Long-Term Growth Enhancement of Baldcypress (*Taxodium distichum*) from Municipal Wastewater Application

I. D. HESSE[1]*
J. W. DAY, JR.
Coastal Ecology Institute and Department of Oceanography and Coastal Sciences
Center for Coastal, Energy, and Environmental Resources
Louisiana State University
Baton Rouge, Louisiana 70803, USA

T. W. DOYLE
US Geological Survey
National Wetlands Research Center
700 Cajundome Blvd.
Lafayette, Louisiana 70506, USA

ABSTRACT / Tree ring analysis was used to document the long-term effects of municipal wastewater on the growth rate of baldcypress [*Taxodium distichum* (L.) Rich.]. The study site, a swamp in St. Martin Parish, Louisiana, has received municipal wastewater for the last 40 years. Growth chronologies from 1920 to 1992 were developed from cross-dated tree core samples taken from treated and control sites with similar size and age classes. Mean diameter increment (DINC) and mean basal area increment (BAI) chronologies were constructed separately for each stand. These chronologies were then summarized by tree and stand into seven nine-year intervals resulting in three pretreatment intervals from 1926 to 1952 and four treatment intervals from 1953 to 1988. Significant differences in growth response between sites showed a consistent pattern of growth enhancement in the treated site coincident with the onset of effluent discharge. The ratio of treated to control baldcypress growth rates (computed from DINC) averaged 0.74 during the pretreatment period and 1.53 during the treatment period. Over the period of study, control DINC decreased from 77 mm to 29 mm/nine-year interval, while treatment DINC increased slightly from 40 mm to 47 mm/nine-year interval. Control BAI did not increase significantly and averaged 192 cm^2/nine-year interval. There was a significant increase in treatment BAI from 129 to 333 cm^2/nine-year interval over the period of record. These results clearly demonstrate sustained long-term baldcypress growth enhancement throughout 40 years of municipal effluent discharge.

Swamp and bottomland hardwood forests are among the most productive wetland ecosystems (Conner and Day 1976, Brown and Peterson 1983). These freshwater forests provide wildlife and fish habitat, improve water quality, attenuate flood peaks, produce timber products, and provide recreational opportunities (Brinson and others 1981, Mitsch and Gosselink 1986). Floodplain forests have also been used to receive wastewater runoff from nearby communities. Many small municipalities lack the facilities and funds for tertiary waste treatment and have considered discharge to wetlands as an alternative to conventional treatment. The use of natural wetlands to treat municipal wastewater offers economical, as well as biological benefits (Fritz and others 1984, Godfrey and others 1985, Breaux and Day 1994).

Studies have shown that swamp forests chemically, physically, and biologically remove pollutants, sediments, and nutrients from water flowing across the forest floor (Kitchens and others 1975, Boyt 1976, Yarbro 1979, Nessel and Bayley 1984, Kuenzler 1987). In general, wastewater additions to natural systems enhance marsh and forest productivity (Sopper and Kardos 1973, Valiela and others 1975, Woodwell 1977, Shure and Hunt 1981), although the effects of these applications on ecosystem structure and function are still being examined. Studies of baldcypress [*Taxodium distichum* (L.) Rich] response in wetlands receiving wastewater have reported increases in tree growth (Mitsch and Ewel 1979, Brown 1981, Nessel and others 1982, Lemlich and Ewel 1984). Some studies, however, have found neutral or negative effects of effluent application on cypress tree growth. For example, wastewater addition did not increase productivity (Straub 1984) or productivity varied with species variety i.e.,

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[1] *Present address:* 6491 Ace Ct., Longmont, Colorado 80503, USA; e-mail ⟨shesse@indra.com⟩.

*Author to whom correspondence should be addressed.

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pondcypress [*Taxodium distichum* var. *nutans* (Ait.) Sweet] vs baldcypress, (Deghi 1984)].

