population mean
t = percentile of t distribution with degrees of freedom = n-1
$s^2$ = population variance
N = individuals in the population

Since not all the parameters in this equation could be gained from the collected data, some had to be estimated. For example, the population variance could not be had from the sample of trees in this study, so it was estimated by the following formula (Freese, 1978):

$$s^2 = (R/4)^2$$

In this formula, R is the estimated range from the smallest to the largest unit value encountered in sampling. From the data, this value was reported to be the largest amount of growth, based on d.b.h., shown by an individual tree during the five years of the study.

Another value that had to be estimated was the t value. In order to use a t table, the degrees of freedom have to be known (n - 1). Since n is the object of these calculations and n must be known to proceed in these calculations, the procedure is to make a reasonable guess at n and then arrive at a value for t. A value of n is guessed at until the calculated values were the same or only slightly different. When using the t tables, the 0.01 probability column was used in order to more accurately determine the number of samples needed.

To exhibit how this formula is used, the following is an example of these calculations using data from plot 10.

n = 15 samples
R = 5.2 cm
E = 1.61327 (This value was determined by calculating the standard deviation of the growth of the trees in this plot. Since the estimated sample number is to be ± E units away from the mean, and since 95% of normally distributed data is usually within two standard deviations of the mean, this value is two standard deviations)
$s^2$ = 0.69
t = 2.977 for 14 degrees of freedom (15 samples)

Using these numbers, the calculated number of cores to be taken from the trees is 5.5 which rounds up to 6. When t is changed to 10 degrees of freedom (11 samples) the outcome for n is 6.18 which rounds up to 7 cores to be taken. When t is changed to 7 degrees of freedom (8 samples), the outcome is 7.46 which rounds up to 8 samples. Therefore, by guessing at the value of n, and obtaining a t value from the corresponding degrees of freedom (n-1), it is reasonable to estimate the number of cores to be sampled from the permanent plots. Table 2 shows the calculated values for the minimum number of <u>Nyssa aquatica</u> cores to be sampled from each plot.

The cores were taken with an incremental borer with a 1/4 inch diameter. The boring end of the corer was placed perpendicular to the tree at the height of the tag. After the borer was removed from the tree with the core, the core was placed in a soda straw. Both ends of the straw were stapled and a tag was attached showing the number of the tree, the species, and the date. A total of 77 cores were taken from the permanent plots. The cores were transported back to the University of North Carolina Wastewater Research Center and stored in a 4°C refrigerator.

## Tree Ring Analysis

Since the rings of *Nyssa aquatica* and *Nyssa sylvatica* var. *biflora* are sometimes difficult to distinguish, it was necessary to cut and polish the cores. Two cuts were made along the length of each core at approximately a 45 degree angle. The surfaces of these two cuts were polished with fine sandpaper. This causes fine particles of wood to embed in the cells thereby making it easier to distinguish earlywood from latewood. The growth rings were measured under a microscope and the width (mm) of each ring or set of rings was recorded.

Cores taken from randomly selected trees provide information on tree growth in addition to the results obtained from the changes in d.b.h.. The tree ring data were examined three ways: (1) five year increments, (2) increments of the sewage-exposed years compared to the following years of the study, and (3) increments of the sewage-exposed years compared to the previous two years. Change in growth between the sewage exposed years and the non-exposed years were compared graphically.

Analysis and Interpretation of Graphs

The original set of graphs show the changes in tree growth assessed from d.b.h. data. Each point on the graph represents the mean growth (x ± 1 S.E.) of each intensively-studied species in plots 5, 6, 8, 9, and 10. The graphs show a high degree of variance around each point and therefore, no growth patterns can be concluded from these graphs. The data for Nyssa aquatica is shown as an example. (Fig. 2)

The second set of graphs (Figures 3-5) show the changes in growth from the core data. This change in growth was measured by three methods: (1) the mean change in growth between the periods of 1986-1990 and 1981-1985, (2) the mean change in yearly growth between the sewage-impacted years (1986-1987) and the following non-impacted years (1988-1990), and (3) the mean change in yearly growth between the sewage-impacted years (1986-1987) and the previous non-impacted years (1984-1985). Method (3) was the most appropriate method of assessing growth change. Figure 3 uses Method (1) of assessing growth change from the cores, Figure 4 uses Method (2) and Figure 5 uses Method (3). These graphs also show the mean and one standard error. The pattern of increased growth immediately downstream (200 m) of the sprayfield is shown by these graphs.

The third set of graphs (Figures 6-23) show the results of the regression analysis. The control used in this statistical study was Plot 10, which was located 225 m upstream of the spray field. This plot was the logical comparison to the downstream experimental plots because it was undisturbed compared to the others. It was assumed that the tree growth measurements had a normal distribution and that any inherent variations found in Plot 10 would also be apparent in the downstream plots. Each core measurement is represented on the graphs and the best fitting line according to the regression equation is included. Figures 6-11 use Method (1) of assessing growth change from the cores, Figures 12-17 use Method (2) and Figures 18-23 use Method (3). The general pattern of increased growth immediately downstream of the sprayfield (200 m) is shown by the best fitting line.

## RESULTS

Tree Importance Values: All Trees

Vegetation analysis procedures provide a general impression of the system being studied. Brown Marsh Swamp is populated with a variety of bottomland hardwood trees. At the beginning of this study, eleven tree species were identified in the ten permanent plots. The spray field at Brown Marsh Swamp, consisting of Plots 1 - 4, was clearly dominated by tupelo gum (*Nyssa aquatica*), but other trees were important in this area before the input of sewage (Kuenzler, 1987). In 1985 at the beginning of this study, cottonwood (*Populus heterophylla*) and ash (*Fraxinus* sp.) were also common in the spray field. However, since approximately 98% of the trees within range of the sewage spray were killed during the two years of sewage input (Kuenzler, 1987), the Importance Values and other parameters of certain tree species have changed in Plots 1 - 4. The total density of trees in the sewage spray field ranged from 0.02 trees/$m^2$ in Plot 2 to 0.08 trees/$m^2$ in Plot 4 (Table 3). Importance Values for the species in the spray field also show the samo general pattern (Table 4). Tupelo gum (*Nyssa aquatica*) consistently had the highest Importance Values in all plots with values ranging from 129.7 in Plot 1 to 213.8 in Plot 3 (Table 4). Other species that had high Importance Values in the spray field were cottonwood (Populus heterophylla), ash (Fraxinus sp.) and baldcypress (Taxodium distichum).

Downstream of the spray field five permanent plots were established along the main channel through Brown Marsh Swamp. Plots 5, 6, 8 and 9 were dominated by tupelo gum (Table 5). Since Nyssa aquatica was not identified in plot 7, and since this plot seemed to be more characteristic of an upland area, this plot was omitted from study. Total tree densities in the four downstream plots ranged from 0.07 trees/$m^2$ in Plot 6 to 0.17 trees/$m^2$ in Plot 8 (Table 5). Nyssa aquatica again consistently had the highest Importance Values, ranging from 85.5 in Plot 9 to 214.3 in Plot 8 (Table 6). Black gum (Nyssa sylvatica var. biflora) and baldcypress (Taxodium distichum) were more apparent in the downstream plots than in the spray field plots. In Plot 9, the extreme downstream station, Nyssa sylvatica var. biflora had an Importance Value approximately equal to Nyssa aquatica (82.9). This plot was located on slightly higher ground than the other plots, which may have had an effect on the species composition of this plot. Other species that were important in the downstream plots were red maple (Acer rubrum), cottonwood and ash.

The upstream plot of Brown Marsh Swamp was Plot 10. The tree density in this plot was 0.16 trees/$m^2$ (Table 5).

As in the other plots used in this study, Plot 10 was dominated by Nyssa aquatica, having an Importance Value of 187.4 (Table 6). Other important trees in this plot were Acer rubrum, Fraxinus, and Nyssa sylvatica var. biflora.

## Sewage Impacts on Tree Growth

The d.b.h. and tree ring measurements were analyzed to determine if sewage inputs affected the growth of the three dominant species. Plots 1-4 were included in the initial graphs using the d.b.h. growth data. In addition, no cores were taken from the spray field because of the serious disturbance to this part of the study area and because so many trees were killed in the spray field.

The figures used to represent the study area show Plot 10 305 meters downstream of the spray field. The previous study of Brown Marsh Swamp (Kuenzler, 1987), indicated that the water nearly returned to normal conditions found above the spray field at this distance downstream. In order to make the comparisons easier, Plot 10 was graphed 305 meters downstream.

Preliminary graphs were constructed using the mean diameter growths from each downstream plot and the upstream plot for each species. Graphs were also constructed using the mean basal area change for each species in all plots to compare these two measurements of growth. The graph of the d.b.h. mean plus or minus the standard error for each plot is shown in Figure 2 as compared to the control. There was no significant difference in the growth of trees in these plots.

Differences in growth among Nyssa aquatica size classes were examined by regression analysis of d.b.h. measurements. distance downstream was the independent variable and the change in growth from 1986-1990 according to size classes was the dependent variable. The graphs and $R^2$ values indicate no significant change in growth with increasing distance downstream.

Data were also examined showing the mean change in growth between sewage-influenced and non-influenced years based on core samples. This change in growth was measured by (1) the mean change in growth between the periods of 1986-1990 and 1981-1985 (Figure 3), (2) the mean change in yearly growth between the sewage impacted years (1986-1987) and the following non-impacted years (1988-1990) (Figure 4), and (3) the mean change in yearly growth between the sewage impacted years (1986-1987) and the previous non-impacted years (1984-1985) (Figure 5). Positive values for the points on these graphs indicate a positive influence of sewage on tree growth. The comparison between the 5-year growth increments (Figure 3) indicated that growth decreased as distance downstream increased. This was repeated in the other graphs produced by the alternate methods of growth comparison. However, this graphical method showed much variation in the data and stronger statistical analyses were needed.

A two-factor ANOVA was performed on the d.b.h. data and the core data using Method 3 of assessing growth change. The purpose for this analysis was to determine if mean growth changes of the three dominant species (tupelo gum, black gum, baldcypress) differed between the permanent plots. The effects of the tree species and plot number were assigned individually and in combination in order to determine the effects, if any, on tree growth. Upon examination of the ANOVA table (Table 7), it was found that the interaction term (TREE*PLOT) showed significance (p=0.001) for the model using the d.b.h. data. This means that there was a significant interaction between the tree species and the different plots. The terms TREE and PLOT also show significant differences (p=0.001) in this model. However, because the interaction term showed significance, these terms alone do not permit conclusions concerning the growth of these trees. The ANOVA model using Method 3 of assessing growth change in the core data shows significance in the PLOT term (p=0.02) which indicates the growth of trees is different among plots. The third ANOVA model on Table 7 was constructed including only the distance downstream as a function of tree growth. Tree species was omitted as a factor from this model because no significance was shown with the second model. This analysis showed, from the high F-ratio, that the growth of the trees among plots varied significantly ($p=0.001$).

