SREL - 53
UC - 66e

FOUR MILE CREEK
BOTTOMLAND RESTORATION PROGRAM

FINAL REPORT as of December 31, 1995

SAVANNAH RIVER ECOLOGY LABORATORY

PRINCIPAL INVESTIGATOR: Kenneth W. McLeod

PRINCIPAL TECHNICAL STAFF: Thomas G. Ciravolo
Michael R. Reed[1]
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GRADUATE STUDENT: Victor H. Parrish[1]

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FUNDED BY WESTINGHOUSE SAVANNAH RIVER COMPANY

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SUMMARY

Since 1990, a series of experiments has examined the appropriateness of 24 tree species for restoring a bottomland and swamp forest to the delta of Four Mile Creek. In addition, the various silvicultural techniques used to maximize the survival of the tree plantings, have been appraised for effectiveness and cost. While the topographic relief on the delta is small (decimeter differences between most sites), it is sufficient to utilize the various flood tolerances of the woody species. Hence, a diverse forest community can be established, using these elevational differences. In the wettest sites where water persists virtually continuously and may be one to two meters deep during large flood events, only the most flood tolerant species can survive, such as *Taxodium distichum* and *Nyssa aquatica*. These species will also survive very well at higher elevations, since the permanent water table never fell below one meter deep. In sites that are not flooded, unless the entire swamp is flooded, several additional species can be used. These include *Fraxinus pennsylvanica, Carya aquatica, Quercus lyrata* and *Quercus nuttallii*. Finally, in slightly higher areas, *Quercus michauxii, Quercus nigra* and *Quercus phellos* would have adequate survival. Other species with similar flood tolerance might also do well, but were not examined in these experiments.

To minimize herbivory and maximize survival, tree shelters should be used if herbivore pressure is high. The prime herbivore of concern is beaver. Thus, any plantings that are frequently flooded may require protection. Other silvicultural techniques, including fertilization and control of herbaceous and willow competition, were not essential to ensure growth and survival.

Finally, survival of the least expensive planting stock, bareroot saplings, was nearly as good as balled and burlapped stock. Thus, unless absolute maximal survival is required, bareroot stock is most economical and produced nearly the same results. One critical characteristic of the bareroot stock is height, which must exceed the flood depth during the growing season. In the case of the Four Mile Creek delta, this was at least 45-60 cm tall.

Trees of various species were successfully established in the Four Mile Creek delta. This is critical to accelerate the succession of this very large disturbed area. By establishing these individuals, their subsequent seed production over the next few years, will greatly accelerate the succession of the entire delta.

INTRODUCTION

On the Savannah River Site (SRS), nuclear production reactors were cooled by a once-through cooling cycle, using water from the Savannah River and discharging the effluent to small tributaries of the Savannah River. Four Mile Creek (also known as Fourmile Branch) is a third order tributary of the Savannah River on the upper coastal plain of South Carolina. It received thermal effluent from C Reactor from 1955 to 1985, which increased the flow rate, water depth and water temperature. Prior to 1955, the base flow was approximately one cubic meter per second, but increased, with the reactor effluent, to approximately 11 cubic meters per second, raising the water depth in the channel by 15 to 30 cm. Effluent temperature at the outfall was approximately 60 C and at the delta was 40 to 45 C, depending on the operation level of the reactor, the season of the year and the specific meteorological conditions. The increased flow rate also increased erosion in the upper reaches of the stream with deposition of this eroded material occurring in the delta averaging 60 cm of newly deposited sand on top of the former substrate.

An additional discharge to Four Mile Creek came from the F and H Chemical Separations Areas. This discharge was variable and ranged from 0.3 to 0.6 cubic meters per second. Tritium, Sr-90 and other radionuclides also entered the upper reaches of Four Mile Creek through leakage from seepage basins in this general area.

By 1961, the combination of factors began to cause tree mortality and the canopy began to open. A canopy loss rate of approximately two hectares per year was estimated. By 1978, 92 hectares (227 acres) of the forest was destroyed. A number of vegetation surveys of the Four Mile Creek delta have been conducted over time. The last survey prior to the cessation of thermal effluent was conducted in 1982 and showed a highly disturbed, thermally altered vegetation. In late June of 1985, C Reactor was shutdown and subsequently retired. Thus, secondary succession of the vegetation in the Four Mile Creek corridor and delta began in the 1985 growing season. In 1987, studies were initiated by Dr. R. R. Sharitz to document the recovery of the vegetation. Permanent plots were established and surveyed for tree, shrub, and herbaceous composition. Shortly after this survey, a lightning strike initiated a fire in the delta. Since it would have been difficult to extinguish and would not likely spread to adjacent lands, it was decided to let it burn itself out. It did not do so for two weeks, burning extensive areas of the delta. In 1988, another lightning strike fire occurred, but this one was very small and burned itself out in only three days.

Several resurveys of the vegetation in the Four Mile Creek Delta have been conducted since 1987, using these permanent plots: in 1989 by Dr. Sharitz's staff, in 1993 by Dr. D. W. Imm's staff and in 1995 by Dr. K. W. McLeod's staff. From these surveys (primarily 1987 and 1989), it is apparent that the corridor and delta of this third order coastal plain stream had been virtually sterilized by the 30 years of thermal effluent. The former woody vegetation could not resprout, nor did a viable woody seedbank exist in the sediment. The natural recovery of the impacted delta was dominated by early successional, wind-dispersed species (broomsedge [*Andropogon* sp.] and loblolly pine [*Pinus taeda*] in dry sites to black willow [*Salix nigra*] in wetter sites).

In 1990, the Mitigation Action Plan (MAP) accompanying the Environmental Impact Statement (EIS) for the Continued Operation of K, L, and P-Reactors called for the restoration of 670 acres (270 ha) of bottomland and swamp forest that had been destroyed as a result of prior reactor operations. The MAP provided the impetus to restore this forest type and thus the need for information on how to successfully do it.

A bottomland restoration program was begun in 1990, funded by the Savannah River Technology Center, part of the Westinghouse Savannah River Company. The program centers around the primary question, "How can forest succession be accelerated?" and seeks to provide information to land managers on the most appropriate species and methods of reintroduction in this severely disturbed habitat of the SRS. This information was gathered through a series of experiments designed to explore the site suitability of different species and the effectiveness of various silvicultural techniques in restoring this area. Over 4500 individuals of 24 woody species (Table 1) were planted in a dozen experiments, located across the impacted delta (Figure 1).

The initial experiments focused on replanting latter successional species into the existing dense early successional vegetation. Since some sites were dominated by *Andropogon virginicus* and *Pinus taeda*, other sites by species of *Scirpus*, *Juncus*, and *Erianthus*, and other sites were almost continuously covered by standing water, it was felt that microtopographic variation was responsible for the current successional communities and could be used to favor the reintroduction of different species into different habitats. Therefore, the experiments were designed to examine specific individual habitats. The latter experiments were concerned with the biotic impacts, i. e. competition with the herbaceous, grass and tree components.

Basic assumptions of the research were:

1) species must be reintroduced through transplanting to ensure that the most desirable species, i.e. heavy-seeded and latter successional, will dominate the site as quickly as possible,
2) large-scale soil disturbance, such as contouring of the site, is not desirable due to low-level radionuclide contamination of the soil,
3) the hydrology of the delta cannot be separated from the influence of the Savannah River, and

Table 1. Species used in Four Mile Creek restoration studies.

SPECIES	EXPERIMENT
Acer rubrum Red maple	IV,V
Betula nigra River birch	IV,V
Carya aquatica Water hickory	XII
Fraxinus pennsylvanica Green ash	III,VI,VIII-X
Liquidambar styraciflua Sweet gum	IV,V
Liriodendron tulipifera Tulip tree	IV,V
Nyssa aquatica Water tupelo	VI-XI
Nyssa sylvatica Swamp tupelo	IV,V
Platanus occidentalis Sycamore	IV,V
Quercus alba White oak	I,II,IV,V
Q. coccinea Scarlet oak	I
Q. falcata var. pagodaefolia Cherry bark oak	XI
Q. laurifolia Laurel oak	XII
Q. lyrata Overcup oak	XI, XII
Q. margaretta Scrubby post oak	I
Q. marilandica Black jack oak	I
Q. michauxii Swamp chestnut oak	I-III
Q. nigra Water oak	I,II,IV,V
Q. nuttallii Nuttall oak	XI
Q. phellos Willow oak	IV,V,XI
Q. rubra Red oak	I
Q. shumardii Shumard oak	III
Q. stellata Post oak	I
Taxodium distichum Bald cypress	I,II,IV-XII

Figure 1. Aerial view of Four Mile Creek Delta in June 1992. Experimental plots are indicated on figure.

4) the existing vegetation should be minimally disturbed to retard erosion.

Most experiments were conducted in the following general manner. Planting occurred in the winter or early spring of a given year. Following planting, survival was determined on a 1-2 week basis for the first growing season to determine whether the plants were alive at planting and to determine the success of initial establishment. Thereafter, survival was usually only determined in the autumn of the year. General description of the existing vegetation in the plots was made and the relative elevation of the individual planting locations was determined.

A centralized meteorological station was established where water depth, solar radiation, rainfall and air temperature were measured. Occasionally, auxiliary meteorological stations were used for particular experiments where a subset of climatic variables was measured.

Each experiment will be reported individually since they were initiated at different times and funded for variable lengths of time (Table 2). Some experiments were preliminary and were completed in two years, while others are ongoing to this date. If the experiment has already been published, the publication will be included. Other experiments were begun more recently and have provided less results. Nevertheless, each individual experiment will be reported and discussed as fully as possible.

CLIMATE AND HYDROLOGY OF FOUR MILE CREEK

The individual species will be profoundly affected both during their establishment phase and subsequent growth into adult trees by the climate and hydrology. The climate and hydrology of any particular year may not be representative of normal or potentially limiting conditions. Therefore, the results of any particular experiment must be evaluated in light of the climate and hydrology which existed during the experiment to determine how the results could be extrapolated to other years.

This variability can be readily observed in the hydrology of the Four Mile Creek delta since 1990. When the Savannah River is low, local rainfall may temporarily pond water on the delta, but any extensive and long duration flooding is outside of the control of the SRS. This greater flooding of the delta is controlled by the height of the Savannah River, in turn controlled by the activities of the U.S. Army Corps of Engineers' Clark's Hill Dam. If the Savannah River is not flooded, then the rainfall and evapotranspiration control the depth to the water table.

Table 2. Starting and ending dates for the 12 experiments.

EXPERIMENT	PLANTING DATE	ENDING DATE
I	Winter 1990	Fall 1994(a)
II	Winter 1990	Fall 1994(a)
III	Winter 1990	Fall 1994(a)
IV	Winter 1991	Fall 1994(a)
V	Winter 1991	Fall 1994(a)
VI	Summer 1991	Summer 1993(b)
VII	Summer 1991	Summer 1993(b)
VIII	Winter 1992	Fall 1994(a)
IX	May/June 1992	Fall 1994(a)
X	June 1992	Fall 1994(a)
XI	April 1993	Fall 1995(a)
XII	Winter 1994	Fall 1995(a)

(a) Funding terminated.
(b) Experiment harvested.

The growing seasons of 1990, 1993, 1994 and 1995 had rainfall below the 1950 to 1981 average, but above average rainfall occurred during 1991 and 1992 (Figures 2 and 3). Rainfall and water releases from the Clarks Hill Dam on the Savannah River have produced very different hydrologic conditions during the growing seasons of each of the last six years (Figure 4). Little flooding occurred during the growing seasons of 1990, 1992, 1993,and 1995 but floodwater accumulated on the delta several times in both 1991 and 1994.

Since the autumn of 1992, the hydrology of the delta has been extremely variable, including extensive floods during the dormant winter season of 1992/93 and 1994/95 and several short duration floods during the 1994 growing season. In between these floods, the summer of 1993 was very dry.

Flooding in the fall and winter of 1992/93 exceeded one meter in depth and was continuously present from mid-November until mid-April. Fortunately, this flood was in the winter when the trees were dormant and not negatively affected. In contrast, flooding during the summer of 1994 was deep enough to overtop the saplings planted in FY94, leading to mortality in some species.

Extensive flooding affected the experiments in unusual ways. Flood depths exceeded the height of the tree shelters, which were placed over the seedlings to deter herbivory, and allowed beaver access to the tops of the plants. Occasionally the water level remained so high that by spring the plants began to leaf out underwater. Usually, the flood would recede before damaging the trees. Flooding persisting through the winter and into the early spring of several years also restricted planting activities, but fortunately did not lead to planting failures.

DESCRIPTION OF EXPERIMENTS

EXPERIMENT I.

The objectives of this experiment were twofold: 1) determine the suitability of nine tree species, primarily oaks, for a relatively dry area of the Four Mile Creek delta, and 2) determine whether fertilization would enhance survival and growth. Transplant units were containerized one-year seedlings, grown from seed collected from Aiken County, SC. Relatively dry areas of the Four Mile Creek delta were determined by the dominance of broomsedge (*Andropogon virginicus*) in the present successional community. Seedlings were hand planted with a 2 x 2 m spacing. At planting, a starter fertilizer tablet (23/2/0 [N/P/K] plus 1% Mg), was placed in the bottom of half of the holes. Treatment sample size was seven per species/treatment combination, with two replicate plots, for a total of 252 seedlings.

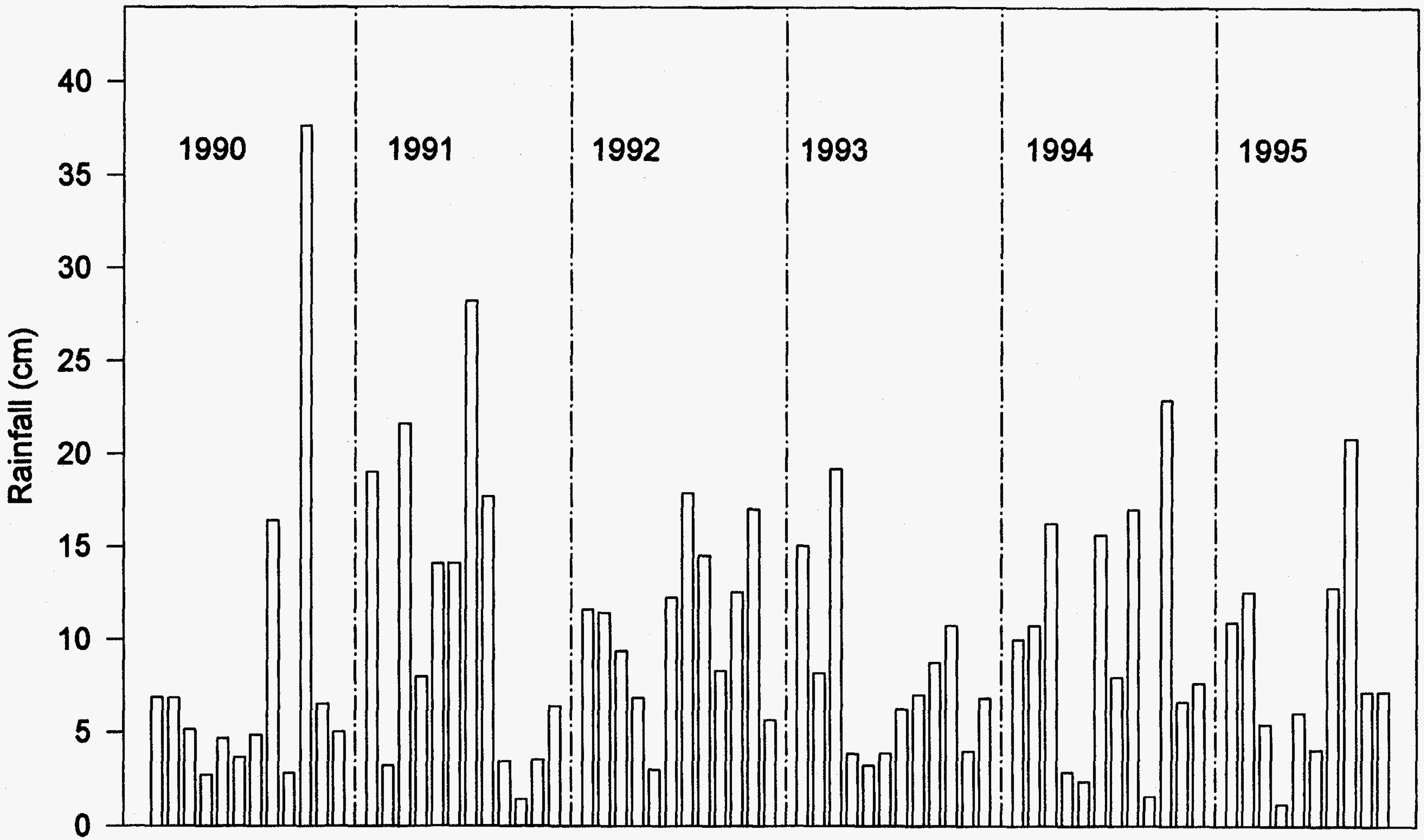

Figure 2. Monthly rainfall at Bush Field, Augusta, Georgia from 1990 to 1995.