The use of wetlands in Louisiana for tertiary treatment of municipal wastewater is especially promising. Forested wetlands represent a large area, comprising approximately 2,281,000 ha (Turner and Craig 1981). Louisiana's subtropical climate and long growing season provide near optimum conditions for nutrient assimilation. Coastal water quality problems are widespread due, in part, to inadequate sewage treatment (LDEQ 1988). Finally, the addition of nutrients and sediments can potentially mitigate declines in swamp productivity due to increased flooding caused by sea-level rise and subsidence (Conner and others 1993). The increased duration of flooding that may accompany wastewater disposal could affect the growth rates of baldcypress (Eggler and Moore 1961, Mitsch and others 1979, Duever and McCollom 1987, Stahle and others 1992, Young and others 1995)—an extremely flood-tolerant species occurring in the Atlantic and Gulf coastal plains from southeastern Texas to southern Delaware, the lower Mississippi River Valley and bottomlands of adjacent drainage areas from Louisiana to southern Illinois and southwestern Indiana.

Baldcypress is one of the most valuable trees (economically and ecologically) of the floodplain forest (Brown and Montz 1986). Baldcypress seeds are eaten by ducks (Martin and others 1961) and squirrels (Brown and Montz 1986), and the sandhill crane eats both the seeds and leaves (Martin and others 1961). Both past and present uses of baldcypress make this species important economically. The heartwood's exceptional resistance to decay has made cypress a favored wood in the construction of buildings, boats, river pilings, and furniture, among many other uses (Brown and Montz 1986).

In this study, we used growth-ring analyses to evaluate the effect of almost 40 years of wastewater discharge on baldcypress. We hypothesized that the addition of wastewater would increase the growth of baldcypress.

Materials and Methods

Site History

The study was conducted in the Cypriére Perdue Swamp, a freshwater forested wetland located in St. Martin Parish, Louisiana (latitude 30°16′N, longitude 91°54′W). It is primarily a baldcypress–water tupelo swamp with an approximate area of 1400 ha. The site is located approximately 2 km southwest of the City of Breaux Bridge, which has discharged secondarily treated municipal effluent into this wetland for more than 40 years (Figure 1). During this time, the city's population increased from 2492 in 1950 (US Department of Commerce 1952) to 6515 in 1990 (US Department of Commerce 1992). Large-scale industrial logging of baldcypress took place in Louisiana from 1890 to 1925, but investigations by Mancil (1972) failed to document the occurrence of this type of logging in St. Martin Parish. Occasional decayed baldcypress stumps found in parts of this wetland indicate that selective logging activity occurred at some point in its history.

Site Characterization

Major vegetative species include baldcypress, water tupelo (*Nyssa aquatica* L.), and red maple (*Acer rubrum* L.). Soils in the study area are classified as Fausse series and characterized by very fine, montmorillonitic, nonacid, thermic Typic Fluvaquents (Murphy and others 1977). St. Martin Parish has a humid, subtropical climate and is characterized by long, hot summers and short, mild winters. The area has a mean annual temperature of 20.2°C and an annual precipitation of 148 cm (Murphy and others 1977). Hydrologic inputs to the site include precipitation, runoff from higher areas, and occasional backwater flooding from the Vermilion River.

Effluent History and Stand Selection

Effluent history was reconstructed from recorded minutes of biweekly city council meetings and from information obtained from townspeople involved with the city's past wastewater treatment operations. Prior to 1946, there was no direct discharge to the swamp because Breaux Bridge, like many small towns in Louisiana at that time, used individually owned septic tanks. By 1948, a sewer network was functioning (without a fully operational treatment facility) and was probably introducing raw sewage to the treated stand.

In 1953, a trickling filter system was installed approximately 1000 m east of the swamp. Municipal wastewater flowed from the trickling filter system, through the Bridge St. canal, and into the swamp at point A (Figure 1; B. Bertrand, city employee, personal communication). Oxidation pond 1 was completed in 1970, by which time the trickling filter system had become nonoperational (Calvin Courville, city engineer, personal communication). Wastewater flowed through oxidation pond 1 and discharged at point B. Two smaller oxidation ponds (2 and 3) were in use by 1980 and wastewater entered the swamp at point C.

Two forest stands, similar in species composition, size, age, and density, were identified within the receiving wetland. One stand, located within the general flow of wastewater effluent downstream from various points of discharge (A, B, and C), served as the treated site.