Because the ANOVA did not fully utilize the information and to analyze the growth data by species, least squares regressions were performed on the three methods of comparing mean growth differences. The results of the ANOVA indicated that the trees were growing at different rates and regression analysis on each species would show the differences. The independent variable used was distance downstream and the dependent variable was change in growth. Since Plot 10 was placed at 305 meters downstream, the regression calculations were performed including and excluding Plot 10 to determine the effects, if any, on the regression. For the 5 year incremental mean changes in growth (Method 1), _Nyssa sylvatica_ var. _biflora_ showed the highest degree of growth change due to sewage inputs with (Figure 6) and without (Figure 7) Plot 10 in the regression. However, the regression of _Nyssa sylvatica_ var. _biflora_ included only three distances downstream while _Taxodium distichum_ and _Nyssa aquatica_ had 5 distances and this may contribute to the increased correlation. The $R^2$ values of 0.55 with Plot 10 (Figure 6) and 0.48 without Plot 10 (Figure 7) show much variation in the data; the points do not fit the regression line very well. The regressions of _Taxodium distichum_ (Figures 8,9) and _Nyssa aquatica_ (Figures

10,11) including or excluding Plot 10 showed little measurable change in growth with increasing distance downstream. However, the models which include Plot 10 show higher $R^2$ values. Both models show the pattern of increased growth of the trees near the spray field.

The regression of the difference in average yearly growth using 1986-1987 as the sewage-impacted years and 1988-1990 as the non-impacted years (Method 2) yielded similar results as above. Nyssa sylvatica var. biflora showed the strongest correlation between a tree-ring widths and the distance downstream including (Figure 12) and excluding (Figure 13) Plot 10. The $R^2$ values for regressions of Nyssa sylvatica var. biflora growth including and excluding Plot 10 were 0.69 (Figure 12) and 0.72 (Figure 13) respectively. Taxodium distichum (Figures 14-15) and Nyssa aquatica (Figures 16-17) showed the same trend of decreasing growth with increasing distance downstream including and excluding Plot 10. Unfortunately, the $R^2$ values were very low.

A third regression of the core data used the difference in average yearly growth with 1986-1987 as the sewage-impacted years and 1984-1985 as the non-impacted years. This approach avoids any after-effects of nutrients trapped in the soil. Once again, Nyssa sylvatica var. biflora showed the strongest correlation for a positive impact of sewage with (Figure 18) and without (Figure 19) Plot 10.

The largest increase in growth occurred in the plots closest to the spray field. The $R^2$ values for the regression with and without Plot 10 are 0.48 (Figure 18) and 0.29 (Figure 19), respectively. Taxodium distichum also showed improved correlation over prior methods using this method. The $R^2$ values increased slightly for regression with (Figure 20) and without (Figure 21) Plot 10 to 0.23 and 0.19, respectively. Nyssa aquatica regression in this manner showed the trend of decreasing growth with increasing distance downstream including (Figure 22) and excluding (Figure 23) Plot 10, but the $R^2$ values remained low.

Summary of Results

The ANOVA models showed that the growth of trees varied significantly among the different plots. The patterns established from the regression analysis show the change in growth of these trees with the addition of sewage. The trees closer to the input of sewage showed higher growth rates during the impacted than during the non-impacted time periods than the trees farther downstream. The regression analysis showed significance for many of the black gum figures. Although other figures show no significant changes in growth, the patterns established by regression in combination with the significant change in growth between plots (Table 7) suggest significant changes in growth among the trees in the plots immediately downstream of the sprayfield.

## DISCUSSION

### Sewage Impacts on the Growth of Flood-Tolerant Trees

The graphs of the change in tree diameter during the five years of this study yielded little information concerning the effects of municipal sewage on the growth of tupelo gum, black gum, and baldcypress. For each species, the variation shown by the standard errors above and below the mean are great and deducing any change in growth between the different plots is difficult. In addition, no pattern of decreasing growth was seen by examining the mean growths of each species in the downstream plots.

The reason why growth changes are not apparent from the preliminary graphs of tree growth based on d.b.h. measurement may be attributed to several factors. Human error in measuring the trees is a possible source of error. Measurements of d.b.h. were made by several different persons during the course of this study, many with no prior experience. Although these mature hardwoods are replenished with sufficient nutrients and water throughout the growing season, they do not grow very fast. Trees have different growth rates from year to year as the environmental conditions other than nutrient inputs change and these different growth rates are inherent in each tree. Since the purpose of this study was to detect only the variations in in growth since sewage loading began, and the trees have undergone variations in growth during their entire lifespan, the recent variations may have been hidden by previous variations. Therefore, measuring the change in diameter of these trees may not yield accurate results over such a comparatively short time period.

Other physical or chemical factors due to the presence of sewage in this swamp may have countered the effect of increased nutrients. The extended hydroperiod of this system due to the addition of sewage water may have caused anoxic conditions which would make the assimilation of nutrients by plants more difficult (Mitsch and Gosselink, 1986). The most productive forested wetlands are those that fluctuate between wet and dry conditions (Ewel, 1975, Ewel and Odum, 1978, Odum, 1984, Mitsch and Gosselink, 1986). Because this swamp would remain wet at sites below the outfall due to the input of sewage, there would be no fluctuating environmental conditions and the effects of increased nutrients to the system may have been eliminated.

The cores taken from randomly selected trees tend to eliminate some of the previous variations in tree growth because the specific years in question can be distinguished and measured. This more precise method of measuring growth is shown in the basic graphs of the core data (Figures 3-5). Increased growth during the sewage-impacted period is associated with a positive point on these graphs. The increased growth can be interpreted as a positive influence of sewage on the trees. As would be expected, the mean changes in growth for Plot 10, the control plot, are very close to zero which indicates no net positive or negative effects acting on the trees. Although there is much variation in the data, all three measurements of growth change indicate an increase in growth as a result of sewage addition to this swamp. The 5-year changes in growth (Figure 3) shows the most variation while the growth change using 1986-1987 as the sewage impacted years and 1984-1985 (pre-sewage) as the non-impacted years (Figure 5) showed the least variation. The latter method also showed less variation than the method using 1986-1987 as the sewage impacted years and 1988-1990 (post-sewage) as the non-impacted years (Figure 4). Therefore, based on the data represented by these figures, the pattern of increased growth as a result of sewage addition is implied, but not proven.

The two-factor ANOVA performed on the d.b.h. and core data was undertaken for two reasons. The first was to determine differences in the growth rates of the three dominant species. The second reason was to assess differences in the growth of trees with respect to the different plots. The first model (Table 7) shows significance in the interaction term. This indicates that there is significant interaction between the tree species and the plots. It is not only the tree species or the plot number which is affecting the growth of these trees, but a combination of these two factors. The significance of the TREE term suggests that different tree species are growing at different rates and therefore should be examined individually by regression analysis Another reason for proceeding with the regression analysis was the significant interaction term in the first model (Table 7). A third reason was the ANOVA was very unbalanced. The number of trees for each species represented in the model were far from equal. Although this does not invalidate the ANOVA, the species comparisons are weakened.

The regression calculations for the core data show the same general pattern shown by the core graphs, namely a decrease in tree growth as the distance downstream increased. Nyssa sylvatica var. biflora consistently showed the highest correlation and the largest change in growth between the impacted and the non-impacted time periods for the three methods of assessing growth change. With few exceptions, both Taxodium distichum and Nyssa aquatica also showed a decrease in growth change between the impacted and non-impacted periods as the distance downstream increased. However, the agreement between the best-fitting line and the data points was generally poor and the slopes of the lines were shallow. One reason for the poor fit and correlation of the data to the equation is the variance in the data. Another reason for the poor fit may be the number of permanent plots downstream of the spray field. Since there were only five plots (including Plot 10) below the spray field, the regression had only five distances with which to work. Combined with so few plots was a substantial degree of variation around them. More plots, and more samples immediately downstream of the spray field may have produced a higher correlation between the change in growth and the distance downstream and consequently a better statistical fit. However, since there was a high degree of variation in these plots, it is likely that additional plots would show variation as well, and therefore the regression analysis would not be improved.

This effect of distance downstream on growth becomes more important when combined with the results from the ANOVA models. The graphs from the regression analysis show the general trend of a decrease in the change of growth between the sewage impacted and non-impacted years as the distance downstream increased. The results from the ANOVA show that there was a significant change in growth between the plots. Therefore, it can be concluded from these two pieces of evidence that the sewage input into this swamp had a positive effect on the surviving trees immediately downstream (200 meters) of the spray field.

Other Important Considerations in Brown Marsh Swamp

The tributaries that flow into Brown Marsh Swamp are in a constant state of flux. The map published by Richardson (1988) shows the main tributaries as they appeared in 1985. Although the permanent plots were established on a main tributary, other water sources flow through these plots. The unknown hydrology of some portions of the swamp may have an effect on the growth of certain areas. Plot 8 consistently showed unusually high growth in comparison to the other downstream plots and this may be due to other tributaries flowing into this plot. Additional tributaries that flow through some plots but not others may have countered some negative effects of the sewage introduction, such as anoxia.

The relative elevation of the permanent plots in Brown Marsh Swamp may also have an effect on the growth of trees and species composition after the addition of sewage. There are shallow waterways where the water is confined during periods of low water, whereas in other places surface water drains completely off. Moderately wet areas are generally the most productive in these wetlands (Ewel and Odum, 1978, Mitsch and Gosselink, 1986). Therefore, the plots downstream of the spray field meeting these moderately wet conditions will be the most productive while areas that are too wet or too dry will be less productive. The elevation of the plots may have a compounding effect on the input of sewage into this swamp. Plots of varying elevation will be affected to a certain degree by the sewage, depending upon their height relative to the rest of the swamp. This also may have influenced the unusually high growth of Plot 8 in comparison to the other downstream plots.

Brown Marsh Swamp Used in Sewage Treatment

Clarkton sewage has been diverted from the section containing the permanent vegetation plots to another tributary of Brown Marsh Swamp for disposal. Many authors have reported the effectiveness of swamps in the Southeast to further treat municipal sewage (Ewel, 1975, Ewel and Odum, 1978, Brinson, 1985, Mitsch and Gosselink, 1986, Guntenspergen et al., 1989). Although trees died in the spray field, the area downstream of the spray field suffered few ill effects from the introduction of sewage. These trees grew faster, apparently in response to the increase in nutrients. Richardson (1988) reported that the potential for nutrient removal by the sediments was great and Kuenzler (1987) reported that the water returned to nearly normal conditions a short distance below (305 m) the spray field. Therefore, it is reasonable to conclude that this swamp functioned effectively in the tertiary treatment of wastewater.

The problems encountered in using the spray field at Brown Marsh Swamp arose from the method of sewage introduction into the swamp. The sewage spray apparently did physical damage to the trees in the immediate vicinity, eventually killing them. Layers of sludge and constant wetness of the tree trunks in the spray field may have been harmful as well (Kuenzler, 1987). Wetlands in the Southeast should be used for the treatment of municipal wastewater only if the stress to the swamp does not disturb these ecosystems. The damage done to the spray field was severe and irreversible. Although no damage is apparent to portions of Brown Marsh Swamp further downstream, evidence of damage within the spray field may surface in the future. Effects to the swamp with the introduction of sewage should be a primary concern to those who are planning to use the nutrient removal capabilities of forested wetlands so that this type of environmental damage is not repeated.

## CONCLUSIONS

1. TREE GROWTH - The trees immediately downstream of the sewage input (200 meters) showed an increase in growth during sewage loading as compared to the control plot and compared to growth previous to the sewage input.