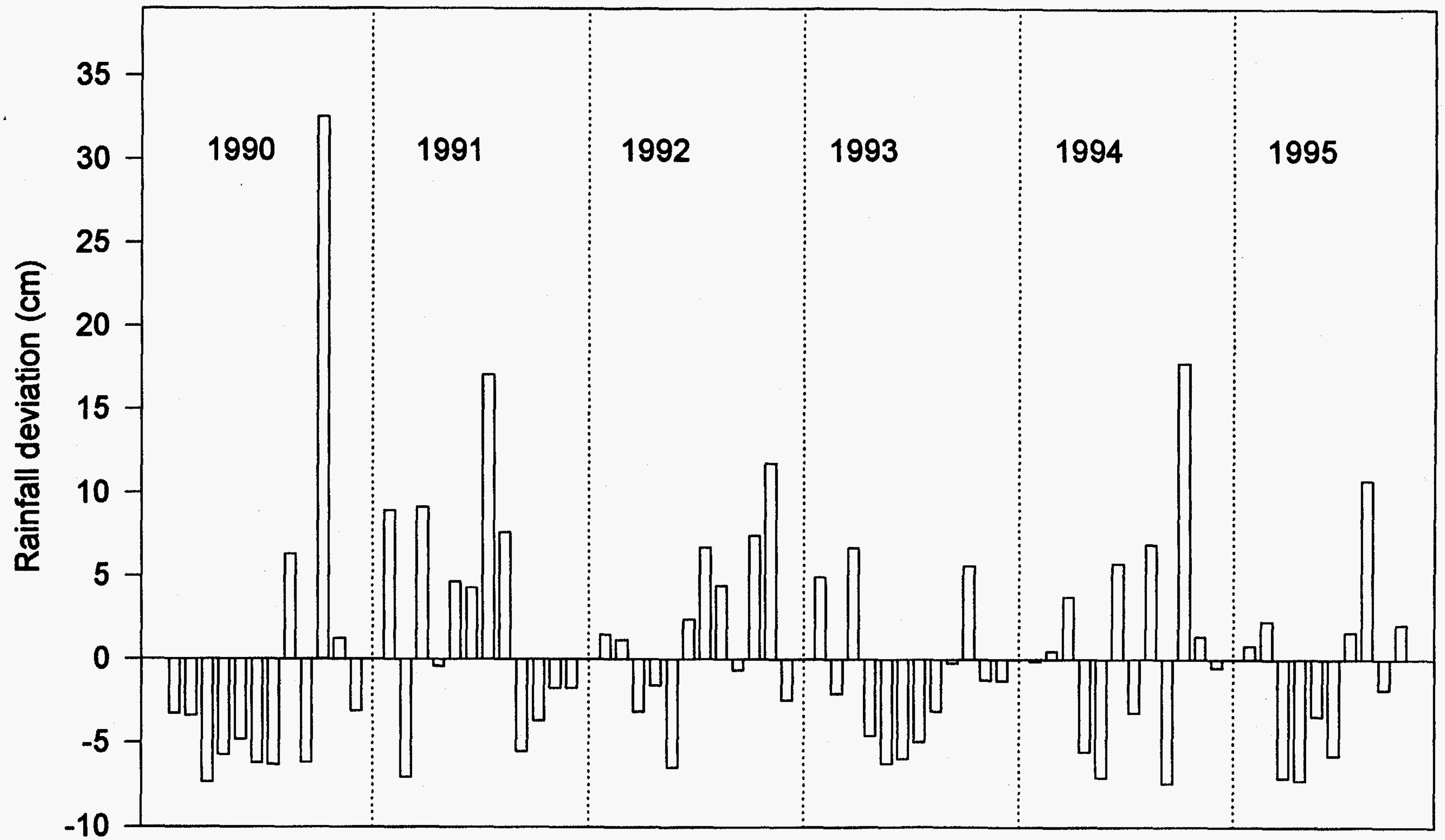

Figure 3. Deviation in monthly rainfall at Bush Field, Augusta, Georgia, contrasted to the 1950 -1981 average.

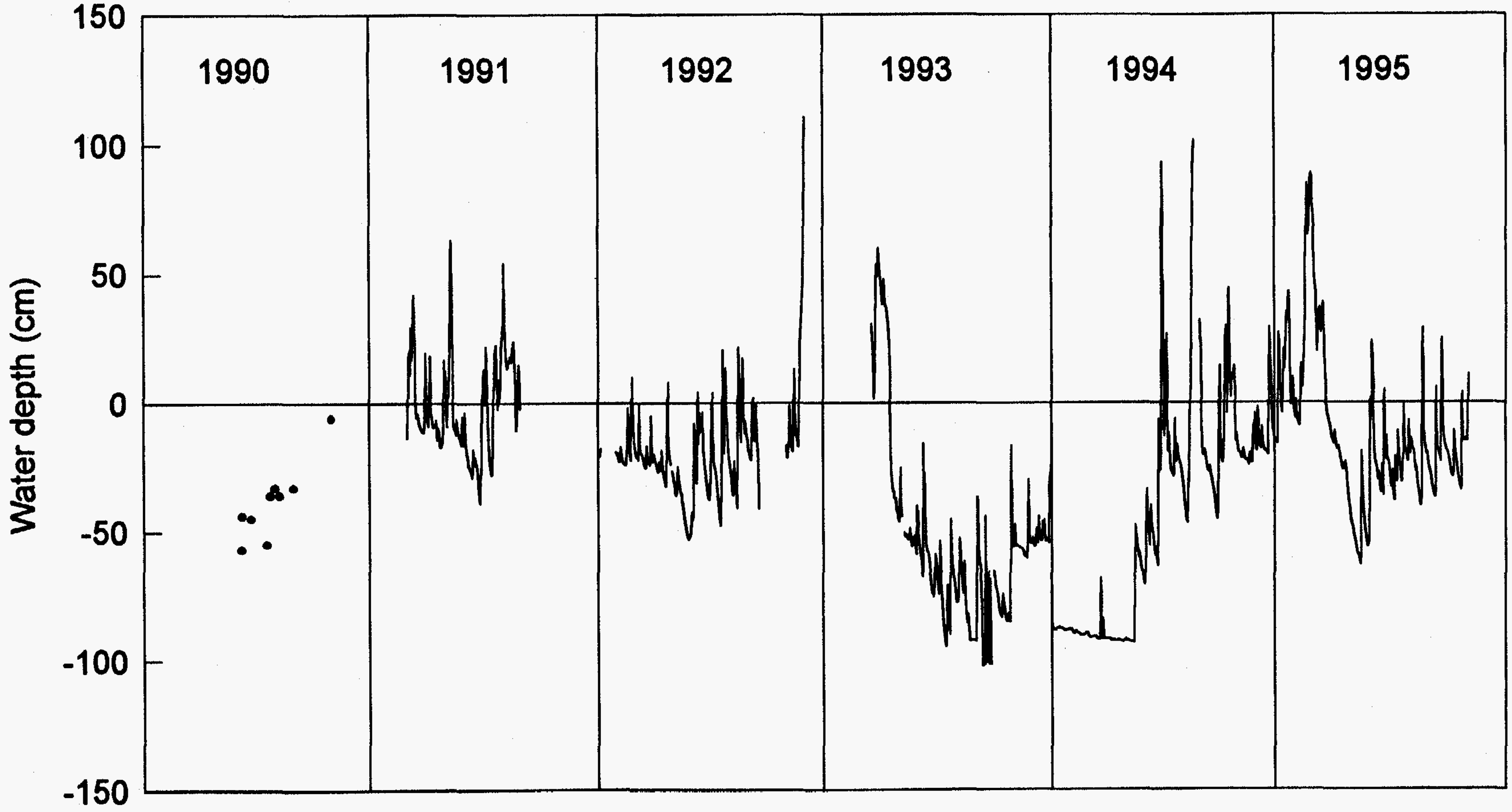

Figure 4. Water depth at Four Mile Creek delta. Positive numbers indicate standing water, negative numbers are depth to water table. Dots are values from a staff gauge and the solid line is data from a continuous recording pressure transducer.

In autumn of 1990, nine species had excellent survival (Table 3), but this year was unusually dry. By 1991, more normal precipitation and occasional flooding returned to the delta and only one species (*Taxodium distichum*) had good survival. All other species had severely impacted survival, with only two other species (*Quercus michauxii*, 46%, and *Q. nigra*, 36% survival in 1991) still retaining viable populations. These two species declined to 36 and 30% survival, respectively, in 1994, while *T. distichum* continued with 68% survival. No difference in survival was observed due to fertilizer treatment.

These nine species were planted in a what appeared to be a dry area of the Four Mile Creek delta. While it was initially felt that these species might be appropriate for this habitat, it is not surprising to find poor survival as the consequences of a wet year (1991) in which significant flooding occurred over these plots. This response enforces the need to know the hydrology of the site and the frequencies of flood events of specific magnitudes. The ability to establish in dry years, such as 1990, may be of little importance relative to the flood tolerance needed for 1991. Therefore, the results of this experiment suggest that the best species for this habitat is *T. distichum*, with *Q. michauxii* and possibly *Q. nigra* appropriate in slightly drier conditions or sites, and that fertilization is not necessary.

Table 3. Percent survival in the autumns of 1990, 1991, 1992, 1993 and 1994 of containerized seedlings planted in dry sites (Experiment I).

SPECIES	1990	1991	1992	1993	1994
Quercus alba	90	11	14	4	4
Q. coccinea	86	0	0	0	0
Q. margaretta	93	4	4	0	0
Q. marilandica	96	0	0	0	0
Q. michauxii	71	46	50	36	36
Q. nigra	82	36	36	32	30
Q. rubra	93	0	0	0	0
Q. stellata	89	25	18	14	11
Taxodium distichum	71	68	68	68	68

Fertilized and non-fertilized treatments combined, due to lack of differential survival.

Data (through 1993) for this particular study was published in the *Proceedings of the Hillsborough Community College Annual Conference of Wetlands Restoration and Creation* and is attached as Appendix I of this document.

EXPERIMENT II.

This experiment used a wet habitat to contrast with the dry, *Andropogon* dominated habitat, used in Experiment I. The wet habitat was identified by the abundance of *Scirpus* and *Juncus* species. Four of the most flood tolerant species used in Experiment I, were also planted in wet habitats resulting in an additional 56 seedlings being used in this wet/dry contrast.

In 1990, survival of all four species in both sites was good (Table 4). Survival of *Taxodium distichum* and *Quercus michauxii* was greater in the wet sites than the dry sites, while *Q. alba* showed the opposite response and *Q. nigra* survival was similar in wet or dry.

Table 4. Percent survival in the autumns of 1990, 1991, 1992, 1993 and 1994 of containerized seedlings planted in both wet and dry sites (Experiment II).

SPECIES	1990	1991	1992	1993	1994
			Wet Sites		
Quercus alba	75	4	0	0	0
Q. michauxii	82	64	64	50	50
Q. nigra	86	25	14	4	4
Taxodium distichum	93	79	79	79	79
			Dry Sites		
Quercus alba	90	11	14	4	4
Q. michauxii	71	46	50	36	36
Q. nigra	82	36	36	32	30
Taxodium distichum	71	68	68	68	68

Fertilized and non-fertilized treatments combined, due to lack of differential survival.

By 1991, survival was good for only two species in the wet sites and good to marginal for three species in the dry sites. *Quercus alba* had been eliminated by the wetter conditions in 1991 at both sites. *Taxodium distichum* and *Q. michauxii* were most appropriate for this wetter habitat and had even better survival than in the dry habitats. Again, no fertilizer effects were observed.

Data (through 1993) for this particular study was also published in the *Proceedings of the Hillsborough Community College Annual Conference of Wetlands Restoration and Creation* (see Appendix I).

EXPERIMENT III.

The objectives of this experiment were similar to those of Experiments I and II, in testing the need for fertilizer. But in this experiment bareroot seedlings provided by the Southeastern Forest Experiment Station in Charleston, SC, were used. These were planted in a wet site with a sample size was 30 per species/treatment combination. Only one species was common to both experiments. A total of 180 seedlings was used in this experiment. Otherwise, all planting, spacing and fertilization details were identical to the previous experiment.

All three species had acceptable to excellent survival following the 1990 growing season (Table 5). By 1991 and thereafter only *Fraxinus pennsylvanica* seedlings had good survival, while survival of the other two species has been reduced to 10% or less by 1994. In the previous two experiments, *Quercus michauxii* had good survival, but not in this experiment. This could be a consequence of the larger size of the stock relative to that used in Experiments I and II or the difference between containerized and bareroot stock. No fertilizer effects were observed in this experiment.

Table 5. Percent survival in the autumns of 1990, 1991, 1992, 1993 and 1994 of bareroot seedlings (Experiment III).

SPECIES	1990	1991	1992	1993	1994
Fraxinus pennsylvanica	97	95	100	97	93
Quercus michauxii	53	17	13	12	10
Q. shumardii	42	7	2	0	0

Fertilized and non-fertilized treatments combined, due to lack of differential survival.

Thus, the results of this experiment adds another species, *F. pennsylvanica*, to the list of viable candidate species for restoration of the Four Mile Creek delta and reinforces that fertilization is not required.

Data (through 1993) from this experiment was also published in the *Proceedings of the Hillsborough Community College Annual Conference of Wetlands Restoration and Creation* (see Appendix I).

EXPERIMENT IV.

This experiment was planted during FY91 and had two objectives: 1) enlarge the suite of species used in the suitability studies, and 2) evaluate the impact of transplant height on subsequent growth and survival. The importance of height can be viewed from both biological and economical perspectives. Taller seedlings have an advantage over smaller seedlings in their probable competitive ability to gain dominance in the future canopy and are better able to withstand the deleterious impacts of floodwater. However, taller seedlings are more difficult to successfully establish. Greater height at transplanting has both positive and negative biological effects, but the economical view is clearer. Taller seedlings are more expensive to buy and to transplant into the field site. It may however be necessary to incur these greater costs to ensure adequate survival.

This experiment uses ten species, with each species having at least three height classes, ranging from 30-45 cm as the smallest to 120 - 150 cm being the tallest. There are three species in common with those species used in the FY90 experiments. All transplants were bareroot and planted by hand, at randomly assigned locations on a 3 x 3 m spacing, along seven transect lines. Sample size was 30 per species/height class combination. The 990 seedlings were transplanted from March 11 to April 22, 1991. This was later than optimal, but unavoidable due to flooding. The relatively late planting date in drier environments would certainly have reduced survival, but did not affect survival in the wet conditions which existed in the spring of 1991.

Only *Taxodium distichum* and *Quercus nigra* had greater than 50% overall survival for all height classes combined in 1991 (Table 6). By 1992, survival of Q. nigra had been reduced to 25%, joining *Q. phellos*, *Platanus occidentalis*, and *Betula nigra* with survival between 25 and 50%. Survival continued to decrease for these four species until by 1994, survival was less than 25% for each species. Only *T. distichum* continued to exhibit excellent survival through 1994. Survival of the other five species was very poor (2 to 8% in 1991 falling to 0 to 6% by 1994).

Table 6. Overall percent survival in the autumns of 1991, 1992, 1993 and 1994 of bareroot seedlings, all size classes combined (Experiment IV).

SPECIES	1991	1992	1993	1994
Acer rubrum	4	4	3	4
Betula nigra	31	27	22	21
Liquidambar styraciflua	8	6	6	6
Liriodendron tulipifera	2	0	0	0
Nyssa sylvatica	2	4	1	1
Platanus occidentalis	33	34	19	16
Quercus alba	3	0	0	0
Q. nigra	51	25	14	11
Q. phellos	44	32	16	15
Taxodium distichum	92	90	87	87

Initial survival of at least one height class of *Q. nigra*, *Q. phellos* and *T. distichum* exceeded 50%, with the best survival found with seedlings 60-90 cm in height (Table 7). The 120-150 cm height class had greater than 40% survival for *B. nigra* and *P. occidentalis*. The transplant height may have been very critical during 1991 due to the frequent and occasional deep flooding of the delta (see Figure 4). Virtually no woody species can survive flooding of the entire aerial portion of the plant during the growing season for an extended time. Hence, the 30-45 cm tall seedlings may have had little or no stem emerging from the floodwater at various times during the spring of 1991. This could account for lower survival of the smallest height class for seven of the ten species. When the transplant height was between 45 and 120 cm tall, there was not a consistent trend in survival versus height. If the transplant was greater than 120 cm tall, then survival was generally very poor. Post-transplant surveys indicate that many saplings in this height class did not leaf out following transplanting (data not shown),indicating the difficulty of transplanting larger stock. The poor survival of large bareroot transplants was not necessarily unexpected. This is a unusually large bareroot transplant. Better survival of this large height class would be expected with balled and burlapped or containerized transplants.