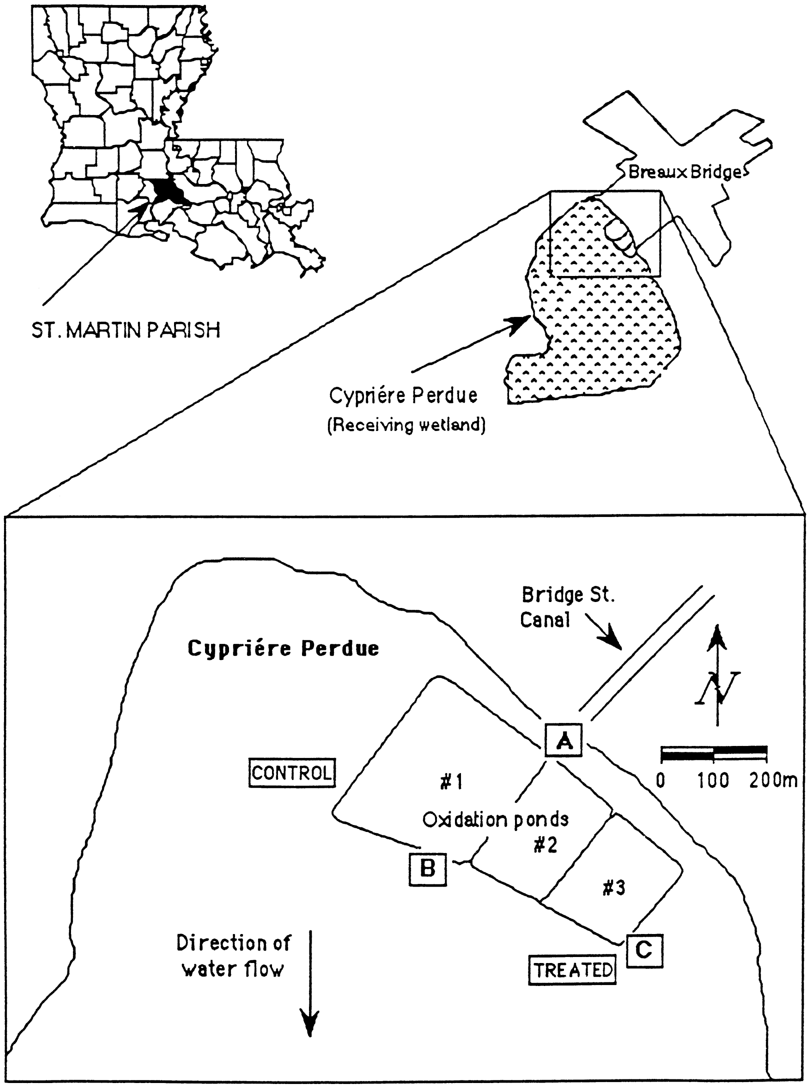

Figure 1. The study site, Cypriére Perdue Swamp, located in St. Martin Parish about 2 km southwest of the Breaux Bridge, Louisiana. Location of the sample sites (treated and control) and points of wastewater discharge through time are shown (A, 1953–1970; B, 1971–1979; and C, 1980–1988).

Actual locations of discharge points A, B, and C were fairly close and were expected to pose less of an effect by location than by the qualitative differences in water quality between time periods. A control site was established in another stand, 700 m upstream from the treated site in the same drainage system. The control site is 9.1 cm higher in elevation than the treated site (Day and others 1993). Individual trees were tagged and measured for diameter at core height, crown ratio, and crown class.

Sample Collection and Processing

Duplicate cores, taken from opposite sides of the bole, were extracted in the spring of 1993 using a 40-cm (16-in.) increment borer. A total of 80 cores was collected from 20 selected codominant baldcypress in each stand. Standard coring methods were modified to extract cores from a concentric bole above the buttress of each tree. Bowers (1981) showed that a greater number of false rings on lobe samples and more missing or merging rings occurred on the furrows of the fluted bole of baldcypress. Core samples were dried and glued into grooved core mounts (Stokes and Smiley 1968, Phipps 1985). A fine polished finish was achieved on each core by sanding with increasingly finer grits of sandpaper to obtain maximum ring definition.

Ring dating was accomplished using standard procedures outlined in Stokes and Smiley (1968). Dating was validated by means of a cross-correlation procedure using time-series offsets to verify dating and measurement accuracy. Reliable dating was attained for 15 trees from the treated site and 17 trees from the control sites. Annual ring widths from 1920 to 1992 were measured to an accuracy of 0.01 mm with the aid of a microscope and a Henson tree-ring measuring system. This sampling period was chosen to provide 30+ years of both pretreatment and treatment growth.