2. SEWAGE EFFECTS ON BROWN MARSH SWAMP - The swamp system downstream of the spray field functioned normally after the cessation of sewage input. The trees appeared to be growing normally at the last sampling period.

3. SEWAGE EFFECTS ON TREE SPECIES - Black gum (*Nyssa sylvatica* var. *biflora*) showed the greatest increase in growth due to sewage loading. Tupelo gum (*Nyssa aquatica*) and baldcypress (*Taxodium distichum*) showed little growth change due to sewage loading.

4. DATA TYPES - Assessing growth changes in trees using tree cores provides more accurate results than using changes in d.b.h.. Cores are more difficult to remove from trees and more time consuming to interpret. The relative ease of measuring the change in d.b.h. is ideal for large numbers of samples.

## RECOMMENDATIONS FOR FUTURE RESEARCH

The following recommendations are proposed for future research in the area of sewage impacts on swamps in the Southeast and, in particular, trees that are specific to forested wetlands:

1. EFFECTS OF SEWAGE ON TREES - The effects of municipal and other types of sewage on bottomland hardwood trees should continue to be studied on longer time scales. This would enable scientists to determine any long-term positive or negative effects on the trees in these systems. In addition to studying the effects of sewage on flood-tolerant trees, studies undertaken to determine the effects on upland trees should proceed. Tree species that have commercial value may benefit from nutrient inputs such as municipal sewage. These high nutrient loads may be helpful in the re-establishment of forests that have been logged.

2. SEWAGE INTRODUCTION INTO SWAMPS - The effects of sewage on the entire swamp ecosystem are poorly understood because this method of sewage treatment has not been studied long. Therefore, more information is needed to determine whether this method of sewage treatment is helpful or harmful to wetlands. In addition, new methods of introducing municipal sewage into swamps should be explored to avoid disturbances

such as occurred at Brown Marsh Swamp. Sewage distribution designs should concentrate on maximizing the swamp's nutrient removal potential while creating the least disturbance to the system.

3. STUDY DESIGNS - The design of the study at Brown Marsh Swamp could be improved by a greater number and different location of permanent vegetation plots. Preliminary studies to determine the hydrology of the forested wetland would aid in the positioning of the plots in the direct flow of the sewage with as litle outside influence from other disturbances as possible. This would help in eliminating some of the variation in tree growth. Additional plots downstream of the spray field may have helped in the statistical analyses, although variation in the data would still be present. The regressions of the data may have been more conclusive if additional points were provided for the model. Research should also be conducted on the fate of nutrients as the move through swamps. Distance downstream is only a proxy for the nutrient concentration in the root zone of soils below a sewage outfall. An effective method of assessing nutrient change in swamp systems is needed to better understand the effects of sewage introduction.

4. ANALYSIS OF TREE GROWTH - The measurement of tree growth change as a result of sewage introduction into a swamp should be studied without the limitations of permanent plots. Cores and d.b.h. measurements should be taken at numerous known distances downstream of the sewage input to determine the effects of nutrients on all exposed trees down the concentration gradient.

Table 1 - Tree Species Identified in Brown Marsh Swamp and Key for Interpretation of Tree Species in Tables.

| KEY NAME | CORRESPONDING SPECIES | COMMON NAME |
|---|---|---|
| NYAQ | Nyssa aquatica | Tupelo gum |
| NYSY | Nyssa sylvatica v. biflora | Black gum |
| POHE | Populus heterophylla | Swamp cottonwood |
| FRAX | Fraxinus spp. | Ash |
| TADI | Taxodium distichum | Baldcypress |
| ACRU | Acer rubrum | Red maple |
| LIST | Liquidambar styraciflua | Sweet gum |
| QULA | Quercus laurifolia | Laurel oak |
| QULY | Quercus lyrata | Overcup oak |
| QUPH | Quercus phellos | Willow oak |
| ULAM | Ulmus americana | American elm |
| ULRU | Ulmus rubra | Slippery elm |
| ULSP | Ulmus spp. | Elm |

Table 2 - Calculations* for Core Sampling with a 1% Level of Significance.

| PLOT | N | R | t | E | n | Actual Sample Size |
|---|---|---|---|---|---|---|
| 5 | 129 | 4.7 | 3.355 | 1.19 | 9 | 10 |
| 6 | 61 | 3.9 | 4.032 | 0.84 | 6 | 10 |
| 8 | 161 | 4.4 | 4.032 | 1.02 | 6 | 13 |
| 9 NYAQ | 45 | 2.0 | 4.604 | 0.51 | 5 | 7 |
| 9 NYSY | 41 | 2.0 | 4.604 | 0.45 | 5 | 7 |
| 10 | 127 | 3.2 | 3.499 | 1.45 | 8 | 8 |
| TOTAL | | | | | | 55 |

* The range, R, was the largest less the smallest change in d.b.h. over the five years. The sample standard deviation, $s_y$ was calculated as R/4. The half-width of the 99% confidence interval was taken as twice the sample standard deviation, $s_y$. The calculated sample size from these specifications was only a guide to the minimum of the actual number of trees selected for coring.

Table 3 - Total and Relative Density of Trees in Spray Field Plots 1-4 at Brown Marsh Swamp, 1990

| TREE SPECIES | PLOT | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| TOTAL # TREES/PLOT | 17 | 12 | 21 | 41 |
| | RELATIVE DENSITY (%) | | | |
| NYAQ | 52.9 | 83.3 | 95.2 | 89.9 |
| NYSY | | | | 5.8 |
| POHE | 23.5 | | 7.3 | 2.9 |
| FRAX | 17.6 | | 31.7 | |
| TADI | | 16.7 | | 1.4 |
| ACRU | | | | |
| LIST | 5.9 | | | |
| QULA | | | | |
| QULY | | | | |
| QUPH | | | | |
| ULAM | | | | |
| ULRU | | | | |
| ULSP | | | | |
| | TOTAL DENSITY (TREES/$m^2$) | | | |
| | 0.03 | 0.02 | 0.04 | 0.08 |

Table 4 - Importance Values for Trees in Spray Field Plots 1-4 at Brown Marsh Swamp, 1990.

| TREE SPECIES | PLOT 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| NYAQ | 129.7 | 182.6 | 213.8 | 172.4 |
| NYSY | 12.2 | | 13.0 | 12.2 |
| POHE | 51.6 | 12.5 | 13.0 | 23.1 |
| FRAX | 40.0 | 18.8 | 19.6 | 53.5 |
| TADI | | 48.6 | | |
| ACRU | 18.6 | 18.8 | 25.3 | 18.4 |
| LIST | 41.9 | | 15.2 | 14.3 |
| QULA | | | | 6.1 |
| QULY | 6.1 | 6.3 | | |
| QUPH | | | | |
| ULAM | | | | |
| ULRU | | | | |
| ULSP | | | | |

Table 5 - Total and Relative Density for Trees in Downstream Plots 5-10 at Brown Marsh Swamp, 1990

| TREE SPECIES | PLOT 5 | 6 | 8 | 9 | 10 |
|---|---|---|---|---|---|
| TOTAL # TREES/PLOT | 141 | 69 | 168 | 117 | 157 |
| | | | RELATIVE DENSITY (%) | | |
| NYAQ | 91.4 | 89.9 | 95.8 | 40.2 | 76.4 |
| NYSY | | 5.8 | | 34.2 | 2.5 |
| POHE | | 2.9 | | | |
| FRAX | | | 1.2 | 1.7 | 13.4 |
| TADI | 2.1 | 1.4 | 2.4 | 3.4 | 1.3 |
| ACRU | 5.6 | | 0.6 | 5.1 | 3.8 |
| LIST | | | | 0.9 | 0.6 |
| QULA | | | | 12.8 | |
| QULY | | | | 0.9 | |
| QUPH | | | | | |
| ULAM | | | | | |
| ULRU | | | | | |
| ULSP | | | | | 0.6 |
| | | | TOTAL DENSITY (trees/$m^2$) | | |
| | 0.14 | 0.07 | 0.17 | 0.12 | 0.16 |

Table 6 - Importance Values for Trees in Downstream Plots 5-10 at Brown Marsh Swamp, 1990

| TREE SPECIES | PLOT 5 | 6 | 8 | 9 | 10 |
|---|---|---|---|---|---|
| NYAQ | 209.0 | 191.7 | 214.3 | 85.5 | 187.4 |
| NYSY | | 25.0 | | 82.9 | 16.6 |
| POHE | 15.4 | 15.5 | | | |
| FRAX | 23.1 | 15.8 | 24.4 | 19.5 | 34.1 |
| TADI | 22.4 | 15.2 | 18.9 | 18.4 | 15.6 |
| ACRU | 29.5 | 15.8 | 23.0 | 25.9 | 24.4 |
| LIST | | 12.3 | 17.1 | 14.1 | 15.8 |
| QULA | | 5.3 | | 40.6 | |
| QULY | | | | 8.6 | |
| QUPH | | | | | |
| ULAM | | 3.5 | | | |
| ULRU | | | 2.4 | | |
| ULSP | | | | 3.7 | 4.9 |

Table 7 - Two Factor ANOVA Using Tree Species and Plots as the factors

Two Factor ANOVA for d.b.h. Measurements
Dependent Variable: Growth
Multiple R: 0.413
Squared Multiple R: 0.171

ANOVA

| Source | S O S | D F | M S | F-Ratio | p |
|---|---|---|---|---|---|
| Tree | 31.043 | 2 | 15.522 | 18.645 | 0 |
| Plot | 20.92 | 4 | 5.23 | 6.282 | 0 |
| Tree * Plot | 22.959 | 8 | 2.87 | 3.447 | 0.001 |
| Error | 462.039 | 555 | 0.833 | | |

Two Factor ANOVA for Tree Cores
Dependent Variable: Growth
Multiple R: 0.596
Squared Multiple R: 0.356

ANOVA

| Source | S O S | D F | M S | F-Ratio | p |
|---|---|---|---|---|---|
| Tree | 0.004 | 2 | 0.002 | 0.456 | 0.636 |
| Plot | 0.052 | 4 | 0.013 | 3.203 | 0.019 |
| Tree * Plot | 0.023 | 8 | 0.003 | 0.708 | 0.684 |
| Error | 0.255 | 63 | 0.004 | | |

One Factor ANOVA for Tree Cores
Model-Growth=Constant+Distance
Multiple R: 0.596
Squared Multiple R: 0.356

ANOVA

| Source | S O S | D F | M S | F-Ratio | p |
|---|---|---|---|---|---|
| Regression | 0.062 | 1 | 0.062 | 14.269 | 0.001 |
| Residual | 0.333 | 76 | 0.004 | | |