Height growth of some of the surviving seedlings has been impressive (Table 8), but the influence of the initial height is lessening over time due to growth. While height may have originally affected survival, it does not appear to strongly

Table 7. Percent survival in the autumns of 1991, 1992, 1993 and 1994 of bareroot seedlings as affected by original height (cm) of transplant (Experiment IV).

	ORIGINAL HEIGHT (cm)				
SPECIES	30-45	45-60	60-90	90-120	120-150
	YEARS				
	91/92/93/94	91/92/93/94	91/92/93/94	91/92/93/94	91/92/93/94
Betula nigra	13/10/07/07	--/--/--	36/36/33/30	--/--/--/	43/36/27/27
Platanus occidentalis	23/23/17/14	--/--/--	33/23/13/13	--/--/--	43/57/27/20
Quercus nigra	43/20/13/10	--/--/--	63/43/23/17	--/--/--	47/13/07/07
Q. phellos	43/53/27/23	--/--/--	67/53/27/27	63/32/10/10	--/--/--
Taxodium distichum	90/93/83/84	93/87/87/87	93/90/90/90	--/--/--	--/--/--

Table 8. Height (cm) of seedlings in the autumns of 1991, 1992, 1993 and 1994 grouped by initial height of transplant (Experiments IV and V).

SPECIES	HEIGHT (cm)	1991	1992	1993	1994
Acer rubrum	TUBEX	59	117	149	195
	30-45	34	38	51	64
Betula nigra	TUBEX	49	107	182	208
	30-45	43	42	38	67
	60-90	78	103	142	223
	120-150	103	112	147	184
Liquidambar styraciflua	TUBEX	49	50	40	75
	30-45	60	48	43	70
	45-60	63	67	86	154
Liriodendron tulipifera	TUBEX	50	.	.	.
	30-45	46	.	.	.
	45-60	75	.	.	.
	121	106	.	.	.
Nyssa sylvatica	TUBEX	32	61	97	91
	60-90	78	75	105	119
	90-120	63	33	.	.

Table 8 (continued). Height (cm) of seedlings (Experiments IV and V).

SPECIES	HEIGHT (cm)	1991	1992	1993	1994
Platanus occidentalis	TUBEX	51	71	101	151
	30-45	41	51	93	150
	60-90	68	96	109	224
	120-150	190	167	159	210
Quercus alba	TUBEX	31	21	.	.
	30-45	27	.	.	.
	90-120	150	.	.	.
Q. nigra	TUBEX	48	78	134	202
	30-45	51	46	73	72
	60-90	81	58	68	89
	120-150	126	148	166	186
Q. phellos	TUBEX	43	57	73	138
	30-45	42	39	53	80
	60-90	109	105	141	168
	90-120	130	92	136	147
	152-182	198	.	.	.
Taxodium distichum	TUBEX	108	158	200	237
	30-45	78	94	126	172
	45-60	107	124	160	223
	60-90	107	126	169	210

affect growth. The height growth also indicates that there are variable lags in growth probably caused by specific climatic conditions, species and initial size (affecting the time necessary to establish itself well). Overall, since neither survival nor height growth were positively related with transplant height, there is no need to purchase larger, more costly plant material. However, a minimum size seedling is indicated to be important to avoid the impact of flood depth. No additional species have been suggested by this species trial as potentially successful in the Four Mile Creek environment.

EXPERIMENT V.

In this experiment, the primary objective was to determine whether a plastic tree shelter made by *Tubex* would increase survival and growth. If increases in growth and survival occurred, then larger plant stock would not be needed and costs could be reduced by using less expensive planting stock. Since there is an obvious cost of the tree shelters, the shelter cost could be balanced by the reduced cost of planting stock. Again both economic and biological questions were addressed in this experiment. The planting stock for this experiment was merged with that in Experiment IV, such that the planting locations for both experiments were randomly assigned along the same seven transect lines. Sample size was also 30 seedlings per species/treatment combination, with the "no-tree shelter" treatment part of the preceding experiment. An additional 300 seedlings were contained in the individual tree shelters, bringing the total number of seedlings in Experiments IV and V to 1290. In this experiment, only 30-45 cm tall seedlings received shelters.

Survival of seedlings contained in tree shelters of the five best surviving species was greater than survival without the shelter (Table 9). For some species it was, nevertheless, far from adequate. In fact, only four species had greater that 40% survival in tree shelters after the first growing season and only two species by the autumn of 1994. Data for the poorest surviving five species is inadequate for analysis.

Tree shelters could not counteract the high mortality of the smallest size class of transplant caused by the depth or frequency of the floodwater during 1991. Minimal transplant height is dictated by the expected height of the floodwater and although tree shelters may influence survival, they are not of critical benefit in tolerating flooding. On the correct size of transplants to withstand flooding, tree shelters will probably increase survival.

Besides increased survival, increased growth is also touted as a benefit of the tree shelters. This height increase was observed for almost all species when contrasting the height of the tree shelter and 30-45 cm size classes in Table 8.

Table 9. Percent survival of 30-45 cm tall bareroot seedlings in the autumns of 1991, 1992, 1993 and 1994 as affected by the use of "Tubex " tree shelters (Experiment V).

	WITH *TUBEX*				WITHOUT *TUBEX*			
SPECIES	1991	1992	1993	1994	1991	1992	1993	1994
Acer rubrum	17	10	10	10	13	17	13	17
Betula nigra	20	13	10	10	13	10	7	7
Liquidambar styraciflua	23	3	3	3	10	10	10	10
Liriodendron tulipifera	3	0	0	0	3	0	0	0
Nyssa sylvatica	7	3	3	3	0	0	0	0
Platanus occidentalis	40	33	27	23	23	23	17	14
Quercus alba	10	3	0	0	3	0	0	0
Q. nigra	53	43	20	13	43	20	13	10
Q. phellos	77	90	57	50	43	53	27	23
Taxodium distichum	90	87	83	87	90	93	83	84

The tree shelters provided both protection from herbivores and also a microenvironment with increased CO_2, humidity and temperature.

The increased growth and survival due to tree shelters is not sufficient to incur their additional costs, unless regulatory demands or the desire to not reenter the site controls the decision making process. This conclusion is relevant to this particular terrestrial habitat. Use of tree shelters may still be necessary where herbivory is more likely or where extensive floodwater would increase the access to beavers.

EXPERIMENT VI.

With increased interest in planting the permanently flooded areas of Pen Branch and Four Mile Creek, new methods would be required. While Four Mile Creek delta is not generally flooded, there are significant areas in which standing water occurs virtually year round, due to microtopographic relief and the isolation of small braided stream segments as the water level declines. Restoration of these habitats will require planting in standing water or alteration of the site.

Since few tree species can tolerate permanently flooded conditions, species selection is very limited. A differential response has been observed in tree seedlings depending on whether the standing water is stagnant or flowing, which modifies the physical and chemical nature of the water.

A small scale simulated wetland experiment was conducted to explore this situation and try an innovative planting technique. Stock tanks were used as pools and water was circulated among four tanks that made up a treatment. Two different circulation rates simulated backwater (slow flow) and stream channel (more rapid) conditions. The water in the pools was kept 15 cm above the root collar of the seedlings. Each pool contained 12 seedlings, four each of *Taxodium distichum*, *Nyssa aquatica*, and *Fraxinus pennsylvanica*. Sample size was 16 seedlings per species/treatment combination.

Since planting into standing water is difficult because of the need to dig a hole underwater, a planting unit was needed which would be bottom-heavy and planted by simply placing on the sediment surface. The planting unit was created by making a "hand-bagged" transplant unit from a containerized seedling and a burlap bag filled with top soil. This was then "planted" by placing on the bottom sediments (15 cm deep) and securing the stem to keep the seedling upright.

Sudden flooding of the seedlings in this experiment during the summer while still metabolically active and fully leaved out, "shocked" all of the species. *Fraxinus* seedlings lost most of their leaves, while *Taxodium* leaves turned red. This red color is characteristic of *Taxodium* but does not necessarily denote potential mortality or even altered photosynthetic rates. *Fraxinus* seedlings did not die but certainly lost a great deal of photosynthetic capability for the remainder of the growing season. *Nyssa* seedlings showed the least response of the three species.

After two years of flooding, all three species had 100% survival. Saplings of *F. pennsylvanica* were in poor overall health in both treatments and were much worse than the other two species. The tops of some *F. pennsylvanica* had died, but the lower stems and root systems were still alive.

This experiment was terminated in July of 1993 with the harvest of the plants and excavation of the root systems from the bottom sediments. Biomass had increased by approximately 50% for all three species in both treatments when contrasted with biomass of trees harvested prior to the experiment. Plants grown in the simulated backwater treatment were slightly smaller in biomass, height, and diameter within each species (Table 10), with only root biomass oppositely affected. This root response is probably indicative of the lower oxygen concentration in the bottom sediments of the simulated backwater pools. Root systems of both *T. distichum* and *N. aquatica* successfully penetrated the burlap and rooted in the substrate, whereas *F. pennsylvanica* showed minimal root penetration and was not anchored in the substrate. Floating, adventitious roots of *Fraxinus* were evident and while they might be better aerated and contribute to continued survival, they would not assist in stabilization in the bottom sediment.

This information suggest that these species could be outplanted into either slow or rapid flowing permanent water field conditions, with *T. distichum* and *N. aquatica* being more suitable than *F. pennsylvanica*. The "hand-bagged" planted unit also looked promising for use in the field .

EXPERIMENT VII.

A second experiment concerned with the planting of seedlings in standing water addressed an observation made in the preceding experiment. When metabolically active seedlings are suddenly subjected to flooding, they are shocked because they are not anatomically or morphologically acclimated to this new environment. Since a seedling cannot be gradually planted in standing water, are there methods to allow the seedlings to acclimate prior to planting? This was the question addressed in the second experiment using simulated wetlands.

Table 10. Biomass, diameter and height in 1993 of saplings grown in simulated stream and backwater conditions (Experiment VI).

SPECIES	STREAM	BACKWATER
Fraxinus pennsylvanica		
Biomass (g)		
Roots - Adventitious	6.73	3.30
Roots - normal	297.69	303.90
Stem	295.95	263.99
Branches	30.55	29.45
Leaves	27.32	17.28
Diameter (cm)	2.09	2.01
Height (m)	2.05	1.90
Nyssa aquatica		
Biomass (g)		
Roots - Adventitious	0.49	0.54
Roots - normal	409.41	424.85
Stem	238.58	214.03
Branches	17.02	18.97
Leaves	24.42	15.80
Diameter (cm)	2.32	2.20
Height (m)	2.23	2.22
Taxodium distichum		
Biomass (g)		
Roots - Adventitious	1.58	0.77
Roots - normal	250.24	285.33
Stem	166.37	149.84
Branches	41.48	40.92
Leaves	38.13	25.05
Diameter (cm)	2.29	2.23
Height (m)	1.35	1.29

In this experiment seedlings of *Taxodium distichum* and *Nyssa aquatica* were slowly acclimated to flooding by gradually (4 cm/week) increasing the floodwater depth, in contrast to a second treatment in which the seedlings were suddenly flooded. One year old containerized seedlings of each species were "hand-bagged" as in the previous experiment. Water circulation simulated the stream channel condition. Sample size was 20 per species/treatment combination.

Final floodwater depth was 15 cm above the root collar when the treatments began in late summer. Initial responses included the development of the red leaf color in *Taxodium*. This was greatly reduced in the younger plants used in this experiment. In the autumn, senescence of both species was much slower than that in the preceding experiment.
Growth of both species in both treatments was considerable during the experiment. Diameter tripled, while height increased by 50%. Biomass was 12X larger than seedlings harvested prior to the experiment. *Nyssa aquatica* had the larger growth increase of the two species. Acclimated plants of *N. aquatica* and *T. distichum* did not have different biomass, height, diameter or survival, when contrasted to non-acclimated plants (Table 11). Only adventitious root biomass showed differences between treatments, but this biomass was very small when compared to the total biomass of the plants. Roots of both species penetrated the burlap bag and grew into the sediment layer.

Prior acclimation to flooding did not affect ultimate survival or growth. Since the acclimation process would be difficult and costly to accomplish in the plant nursery, based on our results it would not be recommended.

EXPERIMENT VIII.

In FY92, three species were planted in permanently flooded field sites to examine the response of different planting stocks. The experiment was designed to build on and expand Experiment VI into field situations. Three flood-tolerant tree species (*Taxodium distichum*, *Nyssa aquatica*, and *Fraxinus pennsylvanica*) were planted in both backwater and stream sites during the winter of 1992. Three different types of planting stock were used: bareroot; hand-bagged (similar to that in Experiments VI and VII); and commercially balled and burlapped. The root system of the bareroot saplings, planted as either bareroot or hand-bagged treatments, was pruned to a 23 cm root length and diameter. The hand-bagged trees were put into a burlap bag and topsoil was added to the bag until the soil ball compared in size to the commercially balled and burlapped trees. The balled and burlapped trees were obtained from a commercial nursery.

Table 11. Biomass, diameter and height in 1993 of saplings grown in simulated wetland conditions with and without prior acclimation to flooding (Experiment VII).

SPECIES	ACCLIMATED	NON-ACCLIMATED
Nyssa aquatica		
Biomass (g)		
Roots - Adventitious	3.76	7.35
Roots - normal	260.11	251.79
Stem	273.33	264.53
Branches	14.00	13.31
Leaves	20.92	20.90
Diameter (cm)	2.94	2.96
Height (m)	2.22	2.23
Taxodium distichum		
Biomass (g)		
Roots - Adventitious	4.09	6.13
Roots - normal	184.25	156.84
Stem	162.83	143.65
Branches	25.95	21.49
Leaves	37.59	36.44
Diameter (cm)	2.63	2.53
Height(m)	1.42	1.36

The hand-bagged and balled and burlapped saplings were planted by placing them on the bottom sediments at locations where the water was 30-60 cm deep. A stake was driven through the bag and the stem secured to the stake. With these two types of planting units, the depth of water to the root collar ranged from 0 to 30 cm. Therefore, the bareroot saplings were planted at two depths (0-30 and 30-60 cm) to determine both the appropriateness of bareroot stock in deep water and to serve as a legitimate comparison for the other planting stocks. Bareroot saplings planted in the shallow depth had their root collar at the same water depth as the hand-bagged and the balled and burlapped saplings. Bareroot saplings planted in the deeper depth had the root collar at the sediment surface (the bottom of the balled and burlapped unit). *Tubex* tree shelters were placed on half of the trees as a test for protection from herbivores.

Survival of *Fraxinus pennsylvanica* declined over time for the deep bareroot and hand-bagged planting stocks, regardless of the presence of tree shelters or site (Tables 12 and 13). Survival of the other two planting stocks (shallow bareroot and balled and burlapped) generally has not declined since the first year, either with or without tree shelters for both sites. *Nyssa aquatica* survival declined for the first two years for all planting stock types at both sites, but survival in 1994 has been equal or greater than that in 1993. Survival of *Taxodium distichum* was greater than 95% for all treatments, except the bareroot stock planted in shallow water at the stream site, which had extensive beaver herbivory.

Balled-and-burlapped planting stock generally had better survival than the other planting stocks for *F. pennsylvanica* (Tables 12 and 13). When planted in deep water, bareroot *F. pennsylvanica* stock and, to a lesser degree, hand-bagged trees had poor survival, while bareroot *F. pennsylvanica* stock planted in shallow water had better survival. Planting stock did not affect survival of *T. distichum*, and produced inconsistent effects in survival of *N. aquatica*.

Tree shelters afforded protection to the trees, as evidenced by higher survival rates (Tables 12 and 13). Herbivory was more common in the stream site than the backwater site (Table 14). Herbivory in the backwater site was not significant until the winter of 1992/93 when the extended delta-wide flooding gave beaver better access to all sites. In the stream site, *F. pennsylvanica* and *T. distichum* were both heavily browsed, while at the backwater site *F. pennsylvanica* was more heavily browsed. Tree shelters did reduce herbivory but did not eliminate it in either site for any species. *Nyssa aquatica* seedlings had the least herbivory probably due to their smaller size relative to the other species.

All three species showed the ability to resprout following beaver damage (Table 15). *Taxodium distichum* was most likely to resprout, while *N. aquatica* and *F. pennsylvanica* were less likely. The resprouting ability of *F. pennsylvanica* in the stream site was greater when tree shelters were present. This indicates that beaver may inflict a different type of damage on the saplings depending on the presence of the tree shelter.