Data analysis

Bole diameter at point of coring and pith dates were used to establish size and age class distributions for both stands. A Satterthwaite-Cochran *t* test procedure was used to test for differences in size structure between stands. Diameter increment (DINC) series were developed for the period 1920 to 1992 for each tree by summing annual ring widths from the duplicate cores. Tree diameter and DINC values were then used to derive yearly basal area increment (BAI). BAI values reduce the effect of decreasing ring widths and year-to-year variation that occur with increasing circumference of the tree (Ewel and Parendes 1984). Mean DINC and mean basal area increment (BAI) chronologies were constructed separately for each stand. A growth ratio by year was then calculated from DINC by comparing mean chronologies of the treated versus control groups to illustrate growth differences between them.

For analytical purposes, growth chronologies of diameter increment and basal area increment were summarized by tree and stand into seven nine-year intervals: 1926–1934, 1935–1943, 1944–1952, 1953–1961, 1962–1970, 1971–1979, and 1980–1988. This resulted in three pretreatment intervals from 1926 to 1952 and four treatment intervals from 1953 to 1988. Tukey's studentized range (HSD) test was used to test for growth differences between the control and treated stands for each interval by period, prior to (1926–1952) and during (1953–1988) wastewater application. The fourth, sixth, and seventh intervals coincided with the initialization of effluent discharge traveling through the trickling filter system; oxidation pond 1; and oxidation pond's 1, 2, and 3, respectively. A repeated measures analysis of variance (ANOVAR) was used to test for differences in growth between intervals and stands after initial wastewater application in 1953 (Proc GLM; SAS Institute 1989).

Results

Size and age structure were comparable between trees sampled in the treated and control stands. Sampled trees in the treated stand were slightly larger (49.0 ± 8.3 cm diameter at coring height) and older (92 ± 26 years) compared to the control (45.7 ± 5.7 cm diameter at coring height and 83 ± 14 years, respectively). No significant differences were found in size class distributions between sampled groups ($\alpha = 0.05$, Satterthwaite-Cochran *t* test). Tree diameters on the control site ranged between 40 and 60 cm, whereas sizes on the treated site ranged between 40 and 70 cm (Figure 2). Age class distributions were also similar between the control and treated sites. With the exception of one individual from the treated site dating to 1842, recruitment years ranged from 1870 to 1940 and from 1880 to 1930 for the treated and control sites, respectively (Figure 3).

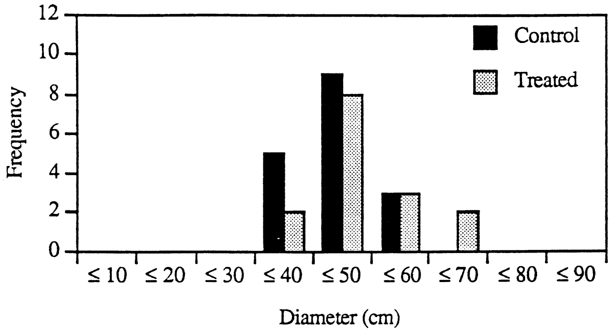

Figure 2. Size class distribution of baldcypress from the treated and control sites in the Cypriére Perdue Swamp.

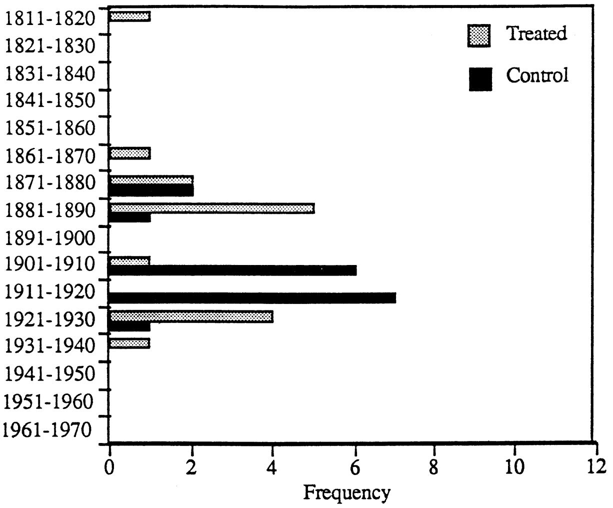

Figure 3. Recruitment year distribution and average age of baldcypress from the treated and control sites in the Cypriére Perdue Swamp.