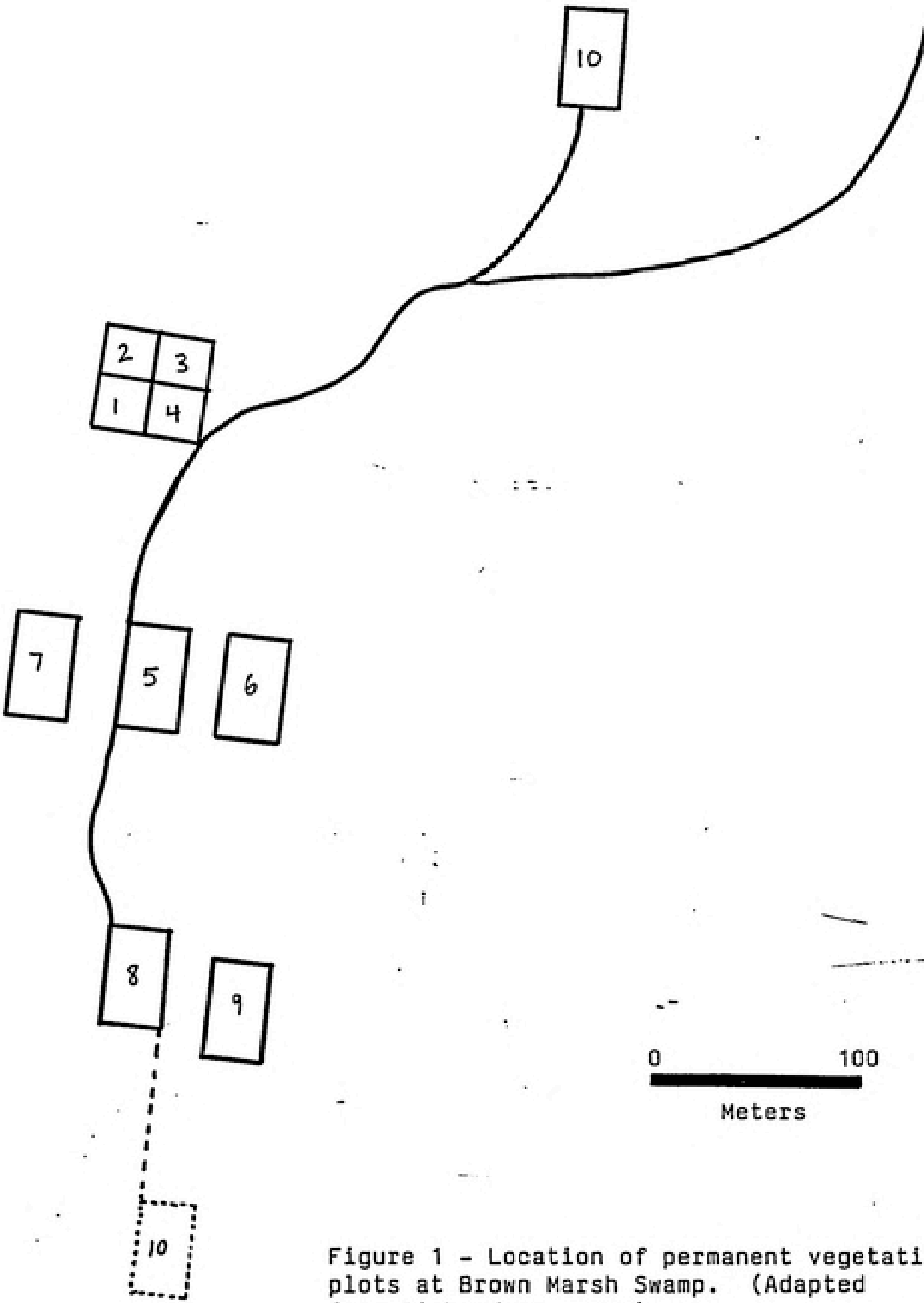


Figure 1 - Location of permanent vegetation plots at Brown Marsh Swamp. (Adapted from Richardson, 1988)

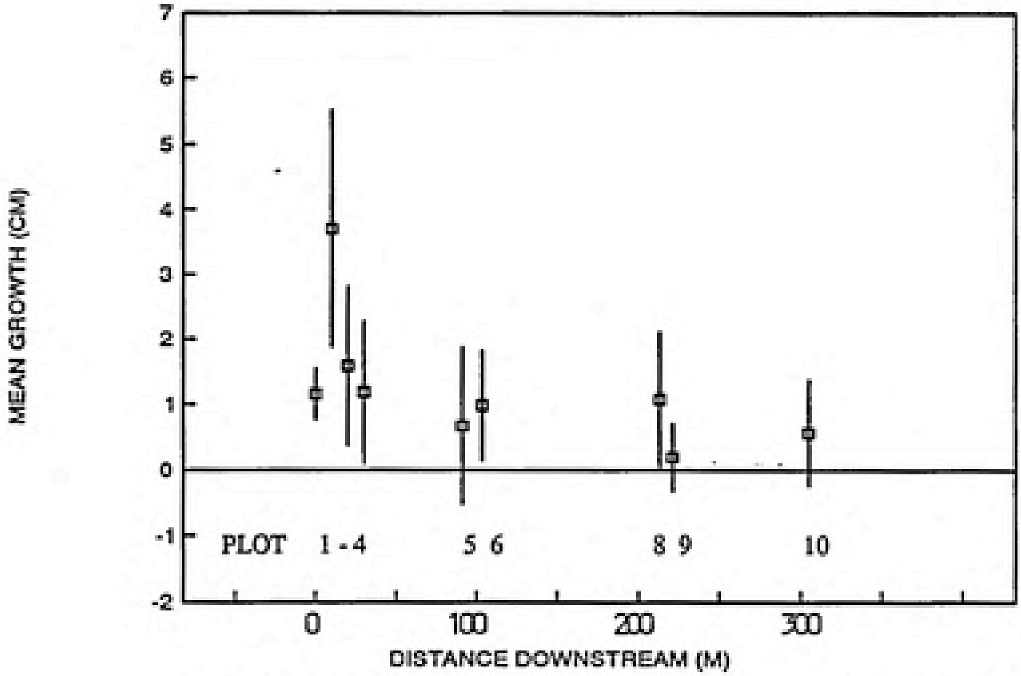


Figure 2 - The mean and standard error growth (cm.) of *Nyssa aquatica* including the spray field plots, from 1986 to 1990. (d.b.h. data)

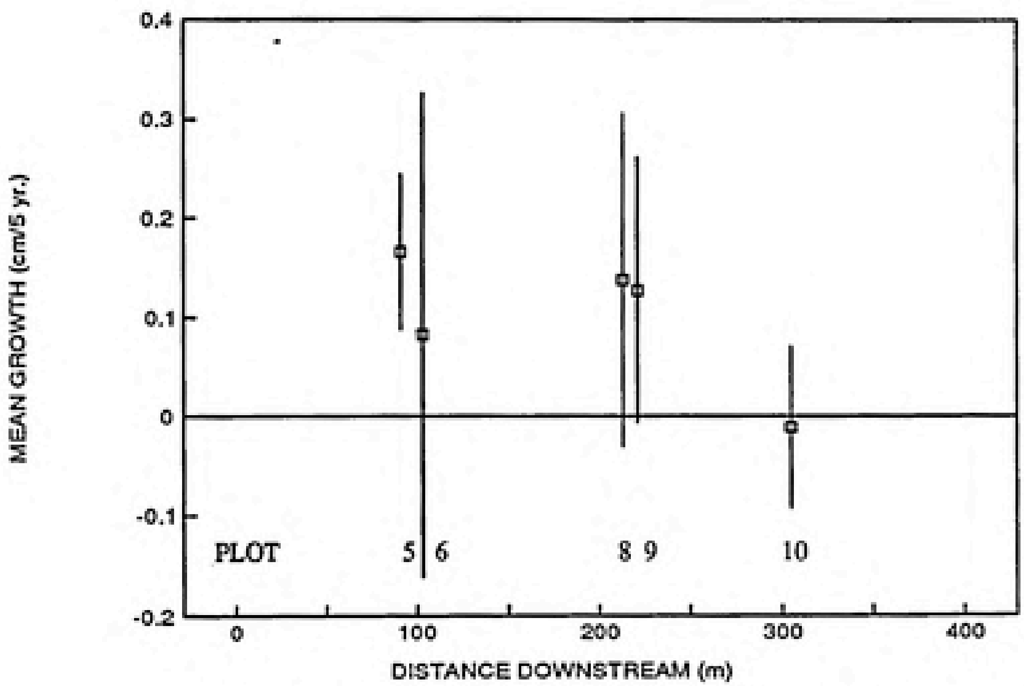


Figure 3 - The mean and standard error change in growth (cm.) of *Nyssa aquatica*. (Method 1 of core data: difference between 1986-1990 growth and 1981-1985 growth)

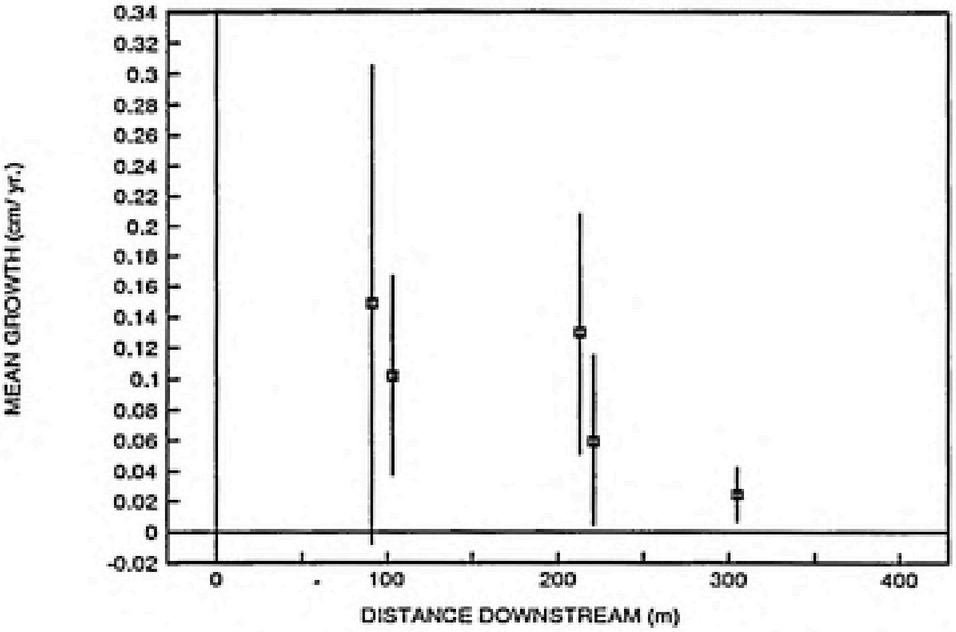


Figure 4 - The mean and standard error of change in growth (cm.) of *Nyssa aquatica*. (Method 2 of core data: difference between 1986-1987 growth and 1988-1990 growth)