Again, *T. distichum* and *N. aquatica* were more successful than *F. pennsylvanica* in establishing in permanent water habitats. Success of *F. pennsylvanica* could be enhanced by the use of balled and burlapped saplings or planting bareroot stock in shallow water. Tree shelters do reduce herbivory, but complete protection should not be expected.

Table 12. Percent survival in 1992, 1993 and 1994 in a backwater site as affected by "Tubex" tree shelter and planting stock type (SBR = Shallow bareroot, DBR = Deep bareroot, HB = Hand-bagged, B&B = Balled and Burlapped). B&B stock not available for Nyssa (Experiment VIII).

	WITHOUT *TUBEX*				WITH *TUBEX*			
SPECIES	SBR	DBR	HB	B&B	SBR	DBR	HB	B&B
	PERCENT SURVIVAL IN 1992							
Fraxinus pennsylvanica	80	65	95	90	90	35	80	100
Nyssa aquatica	85	100	80	--	90	100	80	--
Taxodium distichum	95	100	100	100	100	100	100	100
	PERCENT SURVIVAL IN 1993							
Fraxinus pennsylvanica	60	20	45	95	100	0	50	100
Nyssa aquatica	35	50	20	--	75	80	65	--
Taxodium distichum	95	100	100	100	100	100	100	100
	PERCENT SURVIVAL IN 1994							
Fraxinus pennsylvanica	65	10	25	95	100	0	30	100
Nyssa aquatica	60	60	65	--	80	90	70	--
Taxodium distichum	95	100	100	100	100	100	100	100

Table 13. Percent survival in 1992, 1993 and 1994 in a stream site as affected by "Tubex" tree shelter and planting stock type (SBR = Shallow bareroot, DBR = Deep bareroot, HB = Hand-bagged, B&B = Balled and Burlapped). B&B stock not available for Nyssa (Experiment VIII).

	WITHOUT TUBEX				WITH TUBEX			
SPECIES	SBR	DBR	HB	B&B	SBR	DBR	HB	B&B
	PERCENT SURVIVAL IN 1992							
Fraxinus pennsylvanica	55	20	70	90	85	45	85	100
Nyssa aquatica	90	85	90	--	95	95	80	--
Taxodium distichum	55	100	95	100	100	100	100	100
	PERCENT SURVIVAL IN 1993							
Fraxinus pennsylvanica	40	0	30	35	75	10	55	100
Nyssa aquatica	10	20	30	--	75	45	60	--
Taxodium distichum	55	100	95	100	100	100	100	100
	PERCENT SURVIVAL IN 1994							
Fraxinus pennsylvanica	45	0	30	45	85	0	30	75
Nyssa aquatica	35	25	50	--	75	65	75	--
Taxodium distichum	55	100	95	100	100	100	100	100

Table 14. Percent of saplings with the main stem cut by beaver either in 1992, 1993 or 1994 in each planting site, "Tubex" tree shelter and planting stock type (SBR = Shallow bareroot, DBR = Deep bareroot, HB = Hand-bagged, B&B = Balled and burlapped). B&B stock not available for *Nyssa* (Experiment VIII).

	BACKWATER							
	WITHOUT *TUBEX*				WITH *TUBEX*			
SPECIES	SBR	DBR	HB	B&B	SBR	DBR	HB	B&B
Fraxinus pennsylvanica	10	45	25	20	10	0	10	0
Nyssa aquatica	0	5	0	--	0	0	0	--
Taxodium distichum	0	0	0	0	0	0	0	0

	STREAM							
	WITHOUT *TUBEX*				WITH *TUBEX*			
	SBR	DBR	HB	B&B	SBR	DBR	HB	B&B
Fraxinus pennsylvanica	65	55	60	90	5	10	25	35
Nyssa aquatica	20	30	25	--	5	5	5	--
Taxodium distichum	85	50	65	50	0	15	5	5

Table 15. Resprouting of saplings (those alive in the fall of 1994) that had previously been damaged by beaver cutting the main stem in each planting site, "Tubex" tree shelter and planting stock type (SBR = Shallow bareroot, DBR = Deep bareroot, HB = Hand-bagged, B&B = Balled and Burlapped). B&B stock not available for *Nyssa* (Experiment VIII).

	BACKWATER							
	WITHOUT *TUBEX*				WITH *TUBEX*			
SPECIES	SBR	DBR	HB	B&B	SBR	DBR	HB	B&B
Fraxinus pennsylvanica	1/2[a]	2/9	0/5	3/4	2/2	NA	1/2	NA
Nyssa aquatica	NA	1/1	NA	--	NA	NA	NA	--
Taxodium distichum	NA	NA	NA	NA	NA	NA	NA	NA

	STREAM							
	WITHOUT *TUBEX*				WITH *TUBEX*			
	SBR	DBR	HB	B&B	SBR	DBR	HB	B&B
Fraxinus pennsylvanica	4/13	0/11	1/12	7/18	1/1	0/2	1/5	4/7
Nyssa aquatica	0/4	0/6	0/5	--	0/1	0/1	0/1	--
Taxodium distichum	8/17	10/10	12/13	10/10	NA	3/3	1/1	1/1

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[a] Values indicate (number resprouted)/(number cut by beaver).

EXPERIMENT IX.

Establishment of trees in standing water is difficult due to the inability of the plants to adjust or acclimate to the anaerobic, inundated environment. Roots of tree species that are flood tolerant acclimate through a series of anatomical, morphological and/or physiological changes. This experiment was an expansion of the premise of Experiment VII, asking whether preconditioning to a flooded environment can increase survival and growth, but this time under field conditions.

The same three species of trees were used as in the previous experiment, but only one type of planting stock was used for each species (commercially balled and burlapped trees for *Fraxinus pennsylvanica* and *Taxodium distichum* and hand-bagged trees for *Nyssa aquatica*). Commercially balled and burlapped trees were not available for *Nyssa*. Trees to be acclimated were placed into stock tanks and the water depth slowly increased (6 cm/week) for eight weeks until the root balls were covered with 15 cm of water. An equal number of trees were maintained by only surface irrigating the balled root system (non-acclimated). Acclimated and non-acclimated trees were subsequently planted in the field, starting in the middle of May 1992.

Since the trees had already leafed out before transplanting, they had to be handled carefully. They were transported to Four Mile Creek in a covered truck. Once at Four Mile Creek, the trees were taken by an all-terrain vehicle to their planting sites. Both backwater and flowing stream locations were planted as in the previous experiment in water 30-60 cm deep. Again, half of the trees had *Tubex* tree shelters placed on them for herbivore protection.

In the backwater site, *T. distichum* saplings had very high survival, while *F. pennsylvanica* saplings did very poorly (Table 16), primarily due to herbivory (Table 18). *Nyssa aquatica* saplings, enclosed in tree shelters, had $\geq$ 69% survival regardless of acclimation treatment. Saplings of *N. aquatica* not enclosed in tree shelters had a maximum of 8% survival. Little of the *N. aquatica* mortality can be directly attributed to beaver activity, since the saplings disappeared from their planting locations.

At the stream site, *T. distichum* continues to survive well with only one sapling having died (Table 17). Survival *of Nyssa aquatica* has steadily declined from 1992 to 1994, regardless of the presence of tree shelters. Survival of saplings with tree shelters has remained > 50%, but due to this decline, sapling survival without shelters has been reduced to 8%. Saplings of *F. pennsylvanica* in the stream site have also continued to die over the three year period, similar to *N. aquatica*. While the presence of shelters promoted better survival of *N. aquatica*, it was not due to protection from beaver which damaged very few .

Table 16. Percent survival in the autumns of 1992, 1993 and 1994 in the backwater site affected by "Tubex" tree shelters and degree of acclimation (Experiment IX).

	PERCENT SURVIVAL IN 1992			
	Without Tubex		With Tubex	
SPECIES	Acclim	Non	Acclim	Non
Fraxinus pennsylvanica	0	0	0	0
Nyssa aquatica	69	90	83	80
Taxodium distichum	95	100	100	100

	PERCENT SURVIVAL IN 1993			
	Without Tubex		With Tubex	
	Acclim	Non	Acclim	Non
Fraxinus pennsylvanica	0	5	0	5
Nyssa aquatica	8	0	77	70
Taxodium distichum	100	100	100	100

	PERCENT SURVIVAL IN 1994			
	Without Tubex		With Tubex	
	Acclim	Non	Acclim	Non
Fraxinus pennsylvanica	0	8	0	5
Nyssa aquatica	8	0	69	70
Taxodium distichum	100	100	100	100

Table 17. Percent survival in the autumns of 1992, 1993 and 1994 in the stream site as affected by "Tubex" tree shelters and degree of acclimation (Experiment IX).

	PERCENT SURVIVAL IN 1992			
	Without Tubex		With Tubex	
SPECIES	Acclim	Non	Acclim	Non
Fraxinus pennsylvanica	58	30	89	68
Nyssa aquatica	85	70	85	100
Taxodium distichum	75	60	100	100

	PERCENT SURVIVAL IN 1993			
	Without Tubex		With Tubex	
	Acclim	Non	Acclim	Non
Fraxinus pennsylvanica	21	25	84	90
Nyssa aquatica	23	20	85	80
Taxodium distichum	100	95	100	100

	PERCENT SURVIVAL IN 1994			
	Without Tubex		With Tubex	
	Acclim	Non	Acclim	Non
Fraxinus pennsylvanica	16	20	53	35
Nyssa aquatica	16	0	54	70
Taxodium distichum	100	95	100	100

Table 18. Percent saplings with the main stem cut by beaver in either 1992, 1993, or 1994 by planting site, "Tubex" tree shelters and degree of acclimation (Experiment IX).

	BACKWATER			
	Without Tubex		With Tubex	
SPECIES	Acclim	Non	Acclim	Non
Fraxinus pennsylvanica	100	95	100	90
Nyssa aquatica	15	0	15	0
Taxodium distichum	100	100	0	0

	STREAM			
	Without Tubex		With Tubex	
	Acclim	Non	Acclim	Non
Fraxinus pennsylvanica	89	80	32	10
Nyssa aquatica	8	0	8	0
Taxodium distichum	75	85	15	10

saplings (Table 18). Instead, breakage from birds and insect herbivory were more often the cause of damage.

Beaver damage has been significant for *T. distichum* and *F. pennsylvanica* in both backwater and stream sites when unprotected by tree shelters (Table 18). When tree shelters were used, beaver damage was less, except for *F. pennsylvanica* planted in the backwater site where beaver were successful in extracting saplings enclosed in tree shelters. Saplings of *F. pennsylvanica* were generally killed by beaver since the saplings were frequently dislodged from the sediments and hence had little chance to resprout. Without the excellent resprouting ability of the *T. distichum* saplings (Table 19), beaver would have killed many of the plants.

The results of this experiment were similar to the preceding experiment in supporting *T. distichum* as the best species for restoration in standing water habitats. This was not surprising, nor was the vulnerability of unprotected saplings to damage from beaver. The degree of damage of *N. aquatica* by birds or browsing animals was greater in this experiment than in the other

Table 19. Percent saplings that resprouted and were alive in the autumn of 1994 that had the main stem cut by beaver by planting site, "Tubex" tree shelters and degree of acclimation (Experiment IX).

	BACKWATER			
	Without Tubex		With Tubex	
SPECIES	Acclim	Non	Acclim	Non
Fraxinus pennsylvanica	0	0	0	0
Nyssa aquatica	50	NA	0	NA
Taxodium distichum	100	100	NA	NA

	STREAM			
	Without Tubex		With Tubex	
	Acclim	Non	Acclim	Non
Fraxinus pennsylvanica	18	25	67	50
Nyssa aquatica	100	NA	0	NA
Taxodium distichum	100	94	100	100

experiments. Since these saplings had leaves, they might be more attractive to herbivores and this type of damage be more extensive than for a dormant sapling. In addition, both *N. aquatica* and, to a lesser extent, *F. pennsylvanica* were less successful in establishing themselves while metabolically active. The lack of differential response of acclimated and non-acclimated saplings in this experiment collaborates the findings of Experiment VII.

EXPERIMENT X.

Replanting the disturbed deltas of the SRS requires restoration across a wide diversity of hydrologic and sediment types. To compensate for these site differences, planting techniques will need to vary depending on the specific environment of each location. Very soft sediments are common in the deltas. As this sediment type will not allow a planting hole to be dug, a method of planting a tree without the need for digging was tested. Hand-bagged or balled and burlapped planting stock might be ideal for these soft sediments since the weight would cause the ball to settle into the soft sediments, but it would be nearly impossible to get a heavy planting unit into these sites. Therefore, this experiment examines different methods of root pruning which allows for the insertion of bareroot stock directly into the sediment.

Roots of three flood tolerant species (*Taxodium distichum*, *Nyssa aquatica* and *Fraxinus pennsylvanica*) were pruned to three differing severities. The most severe treatment created a "cutting" by severing the main stem of the tree at the root collar. The stem was then treated with a synthetic auxin to promote adventitious root formation. In the severe root pruning treatment, all but 23 cm of tap root was removed before planting. The moderate root pruning treatment was the least severe, with the lateral roots pruned to a 23 cm diameter and the tap root to a 23 cm length. All trees were then planted by simple insertion into the soil and staked for support. *Tubex* tree shelters were placed on all trees to prevent herbivory.

After three growing seasons, *T. distichum* has the best overall survival in each root-pruning treatment (Table 20). *Nyssa aquatica* also has good survival in the severely pruned treatment and survival equal to *T. distichum* in the moderately pruned treatment. *Fraxinus pennsylvanica* has no surviving individuals in any treatment by 1994.

Taxodium distichum had the largest increase in height among the three species (data not shown). *Nyssa aquatica* had a large amount of stem breakage and herbivory and generally decreased in height. The few *N. aquatica* saplings without physical damage increased in height. Diameter growth of *T. distichum* in the moderately pruned and severely pruned treatments was similar.

Table 20. Percent survival in the autumns of 1992, 1993 and 1994 as affected by root pruning method (Experiment X).

	ROOT PRUNING METHODS								
SPECIES	CUTTING			SEVERE			MODERATE		
	92	93	94	92	93	94	92	93	94
F. pennsylvanica	0	0	0	7	0	0	47	20	0
N. aquatica	27	13	13	87	80	78	100	10	10
T. distichum	47	33	33	100	10	10	100	10	10

The moderately and severely pruned treatments for *N. aquatica* and *T. distichum* have sufficient survival to recommend these two methods for replanting unconsolidated sediments. Neither *F. pennsylvanica* nor the cutting treatment of any of these three species had adequate survivorship to be used.

Data (through 1993) for this particular study was also published in the *Proceedings of the Hillsborough Community College Annual Conference of Wetlands Restoration and Creation* (see Appendix II).

EXPERIMENT XI.

With the cessation of thermal effluent, dense herbaceous vegetation developed over most of the disturbed delta. This vegetation would strongly compete for light, nutrients and space with transplanted saplings and thus potentially restrict the establishment of successional bottomland hardwood species. Since we have assumed that successful reforestation of the delta will require replanting the site, controlling the vegetation may be necessary to reestablish some species in the Four Mile Creek Delta.

Two different methods, each at two intensities, of controlling the herbaceous vegetation were examined in an experiment initiated in the spring of 1993. Competition control methods (physical or chemical) were used to clear the vegetation. Each method was applied to either the whole 16 x 16 m plot or restricted to a 1 m wide strip in which the seedlings were planted. In these latter plots, a 1 m strip of undisturbed vegetation remained between rows of trees. A bush hog mower and/or weedeater physically removed the vegetation, but did not kill it, while "Accord", a wetland approved herbicide, was used to chemically kill the vegetation.

Species planted in this experiment were *Taxodium distichum, Nyssa aquatica, Quercus phellos, Q. nuttallii, Q. lyrata* and *Q. falcata var. pagodaefolia*, the latter three species being new to the restoration program. In each treatment plot, saplings were randomly planted in six rows, with six trees per row on a 2 x 2 m spacing and five replicate plots per treatment. In addition to the four competition control treatments, a control treatment had seedlings planted directly into the existing vegetation. For each species, a total of 150 seedlings (sample size = 6 per species and treatment combination) were planted and each enclosed in a *Tubex* tree shelter.

The initial application of the competition controls was to be in the autumn of 1992, but was not possible due to a flood during the fall and winter of 1992/93. Therefore, this experiment was planted in late April, without the benefit of vegetation control. Application of vegetation control methods were made in late July of 1993 and again in June 1994. Therefore, the survival and growth during 1993 were probably not strongly influenced by the vegetative control treatments.

The late planting did not inhibit bud break with only two of the 900 trees failing to sprout. Treatments did not enhance survival during either 1993, 1994 or 1995, but differential species survival was observed (Table 21). In the autumn of 1993, all six species had overall survival > 90%. During 1994 survival of the species was affected by the summer flood events of that year. Survival of *T. distichum* and *Q. lyrata* was greater than 89%, while survival of *N. aquatica*, *Q. nuttallii*, and *Q. phellos* was in the 70% range. Survival of *Q. falcata var. pagodaefolia* was low (29%). By 1995, survival had further declined, but the species groupings remained the same.