Growth trend differences between the DINC and BAI chronologies are apparent as DINC declined slightly with age (Figure 4a), while BAI increased over time (Figure 4b). Year-to-year variations in growth due to climate conditions (precipitation and temperature) are consistent in both the control and treated chronologies.

The ratio of treated to control mean annual growth from 1920 to 1992 clearly shows an increase in treated growth relative to control during the treatment period (1953–1992, Table 1). Control growth was greater

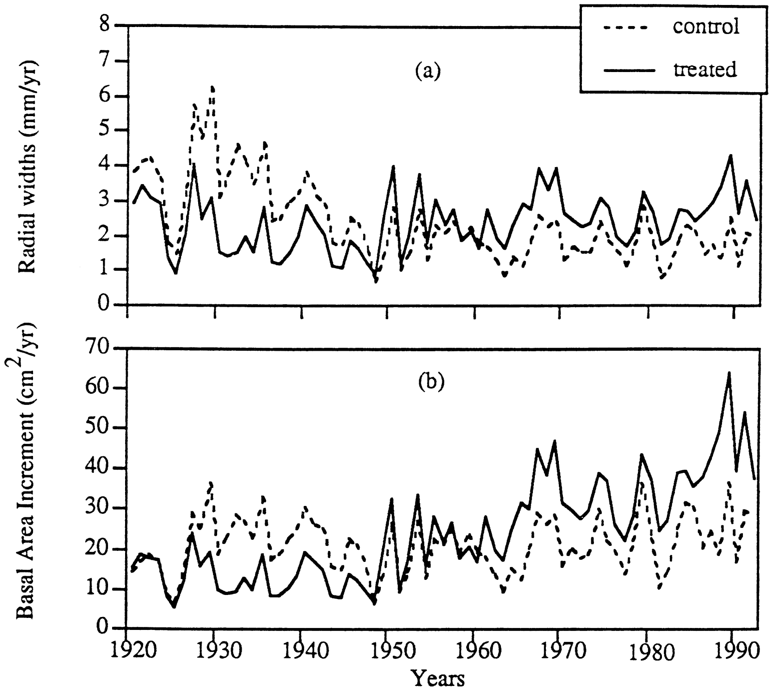

Figure 4. Mean annual ring width chronologies of (a) diameter increment (DINC); and (b) basal area increment (BAI) for baldcypress in the Cypriére Perdue Swamp.

Table 1. Ratio of treated to control mean annual diameter increment baldcypress growth values[a]

Years	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s
0	0.77	0.50	0.75	**1.41**	0.91	**2.02**	**1.52**	**2.25**
1	0.83	0.38	0.76	**1.22**	**1.65**	**1.41**	**2.30**	**1.74**
2	0.73	0.33	0.69	**1.36**	**1.50**	**1.47**	**1.73**	**1.24**
3	0.80	0.47	0.62	**1.36**	**1.98**	**1.53**	**1.44**	—
4	0.76	0.43	0.61	**1.38**	**1.70**	**1.25**	**1.16**	—
5	0.61	0.60	0.72	**1.33**	**2.64**	**1.54**	**1.09**	—
6	0.61	0.51	0.68	**1.13**	**1.48**	**1.27**	**1.80**	—
7	0.71	0.48	0.75	**1.13**	**1.54**	**1.53**	**1.69**	—
8	0.51	0.52	**1.27**	1.00	**1.49**	**1.21**	**2.52**	—
9	0.50	0.61	**1.77**	0.95	**1.64**	**1.14**	**1.66**	—

[a] Bold values (>1) represent greater treated growth proportionate to control.

Table 2. Results from a Tukey's studentized range test performed on nine-year growth summaries of diameter increment and basal area increment compared sites at time intervals

Effluent discharge	Time interval	Discharge point	P[a]	
			DINC	BAI
Pre-discharge	1926–1934	—	**0.0001***	**0.0062***
	1935–1943	—	**0.0001***	**0.0001***
	1944–1952	—	0.8202	0.5131
Discharge	1953–1961	A	0.2361	0.5524
	1962–1970	A	**0.0005†**	**0.0035†**
	1971–1979	B	**0.0300†**	**0.0492†**
	1980–1988	C	**0.0021†**	**0.0061†**

[a] *Control > treated; †treated > control. Bold values are significant at $\alpha < 0.05$.

during the pretreatment years (1920–1948). After 1948, growth rates were consistently faster in the treated site. With the exception of three years (1958–1960), the treated group had faster growth rates throughout the remaining period of record (1948–1992). Both the DINC and BAI records show a reversal in growth dominance from the control in pretreatment years (1920–1947) to the treated throughout the remainder of the record (1948–1992).