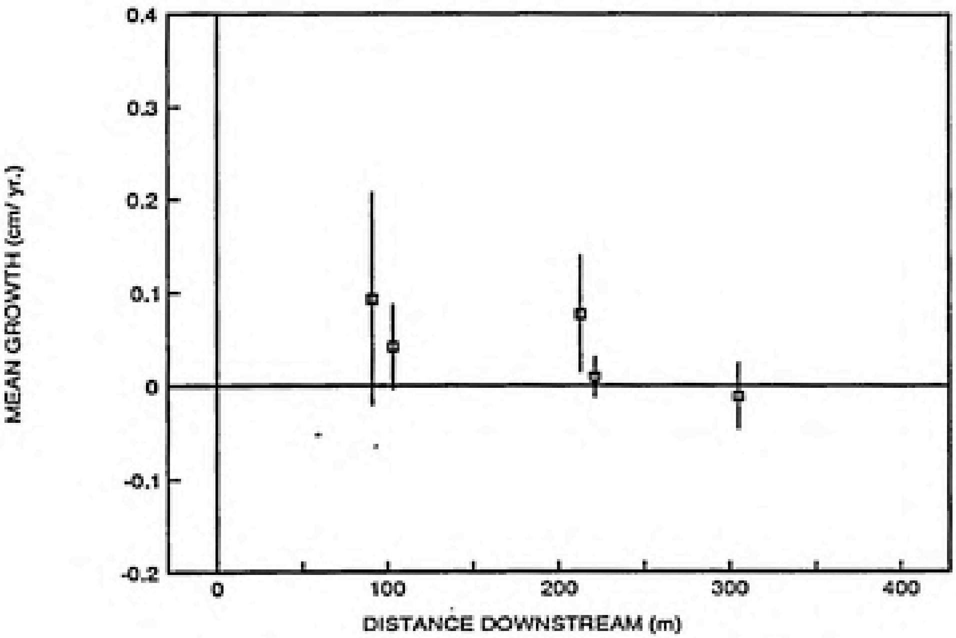


Figure 5 - The mean and standard error of change in growth (cm.) of *Nyssa aquatica*. (Method 3 of core data: difference between 1986-1987 growth and 1984-1985 growth)

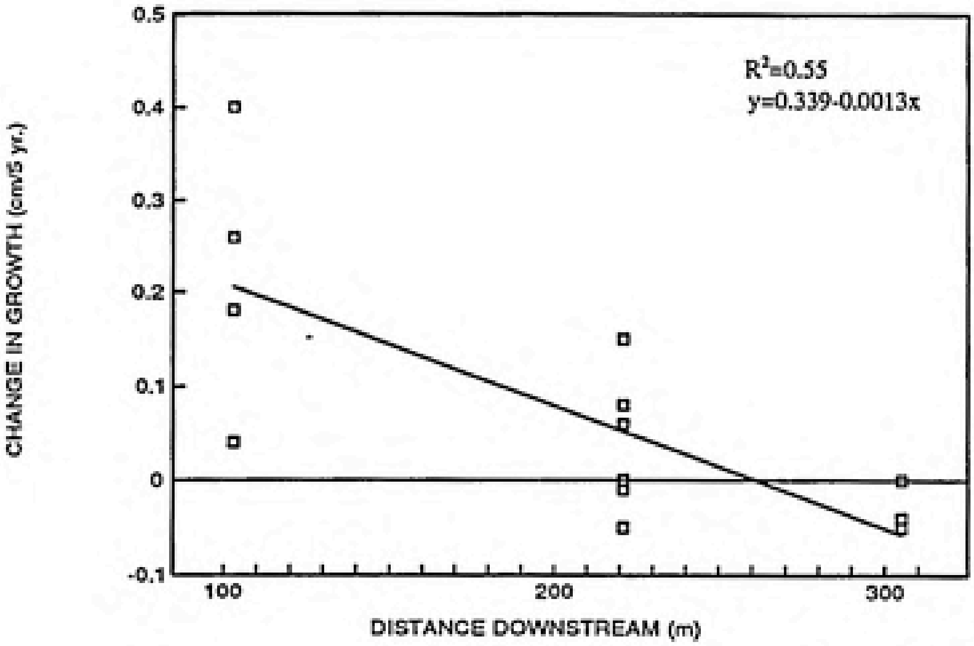


Figure 6 - Regression diagram of change in growth (cm.) of *Nyssa sylvatica* var. *biflora* including Plot 10. (Method 1 of core data: difference between 1986-1990 growth and 1981-1985 growth)

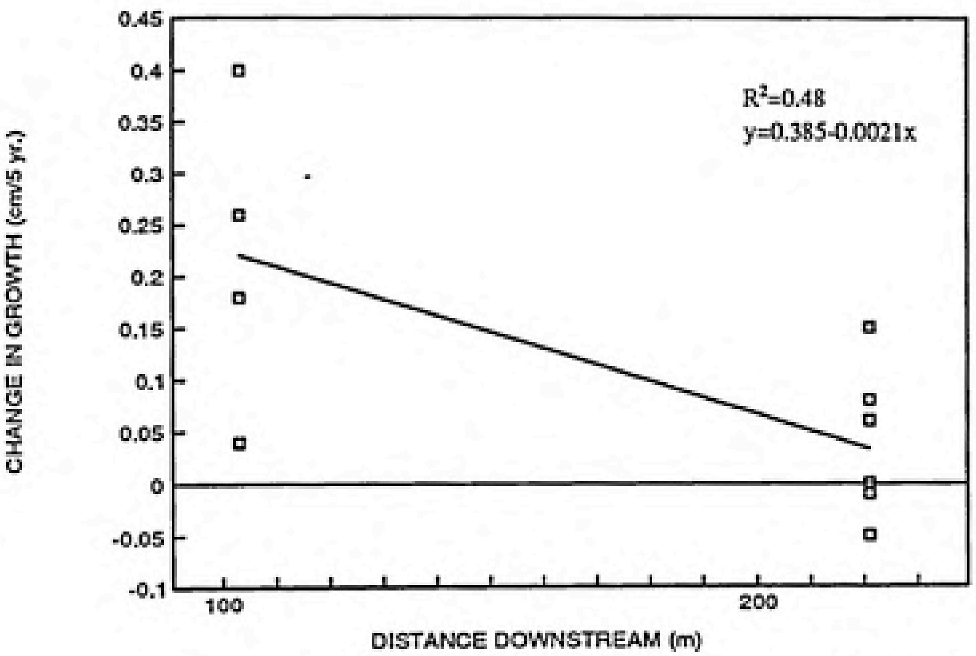


Figure 7 - Regression diagram of change in growth (cm.) of *Nyssa sylvatica* var. *biflora* excluding PLot 10. (Method 1 of core data: difference between 1986-1990 growth and 1981-1985 growth)

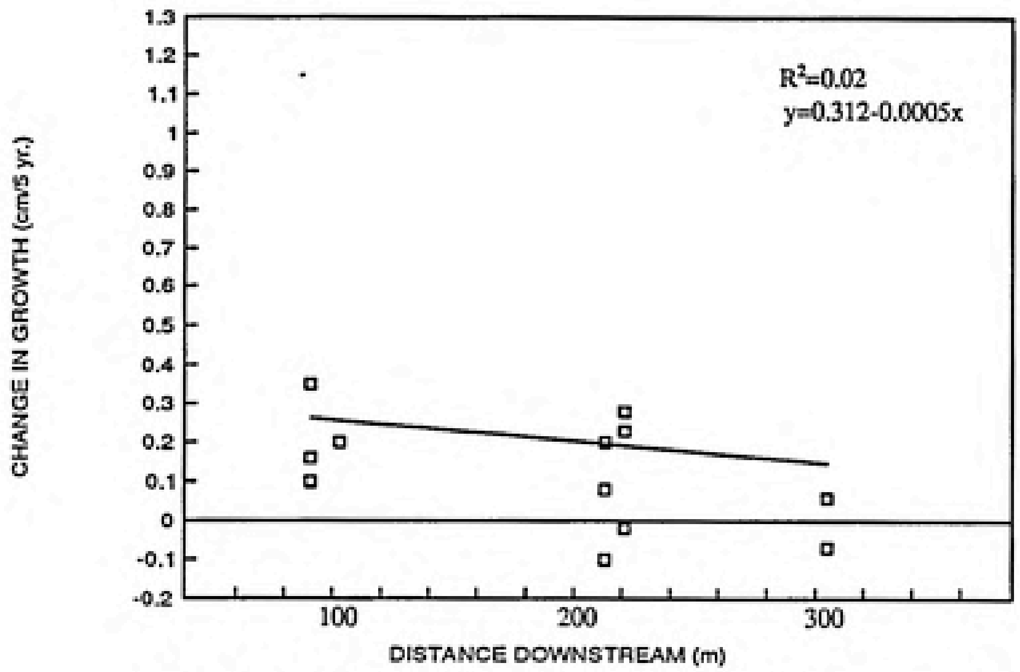


Figure 8 - Regression diagram of change in growth (cm.) of *Taxodium distichum* including Plot 10. (Method 1 of core data: difference between 1986-1990 growth and 1981-1985 growth)

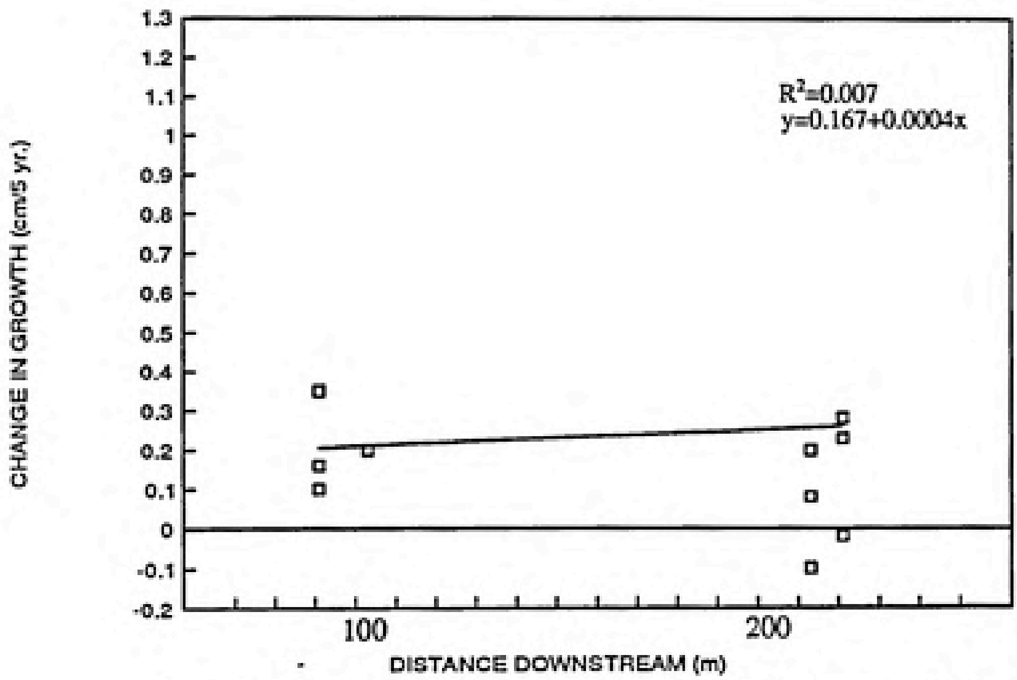


Figure 9 - Regression diagram of change in growth (cm.) of *Taxodium distichum* excluding Plot 10. (Method 1 of core data: difference between 1986-1990 growth and 1981-1985 growth)