Differential survival of the species due to planting elevation was noted (Table 22). Survival increased as planting elevation decreased for *T. distichum* and *N. aquatica*, and less so for *Q. nuttallii*. The opposite trend was observed for *Q. falcata var. pagodaefolia* and *Q. phellos*, while *Q. lyrata* was unaffected by planting elevation. This may be due to the drought which started in the summer of 1993 and continued until June of 1994. Higher elevations may have been droughty and hence stressful. During this time, foliar burn associated with drought stress increased with higher elevation. But more influential is that the low elevations were flooded to a greater extent in 1994 and the flood tolerance of the species became critical.

Planting elevation affected height growth of *N. aquatica* and *T. distichum* by 1994, where seedlings in the lower elevation grew 66% greater than those in the higher elevation group (data not shown). Height growth of the other four species was unaffected by planting elevation, but all had positive growth. Averaging seedlings from all elevations, height growth increases for each species were as follows: *N. aquatica* (90%), *Q. falcata var. pagodaefolia* (30%), *Q. lyrata* (60%), *Q. nuttallii* (72%), *Q. phellos* (69%) and *T. distichum* (78%).

Thus, controlling the herbaceous vegetation was not essential to establish these species in the delta. Flood tolerance has again been indicated to be an important factor to be considered in species selection. All of the species in this experiment except *Q. falcata var. pagodaefolia* were successfully established, although there was differential survival by planting elevation, which could potentially be exploited to increase the species diversity of the area to be restored.

Table 21. Percent survival, as affected by treatment (C = Control; PR = Physically cleared, rows only; HR = Herbicided, rows only; PW = Physically cleared, whole plot; HW = Herbicided, whole plot) (Experiment XI).

SPECIES	YEAR	C	PR	HR	PW	HW	Overall
Nyssa aquatica	1993	93 (4)	93 (4)	93 (7)	90 (4)	97 (3)	93
	1994	87 (8)	67 (12)	77 (7)	67 (7)	73 (11)	74
	1995	83 (7)	63 (10)	73 (8)	53 (6)	70 (12)	69
Quercus lyrata	1993	97 (3)	90 (7)	93 (4)	100 (0)	100 (0)	96
	1994	93 (4)	90 (4)	90 (4)	97 (3)	100 (0)	94
	1995	83 (7)	87 (3)	77 (8)	83 (10)	97 (3)	85
Q. nuttallii	1993	90 (4)	90 (4)	90 (10)	97 (3)	90 (4)	91
	1994	67 (7)	83 (5)	83 (9)	80 (6)	80 (8)	79
	1995	67 (7)	60 (7)	60 (10)	57 (7)	73 (8)	63
Q. falcata	1993	93 (4)	93 (4)	93 (4)	93 (7)	97 (3)	94
	1994	23 (8)	10 (7)	33 (19)	47 (10)	33 (7)	29
	1995	23 (8)	07 (4)	13 (10)	37 (6)	13 (6)	19
Q. phellos	1993	97 (3)	97 (3)	100 (0)	97 (3)	93 (4)	97
	1994	77 (7)	73 (9)	80 (6)	67 (14)	63 (3)	72
	1995	70 (11)	67 (11)	50 (5)	47 (11)	53 (6)	57
Taxodium distichum	1993	93 (4)	97 (3)	90 (7)	97 (3)	90 (4)	93
	1994	87 (10)	90 (7)	83 (7)	93 (4)	90 (4)	89
	1995	87 (10)	90 (7)	83 (7)	93 (4)	90 (4)	89

Mean survival (1 S.E.) in autumn 1993, 1994, 1995. Sample size = 5.

Table 22. Percent survival, as affected by planting elevation, all treatments combined (Experiment XI).

	<--- Wetter									Drier --->		
	0 to +20 cm			+20 to +30 cm			+30 to +40 cm			> +40 cm		
	93	94	95	93	94	95	93	94	95	93	94	95
Nyssa aquatica	100*	95	93	92	71	65	90	67	57	88	50	50
		(41)			(51)			(42)			(16)	
Quercus lyrata	98	95	88	96	96	89	96	91	79	94	94	88
		(41)			(46)			(47)			(16)	
Q. nuttallii	100	90	70	90	69	51	86	81	71	89	74	63
		(40)			(49)			(42)			(19)	
Q. falcata	94	29	10	98	25	16	90	27	18	93	53	47
		(31)			(55)			(49)			(15)	
Q. phellos	100	68	56	93	65	48	95	73	57	100	95	84
		(41)			(46)			(44)			(19)	
Taxodium distichum	97	97	97	91	91	91	91	83	83	94	78	78
		(38)			(47)			(47)			(18)	

* Percent survival in autumn of 1993, 1994, and 1995. Sample size is shown in parentheses.

EXPERIMENT XII.

Large stands of *Salix nigra* exist across the Four Mile Creek delta and corridor. Whether the presence of low density stands of *S. nigra* represent a threat to establishing seedlings (competing for available nutrients, light and water) or a benefit (acting as a nurse crop, providing shelter in a high light environment) was unknown.

Beginning in 1994, this experiment examined seedling response to being planted under *S. nigra.* In the first treatment, seedlings were planted under an existing *S. nigra* canopy. In the second treatment, seedlings were planted following the felling and removal of all *S. nigra* from the plot. Herbaceous vegetation was not removed from the plot. The final treatment consisted of planting areas immediately adjacent to the *S. nigra* plots that were dominated by herbaceous vegetation, typically *Andropogon virginicus*, and not containing any *S. nigra*.

The experiment also served as a species trial for *Carya aquatica* and *Q. laurifolia*, both of which are new to the restoration program. The experiment has five replicate plots of each treatment for a total of 15 plots. The plots measure 10 x 18 m with a 5 m buffer between plots if the adjacent plots differed in treatment. Each plot contained eight seedlings of four species (*C. aquatica, Q. laurifolia*, *Q. lyrata* and *T. distichum*). Each tree was enclosed in a *Tubex* tree shelter to limit herbivory.

After the first growing season (1994), three species (*C. aquatica*, *Q. lyrata* and *T. distichum*) had overall survival of >90%, while *Q. laurifolia* had poor survival (6%, Table 23) due to three growing season floods. Survival declined in 1995 for all species, but was still > 70% for the three species. Survival was not affected by treatment during the first growing season, but after the second growing season (1995) survival was lower in the plots where the willows had been removed than where the willows remained.

Early in the 1994 growing season, when the site was droughty, many saplings planted in the grass area appeared stressed. Saplings were defoliating and the tops died-back, especially *T. distichum*. Saplings planted where the willow canopy had been removed showed similar symptoms, but not quite as severe. Saplings under the willow canopy were generally in better health, with less drought stress symptoms observed. If the drought persisted, many of the stressed saplings might have died. But the drought was replaced by a series of floods which instead tested the flood tolerance of the species.

Table 23. Percent survival (mean and 1 standard error, n = 5) as affected by treatment in the autumn of 1994 and 1995 (Experiment XII).

SPECIES	YEAR	Willow removed	Willow uncut	Grass
Carya aquatica	1994	93 (8)	90(10)	95 (3)
	1995	80 (6)	95 (5)	88 (6)
Quercus laurifolia	1994	10(10)	8 (8)	0 (0)
	1995	0 (0)	0 (0)	0 (0)
Quercus lyrata	1994	98 (3)	95 (5)	98 (3)
	1995	83 (8)	90 (7)	90 (5)
Taxodium distichum	1994	90 (6)	98 (3)	82 (3)
	1995	75(10)	95 (3)	73 (6)

Three species, all known to have good flood tolerance, did very well in this experiment. For the first time during these studies, drought conditions during the first growing season affected the seedlings. These conditions did not persist and hence did not test the drought tolerance of the species, but did give an indication that this could be important in the infrequently dry years. The efforts to remove the willow competition was not necessary to ensure survival and may actually be counterproductive. In this experiment, the willow acted as a nurse crop and increased survival.

DISCUSSION

Many other studies stress that the abiotic environment is critical in the success of any restoration efforts and should be documented prior to restoration, if possible. This could not be done for the delta of Four Mile Creek for numerous reasons and was initially encountered only during the course of these studies.

During reactor operations, the delta was extensively recontoured by the effluent. The delta is presently not characteristic of a typical Southeastern Coastal Plain stream. The sediments are largely dominated by recently deposited sands (up to 60 cm deep). Sands have low cation exchange and water holding capacities and are generally considered to be infertile and potentially droughty for plant establishment without frequent rainfall. Although the upper soils are sandy and could be droughty, a permanent water table exists at approximately 1 m depth.

While the reactor was in operation, the hydrology of the delta was largely controlled by reactor effluent and the influence of the Savannah River was much less apparent. Hence, the real factors that controlled the delta's hydrology were obscured by the large volume of reactor effluent. Once the reactor was shutdown, a different hydrology of the delta was observed. This picture of the delta's hydrology was still biased due to the prolonged drought of the late 1980s.

By 1991, without the reactor effluent and with more normal rainfall, it was observed that the wet extreme of the hydrology of the Four Mile Creek Delta is controlled by the rise and fall of the Savannah River. The extreme flooding events caused by the river are the real limiting factor to successful restoration. The less frequent, less intense and shorter flood events normally associated with the watershed of a stream of this size are far less important. Rain events in the watershed during dry periods become more important and control the depth to the water table. This is when the less flood-tolerant tree species can become established.

The management of the Savannah River by the U. S. Army Corps of Engineers has changed the volume, duration and frequency of flood events downstream of the Clarks Hill Dam. The flood events and their timing are critical to regeneration of downstream areas. The vegetational response will vary tremendously depending on the characteristics of the flood. If a prolonged flood event occurs during the dormant season, minimal damage may occur, but when these flood events occur during the growing season (an unusual event under natural conditions) serious damage may result.

The initial vegetation establishing in the delta did so during drought conditions. Hence, when the delta was initially viewed in the mid 1980s, it had several different plant communities developing on it, ranging from those characteristic of dry to permanently flooded sites. The is analagous to the situation which exists in the succession of abandoned agricultural fields, in that the season of abandonment influences the initial successional stages. If succession had begun during a wet season or year, then the plant communities which developed might be quite different than those observed.

From the observation of the existing vegetation in 1990, the assumption was made that a hydrologic gradient existed across the delta. This assumption was responsible for the design and species selections for the experiments in FY 90 and 91, which examined individual microhabitats and more mesic species. This assumption was ultimately shown to be incorrect. This became very evident by autumn of 1991 (a wetter year) when all species were practically eliminated except for those with very good to excellent flood tolerance. This initial apparent variation in topography is now perceived to have small effects relative to the large scale flood events associated with the Savannah River. Hence, flood tolerance of individual species was of extreme importance and should not be ignored when considering species selection. Maximum survival occurred for wet site species, such as *Taxodium distichum*, *Fraxinus pennsylvanica,* and *Quercus michauxii*.

Another concern of the initial experiments was whether fertilization was necessary to supplement the low fertility of the deposited sands. Since the seedlings did not die during periods of low rainfall, the rooting zone of the transplanted seedlings was obviously deep enough to find available water and hence nutrients from the old stream bottom sediments. Fertilization did not enhance survival of any species in Experiments I-III.

From Experiment IV, it became evident that seedlings must be tall enough to withstand the anticipated depth of floodwater. While 30-45 cm tall seedlings are easier to plant, their survival was less than for 60-90 cm tall seedlings. The maximum flood depth exceeded 45 cm and thus overtopped the smaller seedlings. Few species can survive being overtopped for any length of time during the growing season.

Larger planting stock did not enhance survival. If, to meet specific restoration objectives, large planting stock is desirable, then these must be planted much earlier in the dormant season than was possible in this experiment. Earlier planting will permit better root establishment before spring budbreak and promote better survival. The need to purchase more costly and larger plant materials can be avoided by using stock that is in the 45-60 cm height range. This height should be tall enough to withstand most growing season floods.

To restore sites with water 30-60 cm deep, *T. distichum*, *Nyssa aquatica* and *F. pennsylvanica* planted as balled and burlapped or hand-bagged survived quite well. Bareroot stock of all three species did very well in either 0-30 or 30-60 cm water depths except for *Fraxinus pennsylvanica* in the deeper water. Considering the cost of the three different types of planting stocks, bareroot trees did quite well at a fraction of the cost of either of the other two types. The much lower labor cost of planting bareroot stock would also favor this stock type.

Our attempts to acclimate plants in either the field or the simulated wetland experiments did not prove beneficial. Since acclimation is difficult, costly and time consuming, it is not recommended.

In muck soil habitat where both sediment instability and permanent water conditions exist, *T. distichum* and *N. aquatica* can be successfully established by simple insertion of moderately or severely root pruned bareroot stock.

The plantings in permanent water habitats still must pass the test of successfully anchoring in the sediments by the time the stake disintegrates. In the simulated wetlands experiments, roots of both *T. distichum* and *N. aquatica* were extensively found in the bottom sediments. In addition, the backwater sites dried out almost completely during 1993, leaving the balled and burlapped and hand-bagged saplings sitting upon the sediments. Their root system had escaped the burlap bag and extensively rooted in the bottom, as evidenced by the lack of wilting or mortality.

Control of competing herbaceous or willow vegetation was not necessary for successful establishment of woody seedlings. From these experiments, the influence of small differences in elevation on survival and health in these experiments can be observed. This provides additional evidence to believe that a multiple species community is possible, taking advantage of slight elevation changes. It is also informative to know that under very wet soil conditions, outplanting in late April is still potentially successful.

Protection from herbivory is a difficult problem. If very large areas are to be planted, then herbivory will be low since there is abundant food. Limited plantings, such as ours, may be expected to have greater herbivory. Most of the Four Mile Creek Delta is terrestrial habitat and the primary herbivore was deer, with some damage caused by birds perching on the tops of the trees. Beaver herbivory was strongly limited to those areas where the animals can swim directly to the plants. They do not go far overland in search of food. Unfortunately during flood events, large portions of the delta are underwater and the beaver have access to all of the plantings. On the other hand, when the delta is flooded, beavers have access to a tremendous food source and the plantings are small by comparison. Occasionally the floodwater was higher than the tree shelters, hence the upper portions of the plants were exposed to herbivory. Potential control of beaver may play a very important role in the success of any plantings.

The use of tree shelters is essential to reduce beaver damage in standing water areas. Tree shelters add considerably to the cost of restoration, both in materials and labor. The use of these more costly materials needs to be evaluated relative to the restoration objectives (e.g. successful establishment criteria, required stems per hectare, cost, desirability of a single planting event, etc.). At that point, decisions can be made weighing the advantages of these costly materials versus the requirements of the regulatory objectives of restoration.

Addressing the objectives of this research program, several conclusions can be made from our studies. The first objective was to determine the appropriate species for reintroduction. *Taxodium distichum* has been used in virtually every individual experiment and without fail it has had the best survival. This enforces the obvious conclusion that the Four Mile Creek delta is wet, potentially very wet. Conducting this research over multiple years was critical to determine the true nature of the site. Woody plantings will have to survive the environmental extremes of decades or even centuries. Experiments of one or two years duration cannot provide this perspective.

The excellent survival of *T. distichum* also infers that the water table is never very deep, even when the rainfall is slight and the surface soils appear dry. Thus, it is unlikely that once established, the drought tolerance of species would ever be an important characteristic. The success of *T. distichum* over the entire delta also infers that other woody species with similar flood tolerance would be successful. This is supported by examining the survival of *N. aquatica*, *F. pennsylvanica*, *Carya aquatica*, *Quercus lyrata* and *Q. nuttallii* from a number of our experiments. Three other oak species (*Q. michauxii*, *Q. nigra* and *Q. phellos*) have been shown to be marginally appropriate for restoration of the delta, depending on the elevation of the planting locations.

Future restoration plantings should involve multiple species, with possible differentiation of planting sites by elevation with wetter or standing water sites planted with *T. distichum*, *N. aquatica*, and *C. aquatica* and slightly drier sites planted with *F. pennsylvanica* and *the Quercus* species. This mixed species approach to restoration is desirable for diversity and is accomplishable in the delta. This does not mean that small scale monotypic patches will not occur or are undesirable. In fact, in some very wet areas, there are so few species that can tolerant these conditions that only monotypic communities can be expected to develop.This type of planting (species selected for each planting location) requires that each area and habitat type be evaluated, and that the planting crew must be well-trained and supervised.

Success of restoration should be measured not only at the level of survival of individual plantings, but by how the community develops over the future decades. For instance, although individuals have been successfully established, will the resultant community existing in 10 or 20 years be different as a result of the specific plantings? Will the communities converge on a similar community type, guided by the environmental constraints of the delta? Will this community differ from the result of natural succession? The answer to these questions, although long-term, would provide extremely useful data with which to evaluate the entire process of wetland restoration and appraise its value relative to natural succession.