With the exception of the two intervals occurring at the approximate time of effluent discharge initiation, significant differences were found between the control and treated stands for all growth intervals ($\alpha = 0.05$, Table 2). The nine-year growth summaries of DINC and BAI for the treated and control stand show that growth was greater in the control during the first two intervals (1926–1934 and 1935–1943) of the pretreatment period (Figure 5). By the fourth interval (1953–1961), both growth summaries showed a reversal in growth dominance from control to treated. Thereafter, the treated stand had greater growth. The control stand exhibited a classic negative growth curve in the DINC chronology, expected with increasing age. Conversely, the treated stand had a slightly positive long-term trend, quite uncharacteristic of natural growth. The BAI growth

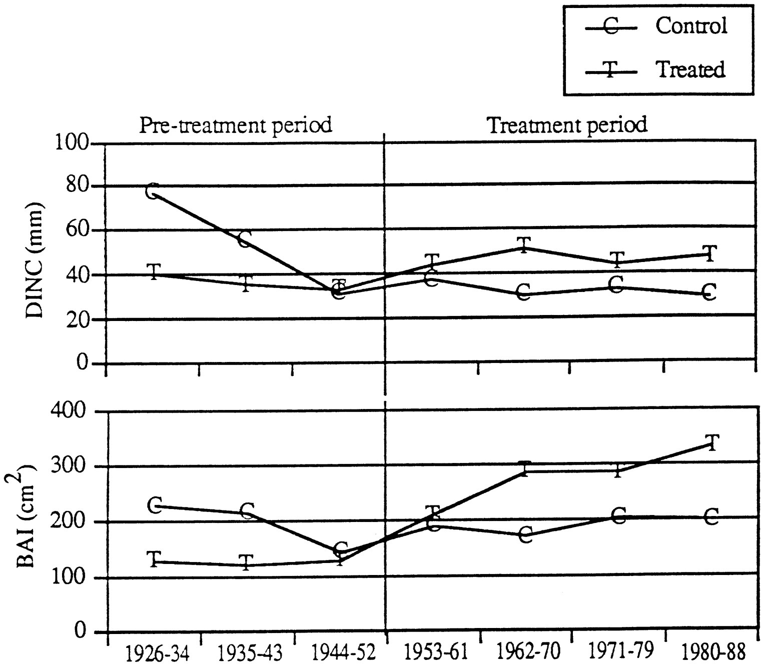

Figure 5. Average periodic diameter increment (DINC) and basal area increment (BAI) growth/tree for each nine-year interval for baldcypress in the Cypriére Perdue Swamp.

Table 3. Results from repeated measures ANOVAR performed on nine-year growth summaries of diameter increment comparing treatment periods during time of effluent discharge[a]

Comparison between intervals	DINC $P > F$			BAI $P > F$		
	Time	Time * site	Relationship, if significant	Time	Time * site	Relationship, if significant
4, 5	0.8251	0.0001	—	**0.0083**	**0.0001**	**5 > 4**
5, 6	0.2262	0.1041	—	0.4195	0.1041	—
6, 7	0.6055	0.2775	—	0.4407	0.2775	—

[a] If treated behaves differently than control, the effect is shown as a significant time * site interaction. Intervals: 4 = 1953–1961 (discharge point A), 5 = 1962–1970 (discharge point A), 6 = 1971–1979 (discharge point B), 7 = 1980–1988 (discharge point C). Bold values are significant at $\alpha < 0.05$.

summary of the control stand showed relatively steady growth over time, while the treated group had a pronounced growth increase coincident with the onset of wastewater application.

The different discharge locations (A, B, and C represented by the fourth, sixth, and seventh time intervals) had little effect on the treated group's growth response. An investigation of both DINC and BAI chronologies between intervals during the treatment period showed the fifth interval of the BAI chronology as significantly greater than the fourth ($\alpha = 0.05$, Table 3).