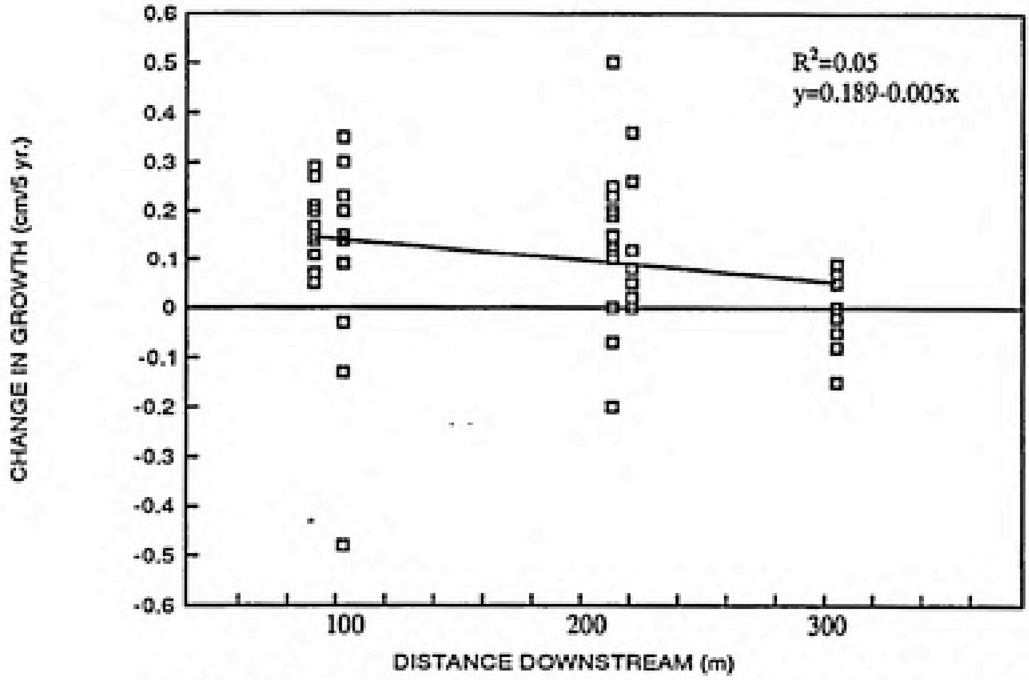


Figure 10 - Regression diagram of change in growth (cm.) of *Nyssa aquatica* including Plot 10. (Method 1 of core data: difference between 1986-1990 growth and 1981-1985 growth)

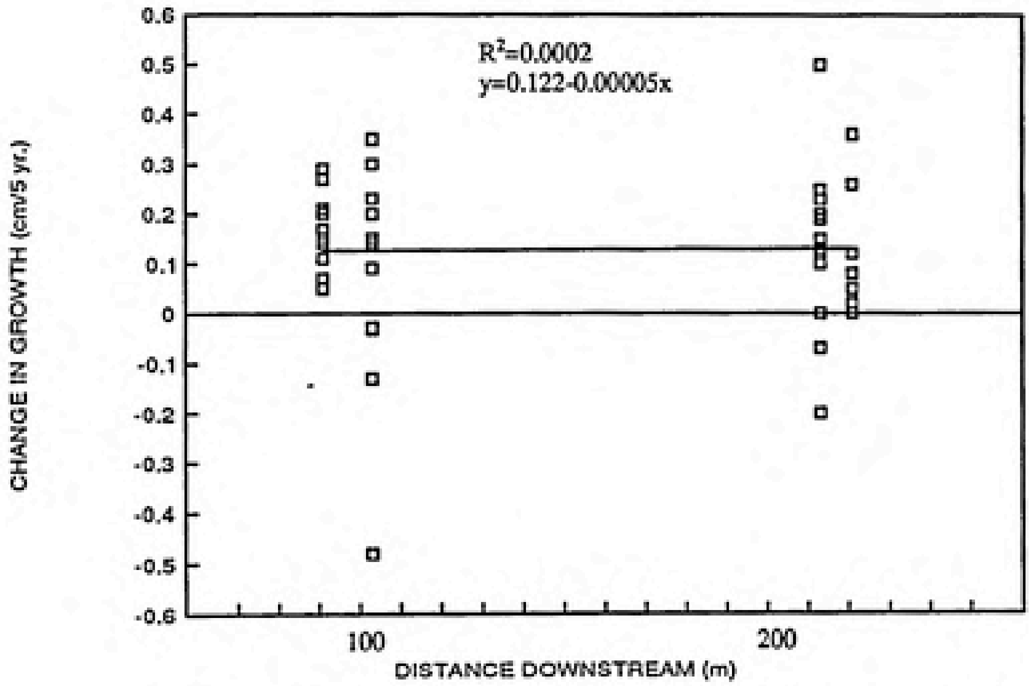


Figure 11 - Regression diagram of change in growth (cm.) of *Nyssa aquatica* excluding Plot 10. (Method 1 of core data: difference between 1986-1990 growth and 1981-1985 growth)

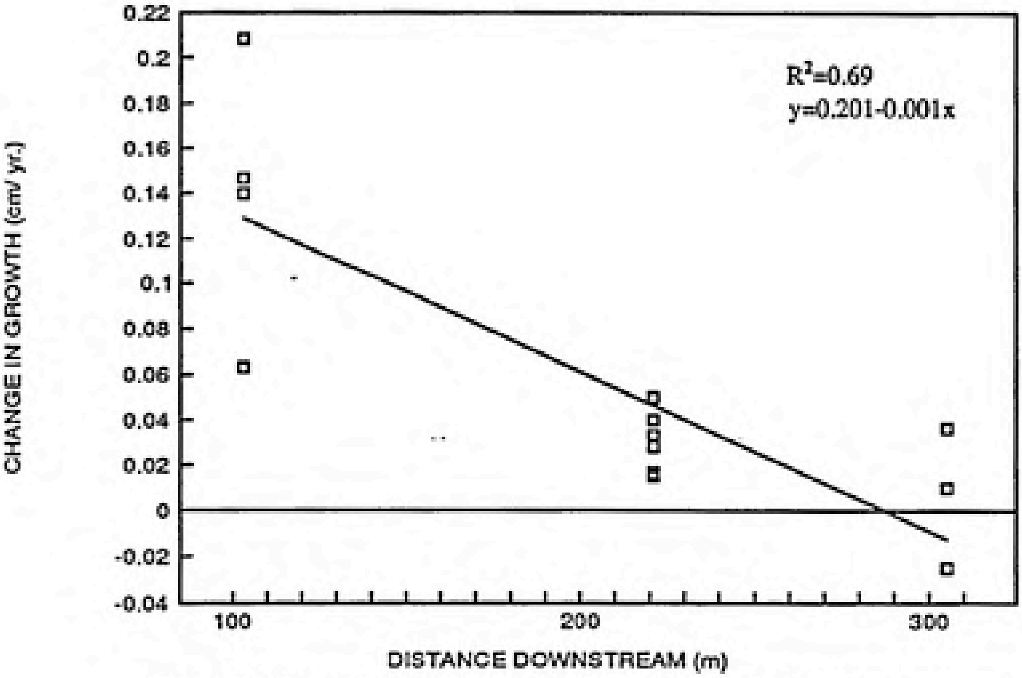


Figure 12 - Regression diagram of change in growth (cm.) of *Nyssa sylvatica* var. *biflora* including Plot 10. (Method 2 of core data: difference between 1986-1987 growth and 1988-1990 growth)

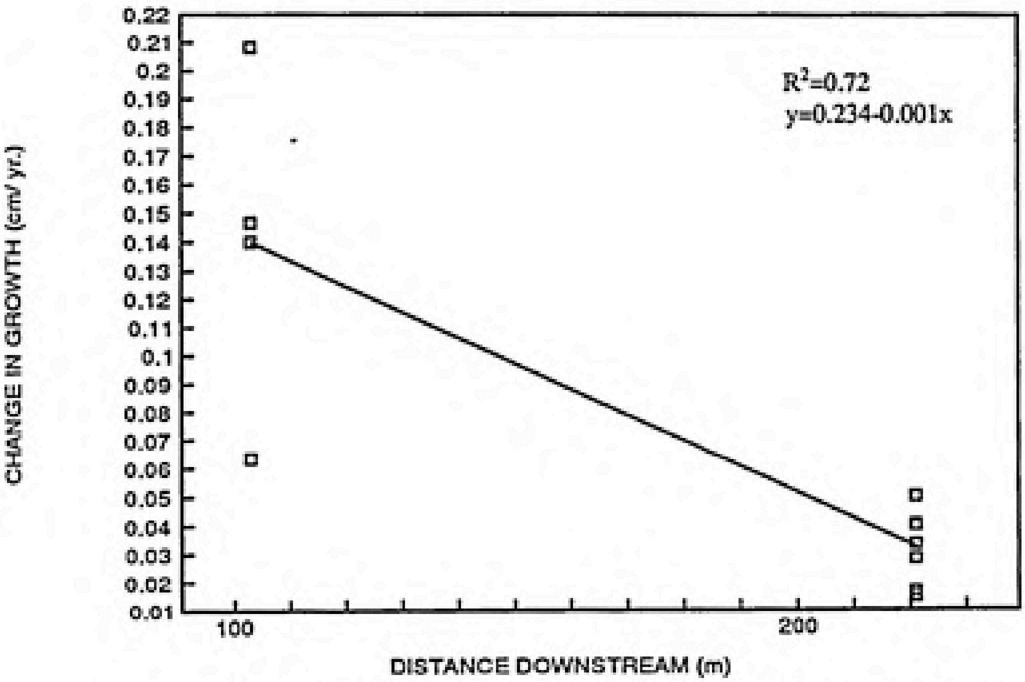


Figure 13 - Regression diagram of change in growth (cm.) of *Nyssa sylvatica* var. *biflora* excluding Plot 10. (Method 2 of core data: difference between 1986-1987 growth and 1988-1990 growth)

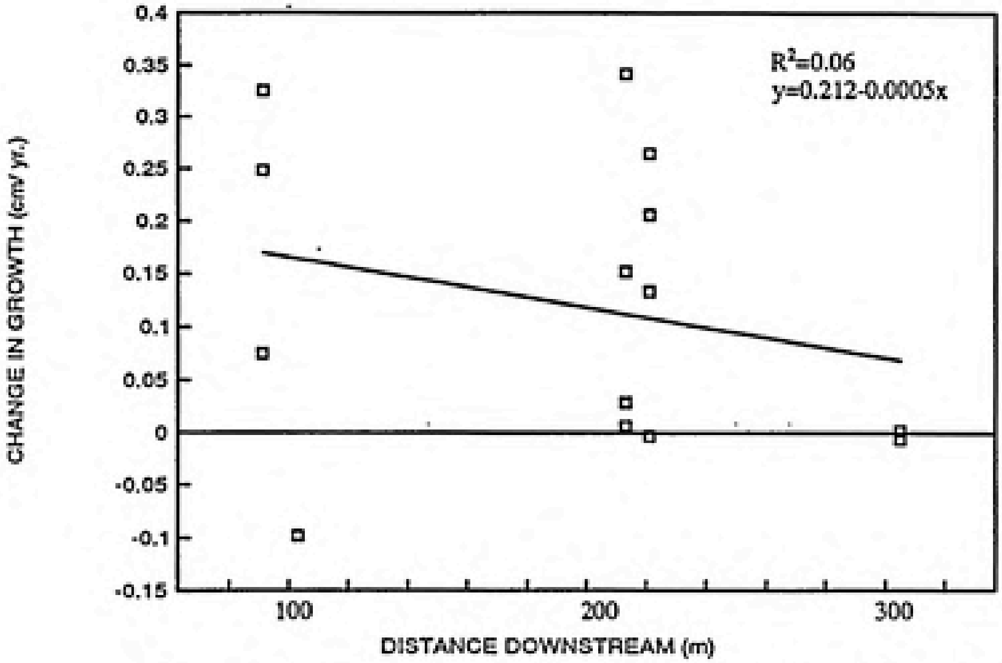


Figure 14 - Regression diagram of change in growth (cm.) of *Taxodium distichum* including Plot 10. (Method 2 of core data: difference between 1986-1987 growth and 1988-1990 growth)