The research over the past 6 years has contributed greatly to the general paucity of knowledge about bottomland forest restoration. In addition, we have successfully established a great many individuals of a number of tree species in the delta. Once they reach maturity and begin producing seed, the succession of delta will be greatly accelerated. For several of these species, including *Fraxinus pennsylvanica* and *Taxodium distichum*, this has already begun. Thus, when the vegetation of the Four Mile Creek delta is examined at some future date tree establishment will be observed to have originated from a great number of points from within the delta, in contrast to the linear succession usually observed only from the margins of the disturbed area.

APPENDIX I.

SELECTION OF WOODY SPECIES FOR BOTTOMLAND RESTORATION

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ABSTRACT

The bottomland forest of a third order stream in the South Carolina coastal plain was slowly destroyed between 1955 and 1985 by thermal effluent. When restoration efforts began in 1990, the site was dominated by several early successional stages , ranging from broomsedge (*Andropogon virginicus*) on dry sites to black willow (*Salix nigra*) in ephemeral pool sites. Successful bottomland forest restoration depends on choosing the correct species and methods of reintroduction for a particular site. The presence of large areas of broomsedge and loblolly pine suggested that some upland as well as bottomland species might do well in this habitat. Therefore, eleven species representing a wide range of site requirements were planted as either containerized or bareroot seedlings into sites varying in apparent soil moisture. After the first growing season, a relatively dry year, survival was > 70% for species as diverse as *Taxodium distichum* and *Quercus marilandica*. The subsequent three years have been much wetter and adequate survival has been limited to *T. distichum* and *Q. michauxii* (in both wet and dry sites), *Fraxinus pennsylvanica* (in wet sites), and *Q. nigra* (in dry sites). Over the four years of the study, growth has been substantial, but beaver herbivory during recent flood events has adversely affected, while not killing, some individuals.

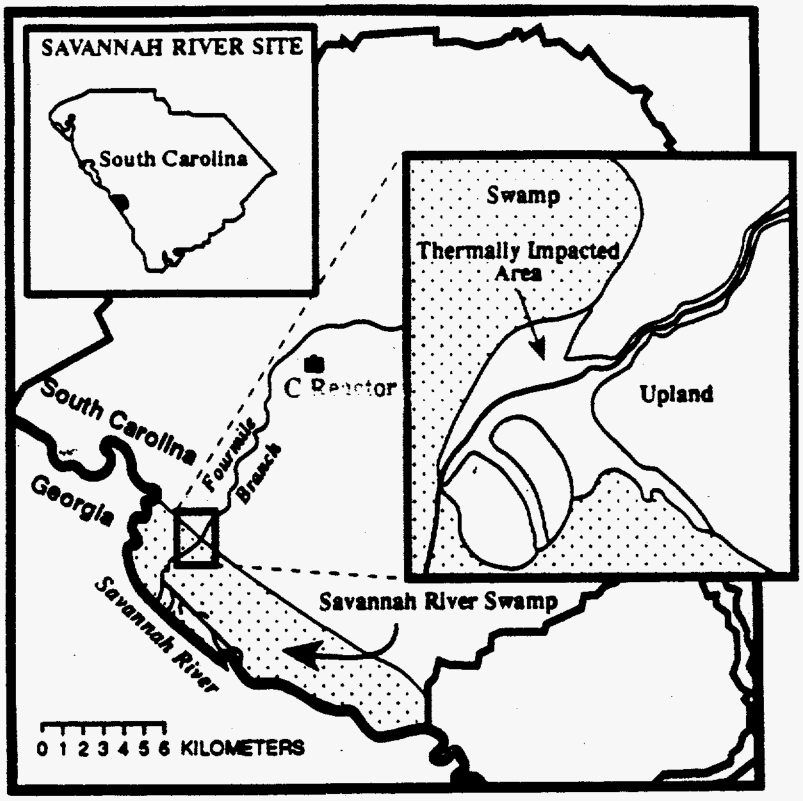
INTRODUCTION

On the Savannah River Site, nuclear production reactors were cooled by a once-through cooling cycle, utilizing water from the Savannah River and discharging the effluent to third order tributaries of the Savannah River. This discharge persisted for 30+ years and changed the stream environment drastically. The flow rate was increased by approximately an order of magnitude, raising the stream level 15 to 30 cm. The water temperature was raised to approximately 45°C at the delta where the tributaries merge with a bald cypress (*Taxodium distichum*) - water tupelo (*Nyssa aquatica*) swamp forest associated with the Savannah River.

In addition, the effluent caused sediment instability with erosion of the streambed in the upper reaches and deposition in the lower reaches. As a result of these discharges, large areas of bottomland and swamp forests were destroyed in three stream systems on the SRS (Sharitz, *et al.*, 1974). These losses include 90 ha of the delta of Fourmile Branch (Jensen, *et al.*, 1984), a stream impacted by C-Reactor (Figure 1).

Since this effluent persisted almost continually from 1955 to 1985, the normal seed bank and sprouting ability of the original forest was eliminated. Therefore, secondary succession, observed as a consequence of other disturbances such as blowdown of clearcutting, was not possible.

Figure 1. Location of the Savannah River Site and the thermally impacted area of the Fourmile Branch delta.



Natural recovery of the vegetation in the delta of Fourmile Branch began in 1985 when the reactor was shut down. Recovery of the vegetation is being documented through the use of permanent plots. The vast majority of woody stems belong to early successional species with few individuals of later successional species present.

Although vegetation recovery is occurring in Fourmile Branch delta, the later successional, bottomland hardwood forest would not likely be well established for at least 50 years. This later successional vegetation would provide a continuous forest canopy and good soil stabilization, along with quality wildlife habitat. Therefore, a research program was begun to investigate methods to accelerate succession and restoration of the vegetation of Fourmile Branch delta.

The restoration is limited by several factors. First, large scale soil disturbance, such as contouring of the site, is not desirable due to the potential resuspension of low level radionuclide contaminated soil. Second, the hydrology of the delta cannot be separated from the influence of the Savannah River, which is controlled by several upstream dams. Finally, it was decided that species reintroduction would be necessary to ensure that desirable species become established in the delta rapidly. Thus, the research has focused on introducing later successional species into the existing dense early successional vegetation. This manuscript reports the results of three experiments designed to determine suitability of various species and their responses to fertilization at planting.

GENERAL SITE DESCRIPTION

When this research program was initiated in 1990, three distinct habitats were observable: dry sites, dominated by *Andropogon virginicus* (broomsedge) and *Pinus taeda* (loblolly pine); wet sites, dominated by *Scirpus sp*. (sedges) and *Juncus sp.* (rushes); and open shallow water sites, comprised of pools and segments of the braided stream with only overhanging vegetation. The initial studies attempted to utilize these apparent site differences to establish a broad suite of species.

The Fourmile Branch delta is atypical of Southeastern stream bottoms. The sediments have a layer of recently deposited sands on the surface. Therefore, without frequent rainfall, the soils of the delta can be droughty, even though a permanent water table exists at approximately one meter. Surface flooding can occur due to local rainfall or when the Savannah River water levels are high.

The general climate of the area includes warm summers and mild winters (see Aiken station of the South Carolina Climatological Data (NOAA, 1992)). The coldest and warmest months are January (mean daily temperature of 7.9°C) and July (mean daily temperature of 26.8°C), respectively, with a mean yearly temperature of 17.9 C. Precipitation averages 121 cm per year with fairly equal distribution throughout the year. Maximum and minimum monthly rainfalls are 13.6 cm (March) and 5.6 cm (October), respectively. Winter rainfall is primarily from frontal activity, while summer rainfall usually results from convective thunderstorms.

MATERIALS AND METHODS

EXPERIMENT I. The objectives of this experiment are twofold: 1) to determine site suitability of nine tree species for a relatively dry area of the delta, and 2) to determine whether fertilization would enhance survival and growth. Nine species (*Quercus alba*, *Q. coccinea*, *Q. margaretta*, *Q. marilandica*, *Q. michauxii*, *Q. nigra*, *Q. rubra*, *Q. stellata*, and *Taxodium distichum*), which represent a wide range in both flood and drought tolerance, were used. The "dry" habitat in which these species were outplanted was defined by the dominance of *Andropogon*. Plants for this experiment were grown from locally collected seed and were two years old at planting. The containerized seedlings were planted on 2x2 m centers, with seven plants per species/treatment in each of two replicated plots. Half of the seedlings received a starter fertilizer tablet (23/2/0 plus 1% Mg), placed at the bottom of the planting hole. Species/fertilization treatment was randomly assigned to planting locations.

Each spring and autumn following planting, survival and health were determined. Dead seedlings were examined to determine the cause of death, if possible. Any signs of herbivory were noted, especially those that might have contributed to seedling death. Height was determined in the autumn of each year. Data were analyzed by one and two way analysis of variance using SAS (1990).

EXPERIMENT II. This experiment is similar to Experiment I, but trees were planted in wet sites to contrast species response to the hydrology of the planting site. "Wet" sites were defined as having the vegetation dominated by *Scirpus* species and *Juncus* species. Four of the species planted in the previous experiment (*Quercus alba*, *Q. michauxii*, *Q. nigra*, and *Taxodium distichum*) were used in this planting. Details of spacing, fertilizer treatments, observations and measurements were the same as in the preceding experiment.

EXPERIMENT III. The last of the three experiments planted in the winter of 1990 differed by using bareroot seedlings of three species (*Fraxinus pennsylvanica*, *Quercus michauxii*, *Q. shumardii*). Bareroot stock was obtained through the Southeast Forest Experiment Station in Charleston, SC. The objectives of this experiment were similar to Experiment II. Differences between these two experiments include type of planting stock and species, with only Q. michauxii in common with the previous two experiments. Sample size per species/fertilization treatment was 30, with only a single wet site plot used.

DESCRIPTION OF THE PLOT ENVIRONMENT. From random locations in each of the five plots in the delta of Fourmile Branch, 12 soil samples were taken for nutrient and textural analysis. These analyses were conducted at the University of Georgia Soil and Plant Analysis Laboratory in Athens, GA. Following planting, the relative elevation of each planting location was determined during a flood event by measuring the depth of water at each location. The plots are fairly small and these measurements were taken in a short time period during which the overall after level remained constant. At a central location on the delta, and automated meteorology station collected various climatic and hydrologic data.

RESULTS

SOILS. While some minor trends might be indicated by the soils data (Table 1), the variance within each plot is so large that it made interplot comparisons insignificant. Considering then the entire data set as characteristic of the soils in the delta, several facts are apparent. First, the soils are composed primarily of sands, characteristic of the Coastal Plain and also indicative of the deposition of materials in the delta as a result of the increased stream flows. The organic matter and nutrient concentrations of the soil are low, but localized areas of higher concentrations exist, as indicated by the high variance. Also characteristic of Coastal Plain soils is the low pH. The elevation of the planting locations within each plot did not vary greatly, but note that while plot four was dominated by the "wet" site vegetation, it was considerably higher in elevation than the other "wet" plots.

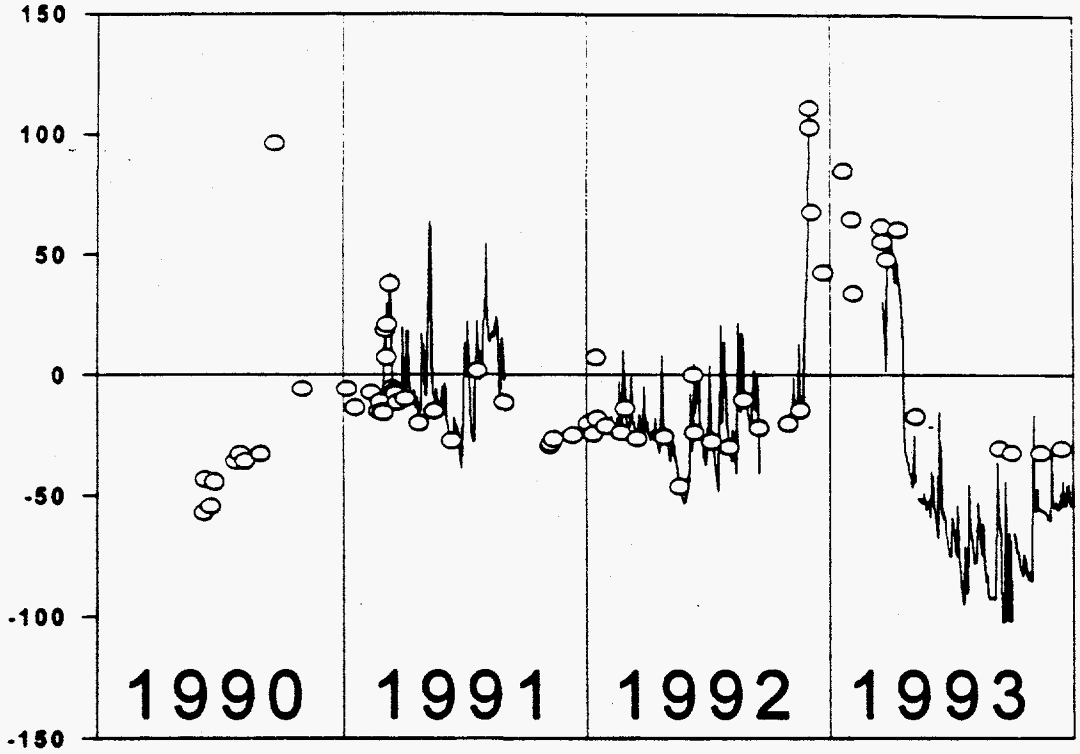
CLIMATE AND HYDROLOGY. The growing seasons of 1990, 1991 and 1993 were warmer than normal, while 1992 was cooler than normal except for the month of July. The growing seasons of 1990 (the first growing season of this study) and 1993 had below normal rainfall, but the rainfall was generally adequate during the other two growing seasons.

The delta of Fourmile Branch is located within the floodplain of the Savannah River, which has three flood-control dams upstream of the site. Releases from these dams affect the hydrology of the delta, independent of the rainfall within the Fourmile Branch watershed. Thus, the rainfall and the water releases from Clarks Hill Dam (the closest reservoir, 130 km upstream) on the Savannah River have combined to produce very different hydrologic conditions during the growing seasons of the last four years. Little flooding occurred during the 1990, 1992, and 1993 growing seasons, but 1991 had several events in which floodwater accumulated on the delta, especially during spring (Figure 2).

Table 1. Relative elevation, soil nutrient levels and soil texture (0-30 cm depth) of experimental plots. Plots 1-4 were used in Experiments I and II, while plot 5 was used in Experiment III. Sample size is 12. Values are mean ± (1 S.D.).

PLOT	1 (Dry)		2 (Dry)		3 (Wet)		4 (Wet)		5 (Wet)	
Relative elevation (cm)	22.1	(5.4)	25.3	(6.3)	3.3	(7.1)	15.9	(6.9)	0.0	(4.9)
Organic Matter(%)	1.3	(1.8)	0.6	(0.5)	4.7	(5.7)	2.3	(4.4)	3.0	(5.7)
pH	4.7	(0.2)	4.8	(0.2)	4.6	(0.2)	4.9	(0.3)	4.7	(0.2)
Total N (%)	0.07	(0.08)	0.04	(0.02)	0.16	(0.10)	0.09	(0.12)	0.09	(0.10)
P (mg/kg)	8.6	(2.7)	8.6	(2.7)	8.6	(2.0)	6.5	(3.3)	8.9	(2.7)
K (mg/kg)	8.1	(3.9)	5.0	(3.6)	9.0	(4.4)	12.0	(8.5)	18.5	(6.0)
Ca (mg/kg)	100.0	(71.2)	52.0	(20.2)	165.3	(72.5)	101.3	(91.5)	131.7	(95.3)
Mg (mg/kg)	13.4	(12.5)	3.9	(2.2)	26.8	(12.2)	13.3	(16.1)	19.4	(16.8)
Sand (%)	87.7	(14.1)	96.5	(2.4)	56.7	(36.4)	81.3	(30.2)	78.8	(33.5)
Silt (%)	6.8	(8.8)	2.2	(1.6)	13.8	(9.5)	7.7	(11.3)	6.9	(7.9)
Clay (%)	4.7	(5.3)	1.3	(1.3)	10.7	(5.4)	3.6	(5.7)	7.2	(16.4)

Figure 2. Hydrology of Fourmile Branch delta from May 1990 to December 1993. Solid line is data from a permanently recording pressure transducer, while the circles are from a staff gauge. Positive values indicate centimeters of water over the soil surface, while negative values are below the soil surface.