Discussion

Forest Stand Comparisons

Both treated and control groups, similar in size and age structure, have the same soil type and are located in stands within the same drainage system. They are separated by approximately 0.7 km and experience similar precipitation and temperature regimes. The treated stand, however, is slightly lower in elevation than the control, resulting in somewhat more frequent and more persistent inundation. It has been commonly shown that the growth of baldcypress decreases with increased flooding (Mitsch and others 1979, Mitsch and Ewel 1979, Conner and Day 1988). Furthermore, Conner and others (1993) found decreased baldcypress growth with an increase in water levels across a flooding gradient. This difference in hydroperiod probably explains the growth differences between stands during the pretreatment period, with lower growth in the more frequently inundated treated stand. If so, the higher growth in the treatment area after effluent application occurred despite the wetter conditions.

Growth Chronology Comparisons

The DINC chronology of the control group exhibited a typical response of decreased growth with age throughout the period of record. This characteristic response for tree species is the effect of decreasing radial increment with increasing age (Fritz 1976). In contrast, the treated group had a trend of slightly increased growth with age during the treatment period. The BAI chronology of the control group showed a relatively characteristic steady growth over time, as demonstrated by Davis (1966), while the treated group exhibited a pronounced growth increase throughout the period of wastewater application. Results suggest that the treated group growth response started as early as 1948, coincident with a newly established sewer network that might have transported raw sewage to discharge point A (Figure 1).

The growth patterns reflected in both the DINC and BAI chronologies were highly correlated, probably due to the same climatic regime and comparable stand structures. In both chronologies, initial growth rates were consistently lower in the treated stand compared to the control prior to effluent application, but the treated stand became the most productive after effluent application was initiated.

Interval Comparisons

Control growth was significantly greater before effluent application, but treated growth was significantly greater than control during effluent application. This treated growth enhancement was sustained for 35 years (the remainder of the period studied). Nessel and others (1982) found somewhat similar results when studying the long-term effects of municipal wastewater on pondycpress in Florida. They used tree-ring analysis to compare a 14-year period of growth before effluent application to a 41-year period of effluent discharge near Waldo, Florida. They reported a significant increase in basal area after effluent application began, but showed no significant increase in diameter growth. Their study also showed a long-term sustained growth enhancement spanning 40 years. Brown (1981) reported a twofold increase in pondcypress growth two years following effluent application when compared to five years preceding application. These findings indicate that cypress communities receiving secondary effluent have the capacity for sustained long- and short-term growth.

Other studies have investigated the effects of different levels of effluent treatment concentration and discharge location on forested wetlands. A comparison of discharge locations in this study showed a significant response in the BAI chronology at discharge point A during the second discharge interval. Discharge point A was the only location to receive 18 years of discharge versus nine years. With this in mind, the increased growth may be due to the cumulative physiological effect of nutrient enrichment on increased crown area and efficiency over time (Waring and others 1980, 1981). Lemlich and Ewel (1984) compared pondcypress tree-ring growth during a preeffluent period to different time intervals when there was raw, primary, and secondary effluent application and reported differences in growth response with the different degrees of sewage concentration. Raw or primary wastewater decreased pondcypress growth, while trees had increased growth over the period when secondary effluent was applied. Lemlich and Ewel (1984) suggested that growth decreases under raw effluent applications could also be attributed to confounding effects of climate or tree age and size.

There are a number of short-term studies of wastewater effects on pondcypress growth in Florida (Mitsch and Ewel 1979, Deghi 1984, Straub 1984). Mitsch and Ewel (1979) measured the growth of pondcypress for one year with dendrometer bands. Although this was only a one-year study, results indicated that the addition of secondary sewage with high nutrients increased cypress tree growth. Wastewater application appeared to increase pondcypress growth, while decreasing baldcypress growth in a four-year Florida study conducted on planted seedlings (Deghi 1984). Deghi suggested that pondcypress occurs more in areas of lower oxygen concentrations than baldcypress and is perhaps better suited for low oxygen conditions found in some wastewater environments. Annual measurements of pondcypress in two sewage domes showed significant differences in only one dome after 5.5 years (Straub 1984). Straub hypothesized that this inconsistency could be due to confounding effects by fire, lag responses, or different ecosystems (cypress dome versus cypress strand).

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