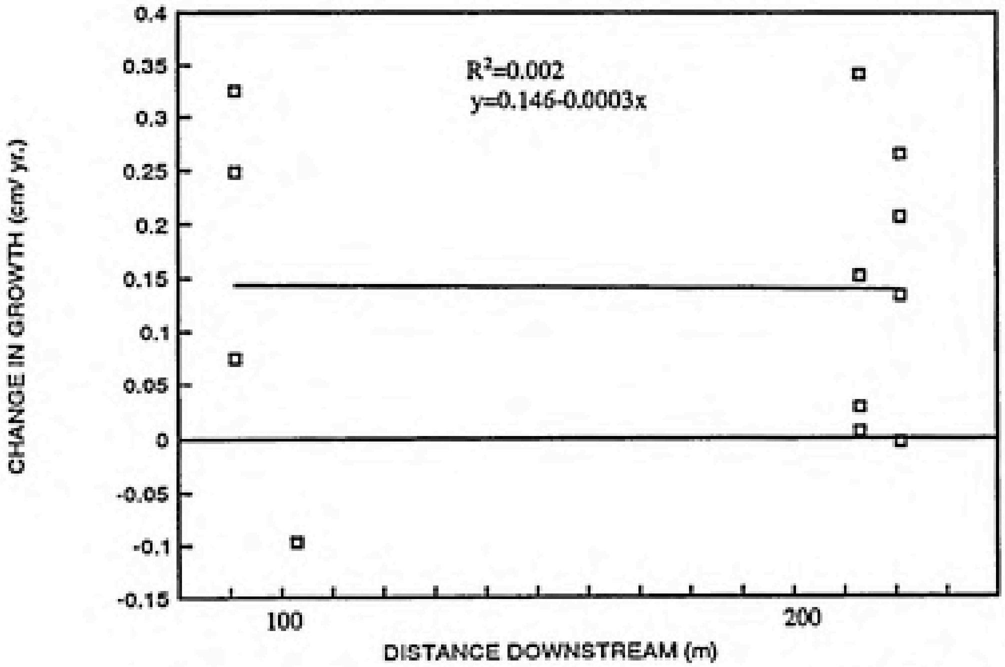


Figure 15 - Regression diagram of change in growth (cm.) of *Taxodium distichum* excluding Plot 10. (Method 2 of core data: difference between 1986-1987 growth and 1988-1990 growth)

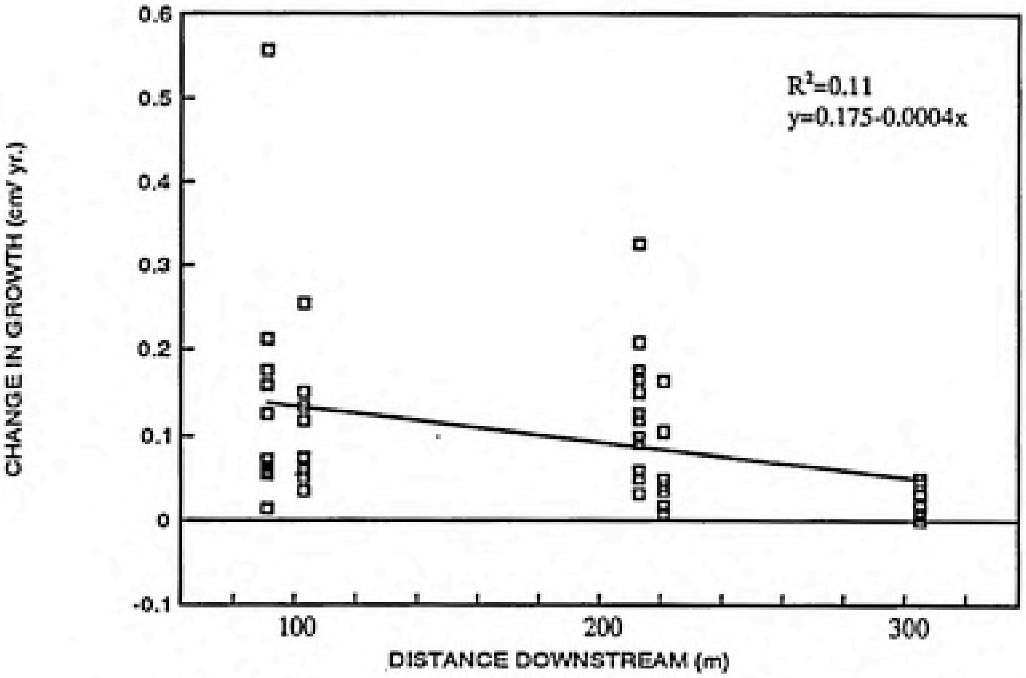


Figure 16 - Regression diagram of change in growth (cm.) of *Nyssa aquatica* including Plot 10. (Method 2 of core data: difference between 1986-1987 growth and 1988-1990 growth)

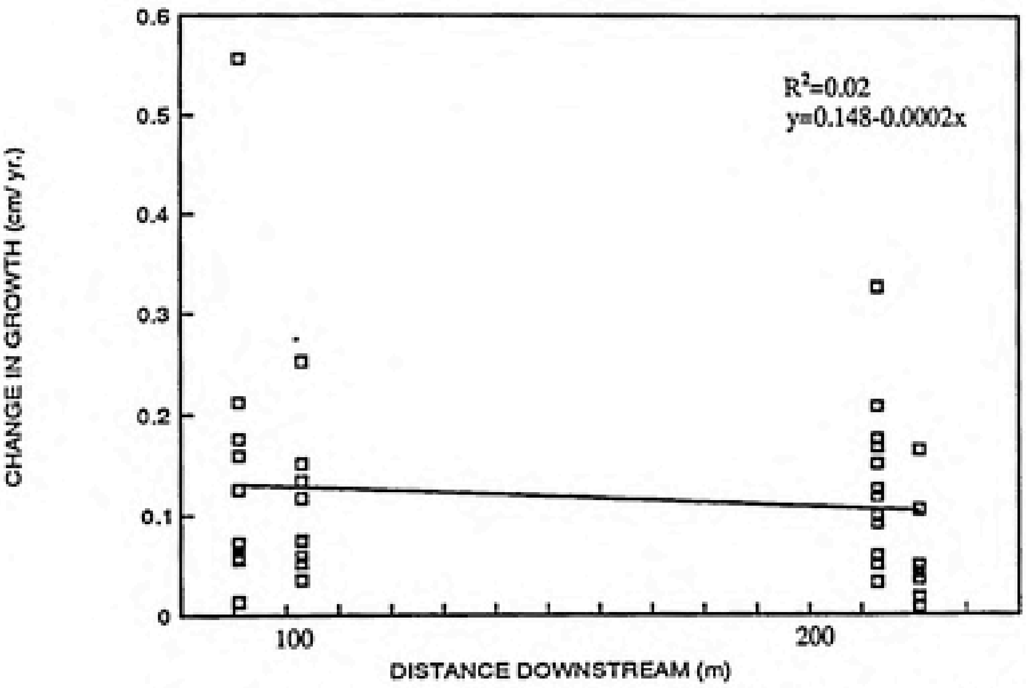


Figure 17 - Regression diagram of change in growth (cm.) of *Nyssa aquatica* excluding Plot 10. (Method 2 of core data: difference between 1986-1987 growth and 1988-1990 growth)

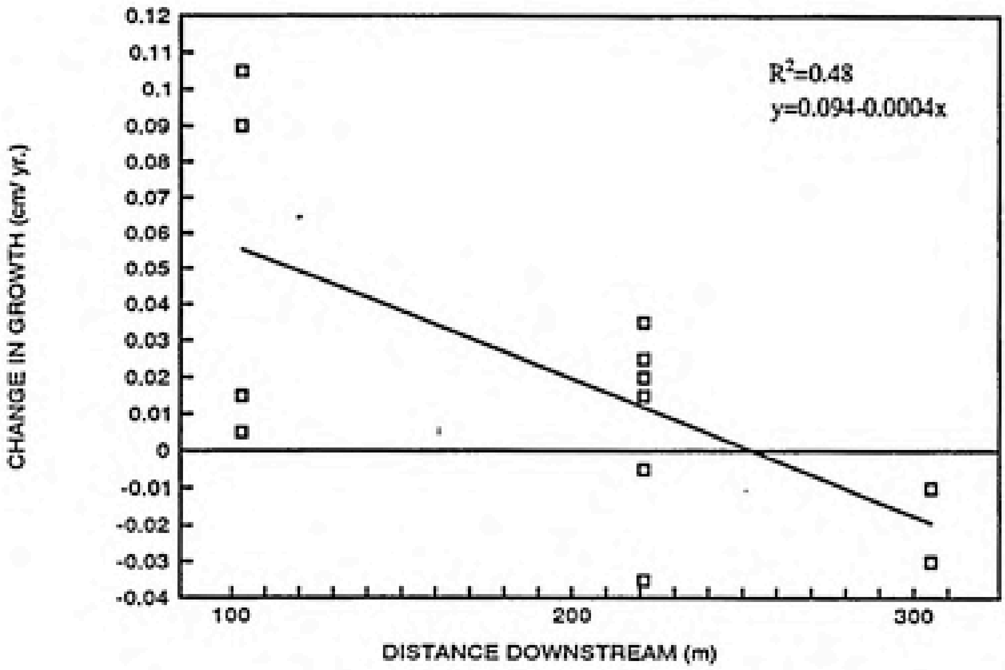


Figure 18 - Regression diagram of change in growth (cm.) of *Nyssa sylvatica* var. *biflora* including Plot 10. (Method 3 of core data: difference between 1986-1987 growth and 1984-1985 growth)