While growing seasons of 1992 and 1993 had little flooding, the fall and winter of 1992/93 had extensive flooding. Water depths in our plots exceeded one meter and were continuously flooded from mid-November until mid-April. The trees were dormant and not strongly affected by this flooding. In March and April of 1993, the plants began to leaf out underwater. Fortunately, the flood waters receded below the soil surface by mid-April. However, it was an unusual hydrologic year, with an extensive, prolonged winter and early spring flood, followed by low rainfall and an increasing depth to the water table over the growing season.

EXPERIMENT I. In autumn of 1990, all nine species had survival greater than 70% in "dry" areas of the delta (Table 2). After this first growing season, no fertilizer effect was observed in survival or height growth ($p = 0.22$) within an individual species.

By 1991 the site hydrology had returned to a more typical situation and survival had been drastically changed. Only three species (*Taxodium distichum*, *Quercus michauxii*, and *Q. nigra*) had survival greater than 35%. This has not greatly changed in the last 2 years. While *T. distichum* did not have the best initial survival, this species currently has much better survival (68%) than any other species.

Over the four years, growth in height of the three surviving species has been substantial, with *T. distichum*, *Q. michauxii* and *Q. nigra* all tripling from their initial height (Table 3). Of the surviving individuals of the two oak species, 70% were classified as in good health, with the remainder either in poor health or with the top leader dead or broken. Over 65% of the surviving saplings of *T. distichum* were in good health, with the remainder having had the main stem cut by beaver during the winter of 1992/93. These six saplings were vigorously resprouting with 11 to 38 new stems emerging per sapling (mean of 25).

Table 2. Percent survival in the autumns of 1990 to 1993 of containerized seedlings planted in dry sites in the Fourmile Branch delta.

SPECIES	1990	1991	1992	1993
Quercus alba	90	11	14	04
Q. coccinea	86	00	00	00
Q. margaretta	93	04	04	00
Q. marilandica	96	00	00	00
Q. michauxii	71	46	50	36
Q. nigra	82	36	36	32
Q. rubra	93	00	00	00
Q. stellata	89	25	18	14
Taxodium distichum	71	68	68	68

Fertilizer treatments were combined, due to lack of significant effects.

TABLE 3. Mean seedling height (cm) in the autumns of 1990 to 1993 of containerized seedlings planted in dry sites on the Fourmile Branch delta.

SPECIES (initial height)	1990	1991	1992	1993
Quercus alba (12.1)	15.7	34.0	34.0	36.0
Q. coccinea (8.2)	12.8	NA	NA	NA
Q. margaretta (9.2)	13.6	23.2	12.0	NA
Q. marilandica (10.1)	15.8	NA	NA	NA
Q. michauxii (25.1)	32.2	63.5	75.2	76.4
Q. nigra (23.6)	38.4	65.1	76.9	84.4
Q. rubra (11.5)	18.9	NA	NA	NA
Q. stellata (10.6)	16.4	36.9	39.3	34.7
Taxodium distichum (70.9)	78.7	127.7	159.7	214.7

Fertilizer treatments were combined, due to lack of significant effects.
NA = Not applicable, all seedlings dead.

EXPERIMENT II. Survival in 1990 for the four species planted in "wet" areas exceeded 70% (Table 4). Fertilization was not responsible for any changes in survival or height growth (p = 0.12). Since then, survival of *Q. alba* and *Q. nigra* have declined to very low levels. *Taxodium distichum* and *Q. michauxii* have survived well and both of these species have higher survival in "wet" than "dry" sites (Table 2). While *Q. alba* had poor survival in either sites, *Q. nigra* had better survival in "dry" than "wet" sites.

Height growth of the *T. distichum* and *Q. michauxii* in the "wet" plots (Table 5) was greater than in the "dry" plots (Table 3). These species increased height by three and five times that of the original height, respectively. Health of these two species was very similar to that observed in the "dry" plots. Deer and beaver herbivory were less in the "wet" plots.

Table 4. Percent survival in the autumns of 1990 to 1993 of containerized seedlings planted in a wet site on the Fourmile Branch delta.

SPECIES		**1990**	**1991**	**1992**	**1993**
Quercus alba		75	04	00	00
Q. michauxii	82	64	64	50	
Q. nigra		86	25	14	04
Taxodium distichum	93	79	79	79	

Fertilizer treatments were combined, due to lack of significant effects.

Table 5. Mean seedling height (cm) in the autumns of 1990 to 1993 of containerized seedlings planted in a wet site on the Fourmile Branch delta.

SPECIES (initial height)		**1990**	**1991**	**1992**	**1993**
Quercus alba	(11.3)	16.4	NA	NA	NA
Q. michauxii	(26.1)	34.8	80.3	110.4	129.8
Q. nigra	(26.4)	40.5	91.5	110.0	77.0
Taxodium distichum	(70.2)	80.3	123.1	180.2	235.3

Fertilizer treatments were combined, due to lack of significant effects.
NA = Not applicable, all seedlings dead.

EXPERIMENT III. The larger bareroot planting stock used in this experiment generally did not survive as well as the smaller containerized stock used in Experiments I and II. After the initial growing season, only *F. pennsylvanica* had good survival. Survival of *Q. michauxii* and *Q. shumardii* was < 55% (Table 6). Again, fertilization had no effect on survival or growth ($p = 0.51$).

By the end of the second growing season (1991) and a return of more typical hydrology, survival of the two oaks was < 20%, while survival of *F. pennsylvanica* was 97%.

Height of *F. pennsylvanica* and *Q. michauxii* saplings, had tripled by autumn of 1993 (Table 7), but only seven of the latter species were still surviving. Over 74% of the remaining *F. pennsylvanica* saplings were in good health, with 17% in poor health and 9% having the top leader dead or broken.

TABLE 6. Percent survival in the autumns of 1990 to 1993 of bareroot seedlings planted in a wet site on the Fourmile Branch delta.

SPECIES		1990	1991	1992	1993
Fraxinus pennsylvanica		97	95	100	97
Quercus michauxii		53	17	13	12
Q. shumardii	42	07	02	00	

Fertilizer treatments were combined, due to lack of significant effects.

TABLE 7. Mean seedling height (cm) in the autumns of 1990 to 1993 of bareroot seedlings planted in a wet site on the Fourmile Branch delta.

SPECIES (initial height)	1990	1991	1992	1993
Fraxinus pennsylvanica (57.1)	62.7	88.4	110.9	149.9
Quercus michauxii (34.7)	38.9	69.1	87.0	130.3
Q. shumardii (57.3)	58.7	58.1	26.5	NA

Fertilizer treatments were combined, due to lack of significant effects.
NA = Not applicable, all seedlings dead.

DISCUSSION

The hydrology of the site is exceptionally important in determining the survival of the various tree species. Each species will be profoundly affected both during establishment and subsequent growth into adult trees. However, the climate and hydrology of any individual year may not be typical. Therefore, the results of any particular experiment must be evaluated in light of the climate and hydrology which existed during the experiment to determine how the results could be extrapolated to other climatic years.

Based on the species' responses after the first and subsequent growing seasons, very different recommendations would have been made for replanting. A broad range of species was indicated to be potentially suitable following the results of the relatively dry, first growing season. But, once the typical hydrology of the site returned in 1991, only flood-tolerant species (*Taxodium distichum* and *Fraxinus pennsylvanica*) continued to have excellent survival. Thus, other woody species with similar flood tolerance might also be successful, such as *Nyssa aquatica*, and *N. sylvatica* var. *biflora*.

The degree of flood tolerance may also play an important role in selecting species for "dry" and "wet" sites, as slight elevation differences did lead to differential survival among the 11 species. This difference might be exploitable by planting *Quercus michauxii* and *Q. nigra* in the "drier" end of the gradient.

Since flood-tolerant species are not usually very drought tolerant, the success of these species indicates that drought conditions did not exist even when the rainfall was slight and the surface soils were apparently dry. The water table (Figure 2) and its associated capillary fringe did not recede below the rooting depth of these species. Thus, it is unlikely that the drought tolerance of species, once established, would ever become an important characteristic.

Although Clewell and Lea (1989) indicated that fertilization is usually necessary for successful restoration, it had no effect in our studies. This result may be due to the type or rate of fertilization or possibly to the fact that the existing vegetation may have been able to exploit the fertilizer before our seedlings could use it.

Herbivory was not a critical factor during floods of typical years. But during the winter of 1992/93 when the entire delta was under water, beaver had access to all plantings and definitely had an impact. Fortunately, the resprouting ability of the species can prevent mortality. Herbivory, other than from beaver, was not influential.

RECOMMENDATIONS FOR RESTORATION

Future restoration plantings should involve multiple species, with possible differentiation of planting sites by elevation. Drier sites could be planted with several Quercus species, while wetter sites could be planted with flood-tolerant species, such as Taxodium distichum and Fraxinus pennsylvanica. This mixed species approach to restoration is desirable for diversity and is accomplishable in the Fourmile Branch delta. This certainly does not mean that small scale monospecific patches will not occur or are undesirable. In fact, in some wet areas, there are so few species that can tolerate these conditions that only communities of low tree diversity can be expected to develop.

ACKNOWLEDGEMENTS

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APPENDIX II.

PLANTING UNCONSOLIDATED SEDIMENTS WITH FLOOD-TOLERANT SPECIES

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ABSTRACT

Restoration of severely disturbed swamp forests often necessitates the use of innovative methods due to unconsolidated sediments and almost continuous flooding. Because of the difficulty of working in this habitat, methods such as planting saplings by simple insertion are highly desirable. Saplings of three flood-tolerant tree species (*Fraxinus pennsylvanica*, *Nyssa aquatica* and *Taxodium distichum*) were root pruned to three severities (moderately root pruned, severely root pruned and cutting) and out planted by insertion into unconsolidated sediments of a severely disturbed stream delta. Survival was greater than 80% for *T. distichum* and *N. aquatica* when the roots were either moderately or severely pruned, but less than 33% for cuttings. *Fraxinus pennsylvanica* did poorly with moderately root-pruned saplings having the greatest survival (20%). There was no difference in height and diameter growth between treatments with good survival. *Taxodium distichum* and *N. aquatica* can be successfully reestablished by these methods using either moderately or severely root-pruned saplings.

INTRODUCTION

Innovative methods are often required for the vegetative restoration of severely disturbed swamp forests. The wide range of existing microsites dictates that planting techniques must be adaptable. Thus, many different methods or variations of replanting may be used to restore an entire site.

One soil type commonly found in wetland restoration projects is unconsolidated sediments. They are often referred to as muck, mire or loose soil and may be either organic or inorganic. The unconsolidation or looseness makes it difficult to walk or work in the sediments, yet may constitute a significant portion of a restoration area. The soft nature of unconsolidated sediments does not allow a planting hole to be dug, so alternative methods of plant establishment need to be developed. In addition, these sediments are often permanently to seasonally flooded even during the planting season, so appropriate species for reintroduction are limited by their flood tolerance.

Some successful planting methods have included root pruning of the saplings so they may be simply inserted into the soil. In replanting Louisiana swamps, Conner and Flynn (1989) successfully planted Taxodium distichum saplings in which the lateral roots were pruned to 2.5-5.0 cm in length. One-year-old cuttings or whips of selected hardwood species have also been successfully outplanted in restoration projects (Clewell and Lea 1989). Although root-pruned saplings have been tried before, there has been a direct comparison of different root pruning methods on the growth and survival of outplanted saplings. The objective of this study was to test the feasibility of establishing differentially root-pruned saplings, outplanted in an area of unconsolidated sediments.

SITE DESCRIPTION

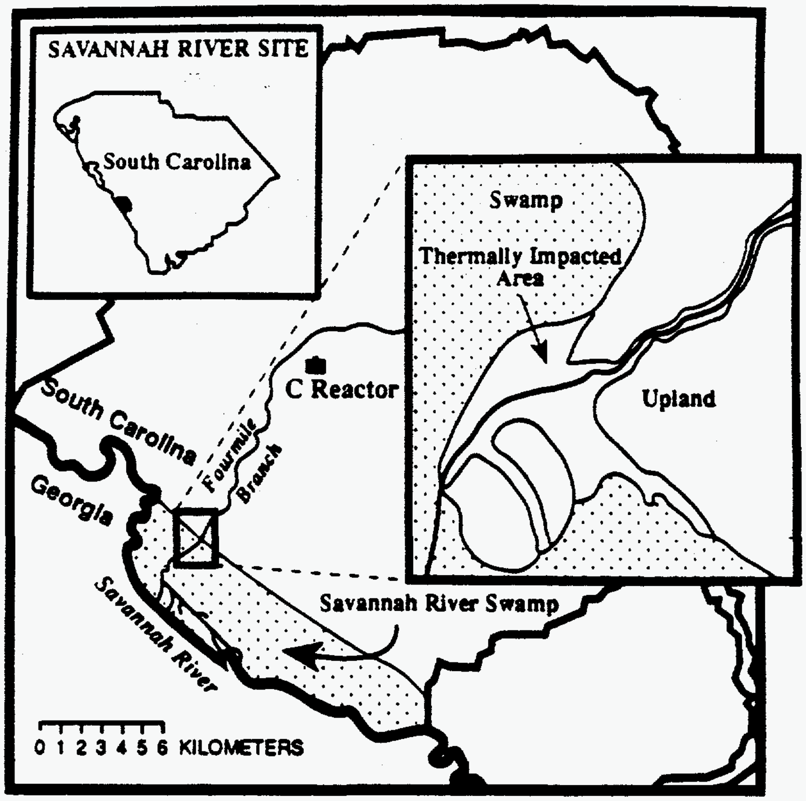
The Savannah River Site is a nuclear materials production facility located adjacent to the Savannah River in the upper coastal plain of South Carolina. During the production of nuclear materials, waters for cooling the production reactors was drawn from the Savannah River. The resulting thermal effluent was then discharged into several streams that drain into the Savannah River. Since 1953, thermal effluent has been released into the streams and through a bald cypress-water tupelo swamp, leaving the corridors and deltas of three streams denuded of existing forest vegetation (Sharitz *et al* 1974).

Fourmile Branch is one of three streams that was deforested during reactor operations between 1953 and 1985 (Figure 1). During this time, water volume increased from 1.0 to 11.3 m^3s^{-1}, eroding the upstream sediments and redepositing them in the stream delta within the Savannah River Swamp (Jensen *et al* 1984). As the base flow returned to pre-reactor levels, a terrestrial habitat emerged containing within it a braided stream with isolated sloughs and pools. Since 1985, the stream corridor and delta have been naturally revegetated with early successional vegetation. Later successional species are generally absent from the site. In 1990, an attempt to restore Fourmile Branch delta by accelerating succession through the introduction of saplings of later successional species was implemented. This manuscript reports one aspect of those species' introductions.

MATERIALS AND METHODS

Three bottomland tree species (Fraxinus pennsylvanica (green ash), Nyssa aquatica (water tupelo) and Taxodium distichum (bald cypress)) were outplanted into muck soils, following three different degrees of root pruning. These species were chosen because of their range in flood tolerance from moderately tolerant (F. pennsylvanica)

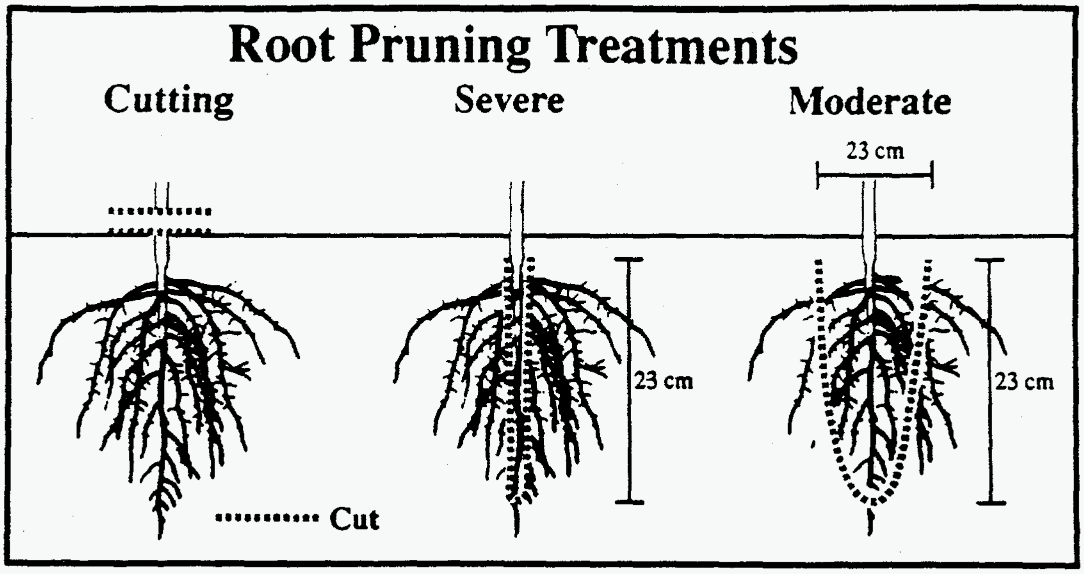
Figure 1. Location of Fourmile Branch and the Savannah River Site in South Carolina.



to very tolerant (*N. aquatica* and *T. distichum*) (Hook 1984). Bareroot stock of *F. pennsylvanica* and *T. distichum* were obtained from a commercial nursery. *Nyssa aquatica* was containerized stock grown in small tree pots from seed collected locally. Both *N. aquatica* and *T. distichum* were two-year-old stock, while *F. pennsylvanica* stock was three years old. Initial height of the *F. pennsylvanica* saplings was greater than 2.0 m, while *T. distichum* averaged 1.3 m and *N. aquatica* 0.9 m.