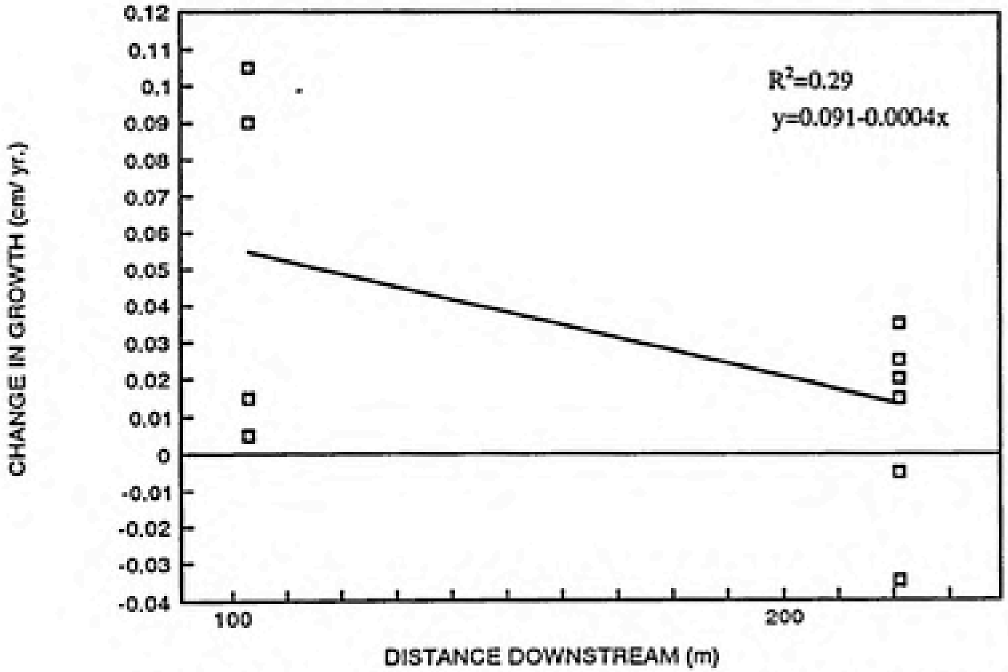


Figure 19 - Regression diagram of change in growth (cm.) of *Nyssa aylvatica* var. *biflora* excluding Plot 10. (Method 3 of core data: difference between 1986-1987 growth and 1984-1985 growth)

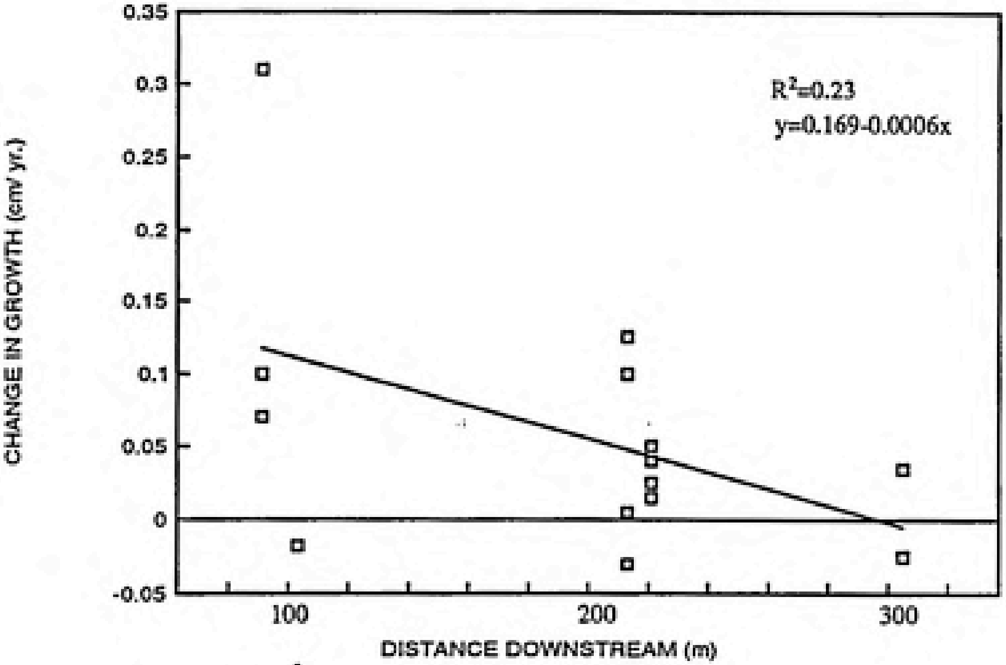


Figure 20 - Regression diagram of change in growth (cm.) of *Taxodium distichum* including Plot 10. (Method 3 of core data: difference between 1986-1987 growth and 1984-1985 growth)

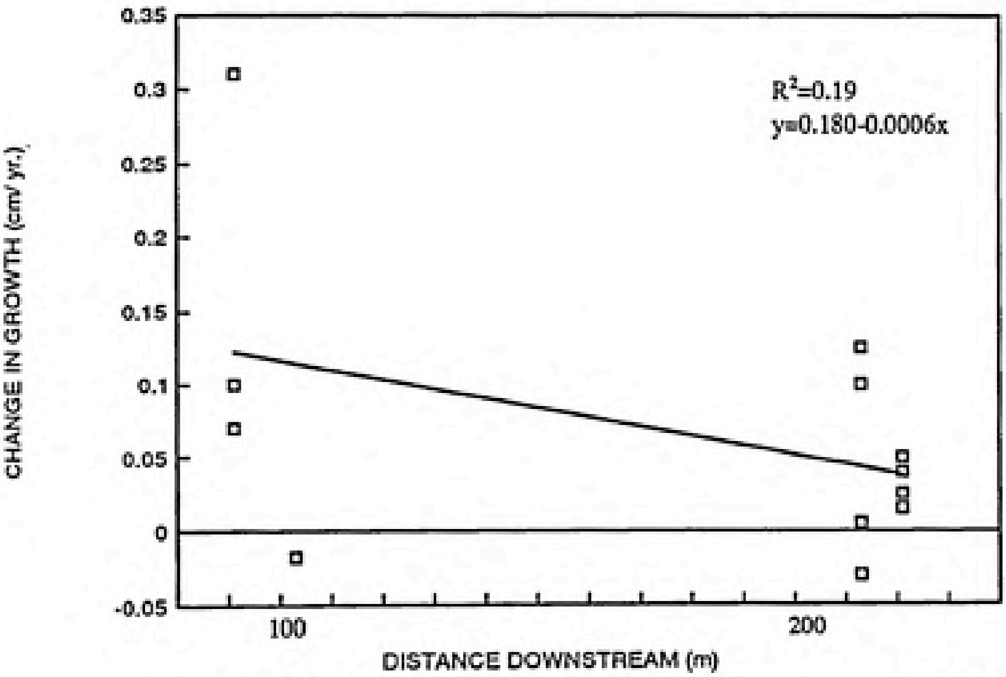


Figure 21 - Regression diagram of change in growth (cm.) of *Taxodium distichum* excluding Plot 10. (Method 3 of core data: difference between 1986-1987 growth and 1984-1985 growth)

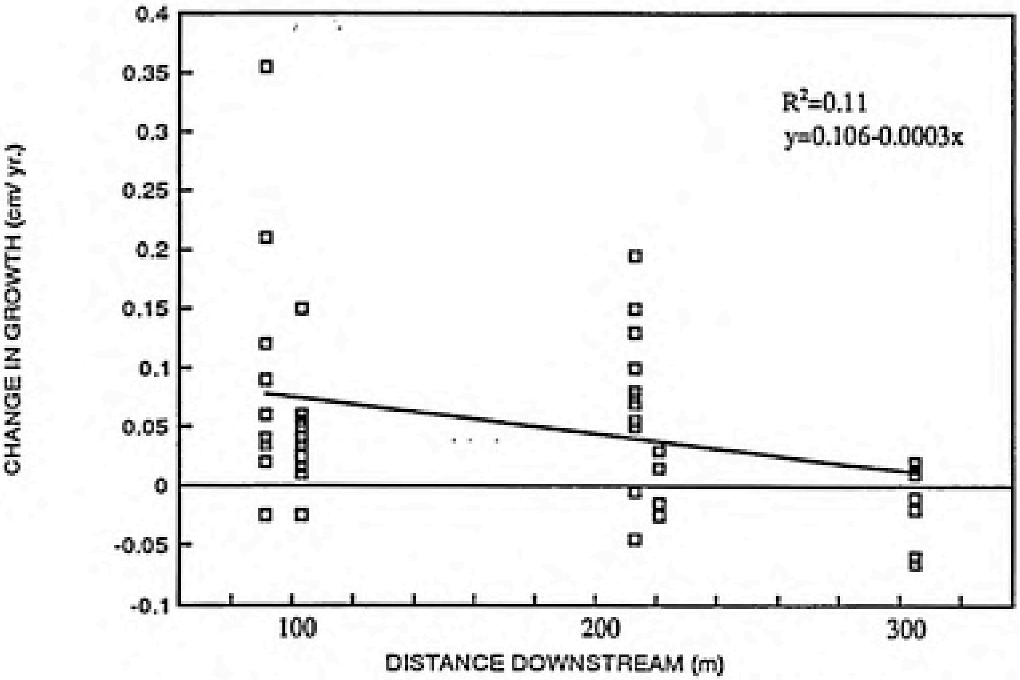


Figure 22 - Regression diagram of change in growth (cm.) of *Nyssa aquatica* including Plot 10. (Method 3 of core data: difference between 1986-1987 growth and 1984-1985 growth)

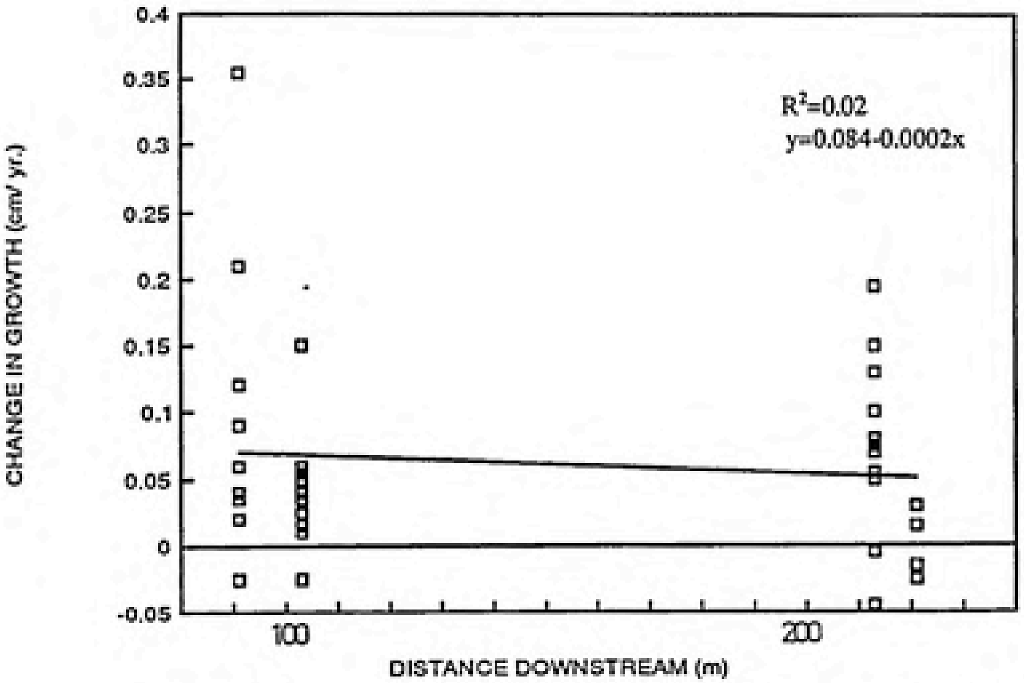


Figure 23 - Regression diagram of change in growth (cm.) of *Nyssa aquatica* excluding Plot 10. (Method 3 of core data: difference between 1986-1987 growth and 1984-1985 growth)

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