Saplings were root pruned to three different severities (moderately, severely and cutting) (Figure 2). The least severe treatment, (moderately pruned), had lateral and tap roots pruned to a 23 cm spread. The moderately pruned saplings were the most difficult to plant by simple insertion because they retained the most roots. Tap roots were shortened to 23 cm and all lateral roots were removed from the severely pruned saplings. Both the moderately and severely pruned saplings were inserted into the sediment to the root collar. The cutting treatment was the most severe with all roots removed.

Figure 2. Root pruning treatments.



Cuttings were made by severing the sapling at the one-year-old wood. Rootone F (a mixture of synthetic auxins) was applied before the cuttings were inserted 20 cm into the sediment.

Treated saplings were randomly assigned to planting locations with 1.0 m spacing. Each treatment contained 15 saplings of each species. Following planting on March 17, 1992, each sapling was enclosed in 1.0 m staked Tubex tree shelter. Shelters were used to deter herbivory. All planting locations had soft sediments, and were flooded by less than 20 cm of water.

Height and diameter measurements were taken at planting and then annually for height and biannually for diameter. Height was measured from the soil surface to the tallest leader. Diameter measurements were taken at permanent marks on the stem that were 20 cm from the soil surface. All data were analyzed by using SAS (1990).

Survival of the plantings was assessed weekly at the beginning of the experiment until budbreak, then biweekly for the remainder of the first growing season and bimonthly during the second year. Trees with at least one leaf were considered to be surviving. The fullness of foliage was also noted for each sapling. If the sapling had a normal healthy amount of foliage, then it was considered in full foliage. But if the sapling was defoliating, (an indicator of stress), that was also noted.

During the survival assessments herbivory of the saplings was also recorded. Potential causes of herbivory included grazing (deer), stem breakage (deer or birds) and main stem cut (beaver).

Hydrological data were collected beginning in the spring of 1990 at a location near the center of the delta. Water-table depth was measured using a pressure transducer located in a 1.0 meter deep well or by a staff gauge. Temperature was measured with a model 207 probe, and was collected hourly by a Campbell Scientific, Inc. 21x Micrologger.

RESULTS

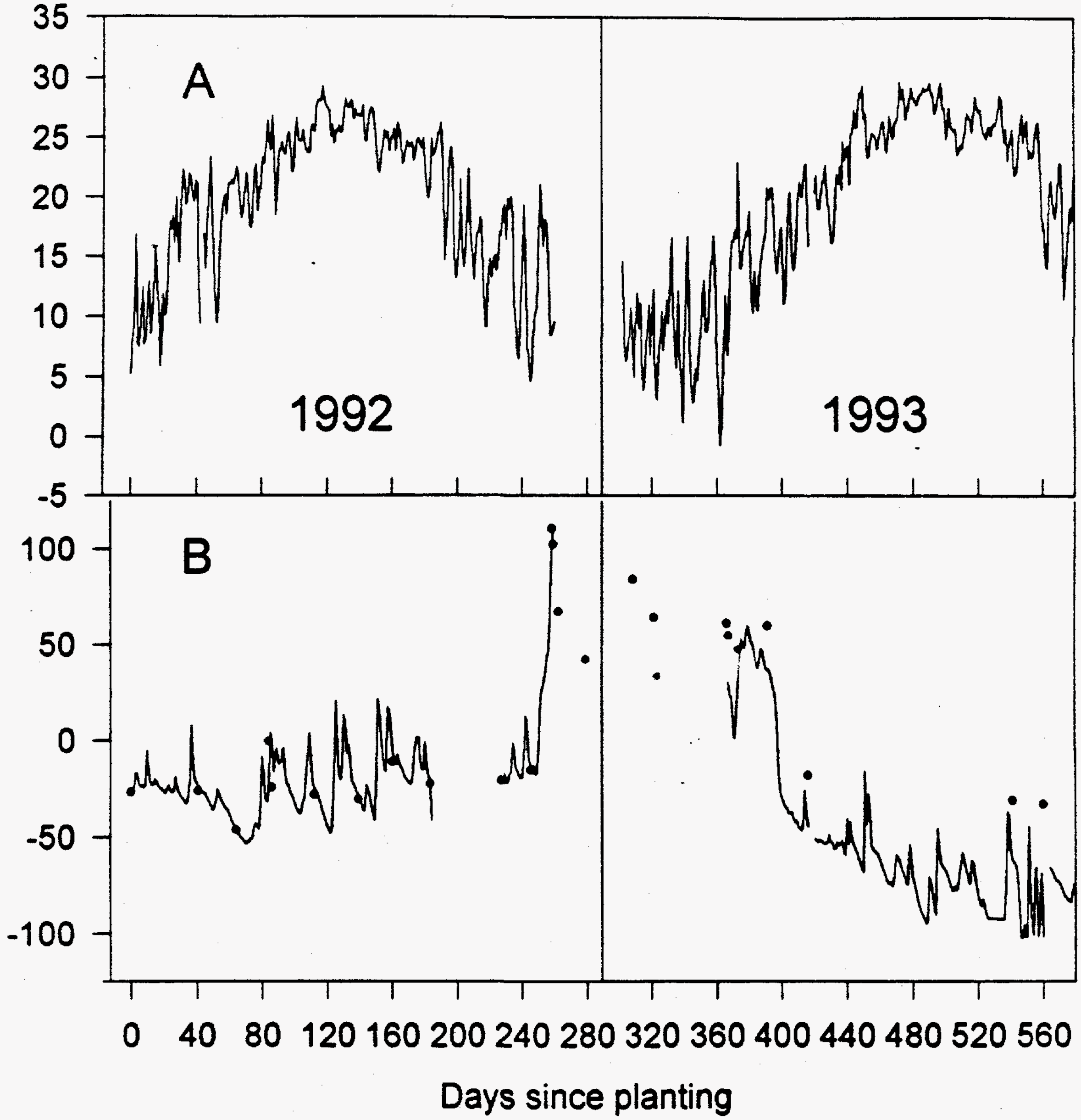
The site was generally wet during the 1992 growing season, with the driest period being between day 60 to 90 (May 16th through June 16th) (Figure 3). The end of the first growing season had a deep flood, greater than 1 meter, that extended from day 280 to day 410 (November 1992 to April 1993). The remainder of 1993 was droughty, with infrequent rain and a low water table. Summer mean daily temperatures were normally above 25 °C (Figure 3).

Taxodium distichum and N. aquatica had 100% budbreak in all treatments. in contrast, only the moderately pruned F. pennsylvanica saplings had 100% budbreak, while severely pruned saplings and cuttings had 53 and 87% budbreak, respectively.

Of the trees that broke bud, we determined the number of saplings in leaf at each assessment date. For F. pennsylvanica, the moderately pruned treatment saplings were not 100% in leaf until July (day 97) (Figure 4). The percent in leaf declined until 20% remained at the end of 1993 (day 567). The severely root-pruned saplings were never 100% in leaf at any assessment. Some of the saplings in leaf on one assessment would defoliate before the next assessment and be replaced by another sapling in leaf. But by May (50 days since planting) survivorship began a constant decline with only a few saplings surviving to the start of the second year. These remaining saplings died by autumn of 1993. Cuttings of F. pennsylvanica that broke bud were 100% in leaf by the first assessment. By early May (day 40), survivorship had dropped sharply until all saplings had died by fall of 1992 (day 185).

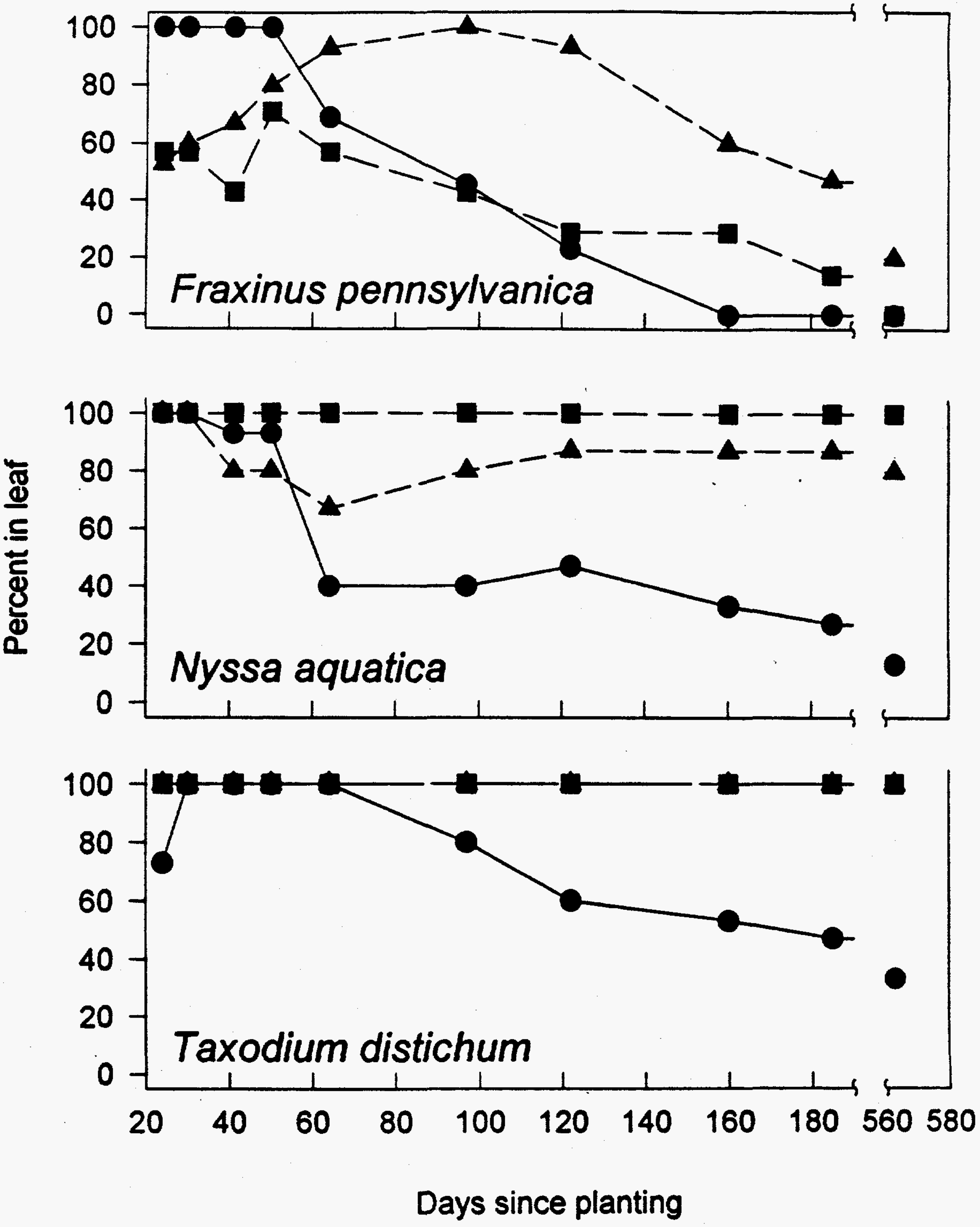
Nyssa aquatica saplings in the moderately pruned treatment of were 100% in leaf during the entire experiment (Figure 4). In the severely pruned treatment, 30% of the saplings had either died or defoliated by May (day 64), but a few saplings resprouted in July (day 97). The percent in leaf then remained almost constant for the remainder of the experiment with 80% in leaf at the end of the 1993 growing season. Nyssa aquatica cuttings respond similarly to the F. pennsylvanica cuttings. During May (starting on day 50), survival sharply declined and only 13% were alive at the end of the experiment.

Figure 3. (A) Mean daily air temperature (°C) and (B) depth of water (cm) at the meteorological station. Solid line is data from a permanently recording pressure transducer, while the ● are from a staff gauge. Positive values indicate standing water above the soil surface, while negative values indicate the water table is below the soil surface.



Both the severely and moderately pruned *T. distichum* saplings were 100% in leaf during the 1992 and 1993 growing seasons (Figure 4). Like the other two species, survival of *T. distichum* cuttings also began to decline starting in May (day 64), but 47% were still in leaf by the fall of the first year. More saplings died the second year until only 33% remained alive in the autumn of 1993.

Figure 4. Percent in leaf for the three species at each sampling date during the 1992 growing season and the autumn 1993. ● = Cutting, ■ = Severe and ▲ =Moderate.



All species had damage from herbivores (deer/beaver) or birds. Herbivory did not occur within the tree shelters, but instead was restricted to the portion of sapling emerging from the top. Herbivory from beaver was limited to a deep flood event during the winter of 1992/93 when flooding depth was greater than the height of the tree shelters. Most damage was from birds breaking the main stem above the tree shelters and deer browsing the exposed tops of the trees.

Both *F. pennsylvanica* and *T. distichum* had minimal herbivory (< 5%). *Nyssa aquatica* had the most herbivory, with saplings in the moderately and severely pruned treatments having 88% and 50% herbivory, respectively. *Nyssa aquatica* cuttings had no herbivory.

The amount of foliage and health of the trees surviving in the autumn of 1993 varied for each species, but was not affected by treatment. The three remaining moderately pruned *F. pennsylvanica* saplings all had sparse foliage. All severely pruned or cutting *F. pennsylvanica* saplings were dead. *Nyssa aquatica* had 55, 50 and 100% in full foliage for the moderately pruned, severely pruned and cutting treatments, respectively. All *T. distichum* were in full foliage. Although both the *N. aquatica* and *T. distichum* cuttings were 100% in full foliage, only a few saplings were still alive.

Due to the effect of herbivory in decreasing the height of saplings, only trees without herbivory were used in the growth analysis. Poor survival of the cutting treatments and *F. pennsylvanica* excluded them from this analysis.

Nyssa aquatica increased in height, but only two moderately and four severely pruned saplings were not affected by herbivores. Height growth for the two treatments increased by an average of 6 cm with a rage of -19 to 35 cm. Diameter also increased for both treatments an average of 6 mm.

The moderately and severely pruned *T. distichum* had a mean height growth of 56 cm for both treatments. No significant differences were noted between the moderately or severely pruned treatment for either *N. aquatica* or *T. distichum*.

DISCUSSION

The site was flooded at the beginning of the first growing season. The sediment, with the exception of brief periods, was constantly saturated, and often had standing water. Because of this inundation, saplings of all three species in the cutting treatment and all the *F. pennsylvanica* saplings did not appear to have produced new roots and subsequently had poor survival. Even though a late spring partially delayed budbreak, the increasing temperatures and depth to the water table in the summer of the first year also hastened the death of the cuttings and of all of the treatments of F. pennsylvanica.

The winter of 1992/93 had a very deep flood of over one meter, topping most of the plantings. Survival was not significantly affected by being deeply flooded, because the trees were dormant. The drought during the summer of 1993 (second growing season) also did not affect survival.

None of the three root pruning treatments were appropriate for F. pennsylvanica. Of the three species, F. pennsylvanica is more readily propagated by woody cuttings (Dirr 1987) than the other two species, but our results indicated that the cuttings of F. pennsylvanica did poorly, probably due to less flood tolerance. The ecotype of F. pennsylvanica obtained for the experiment (F. pennsylvanica var. subintegerrima) may have been less suitable for such a wet site than F. pennsylvanica var. pennsylvanica (Wharton 1973). In all likelihood, neither ecotype would have had good survival. Saplings in the moderately and severely pruned treatments had almost equal survival and growth for the N. aquatica and T. distichum. These species were well suited for the area and long-term survival should remain high.

Beaver had access to the tops of the trees above the tree shelters during the winter flooding of 1992/93. While the beaver cut the tree tops, survival was not reduced. Deer browsing almost completely defoliated many of N. aquatica saplings and the main stems were often broken, probably by wading birds landing on them to access adjacent pools. Herbivory did not greatly affect either F. pennsylvanica or T. distichum. While damage from animals reduced growth, all trees survived and resprouted.

Restoring unconsolidated sediments is possible using either moderately or severely root-pruned saplings which allow for planting by simple insertion. With the proper species or ecotype selection and root pruning severity, unconsolidated sediment can be restored using this planting method.

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