5-1998

Tree Seedling Establishment Across a Hydrologic Gradient in a Bottomland and Restoration

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TREE SEEDLING ESTABLISHMENT ACROSS A HYDROLOGIC GRADIENT IN A BOTTOMLAND RESTORATION

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ABSTRACT

Seedling establishment and survival on the Savannah River Site in South Carolina is being monitored as part of the Pen Branch Bottomland Restoration Project. Bottomland tree species were planted from 1993-1995 across a hydrologic gradient which encompasses the drier upper floodplain corridor, the lower floodplain corridor and the continuously inundated delta. Twelve species were planted in the three areas based on their flood tolerance and the hydrology of the area. Planted areas are separated by unplanted control strips to assess natural regeneration. A seedling survey conducted in 1997 showed that planted areas had significantly greater seedling densities than unplanted control sections. Water tupelo (*Nyssa aquatica),* green ash (*Fraxinus pennsylvanica*), sycamore (*Platanus occidentalis),* and persimmon *(Diospyros virginiana)* had the highest percent survival in the upper corridor while baldcypress (*Taxodium distichum)* had the best survival in the wetter lower corridor and delta. Water tupelo and green ash survival was low in wetter areas. Survival of planted species is dependent on hydrology, competition and herbivory although it is not possible to differentiate these effects from the available data.

INTRODUCTION

For over thirty years the bottomland hardwood system of the Pen Branch corridor and delta. was used for the discharge of coolant water from a nuclear reactor. Prior to reactor start up, flow in Pen Branch was typically 1-2 m^3/s. Reactor operations raised the flow to as much as 10-12 m^3/s during reactor pumping (Nelson, 1996) and coolant waters were consistently 40-50 °C. By 1989, when the reactor was retired, this high-temperature and, elevated flow effluent had removed virtually all vegetation within the floodplain and ehminated the seed bank and root stock. By the early 1990's early successional vegetation covered the floodplain and delta with very little sign of the predisturbance bottomland forest.

In 1992, the USDA Forest Service began efforts to accelerate the restoration of the Pen Branch system to its previous bottomland state. The area was divided into three habitats or sections (Figure 1) based on hydrology and vegetation present: upper corridor (25 ha), lower corridor (16 ha), and delta (50 ha). Approximately 75% of the area was planted with native bottomland species using various site preparation techniques depending on the initial conditions present in the sections. The virtually unbroken thickets of black willow (*Salix nigra)* in the upper corridor were herbicided and burned to allow access and reduce overstory competition. The upper corridor was planted with cherrybark oak (*Quercus falcata var. pagodifolia*), swamp chestnut oak (*Q. michauxii*), water oak (Q. *nigra),* shumard oak (Q. *shumardii*), water hickory (*Carya aquatica),* pignut hickory (*C. glabra*), persimmon (*Diospyros virginiana*), sycamore (*Platanus occidentalis),* swamp tupelo *(N. sylvatica var. biflora*), green ash, water tupelo, and baldcypress (Table 1). The lower corridor was relatively open, and planting was done under the broken black willow canopy. The lower corridor was planted with cherrybark oak, swamp chestnut oak, green ash, water tupelo, and baldcypress (Table 1). The areas to be planted in the delta were herbicided to prevent competition from black willow on the ridges and cattails in the sloughs and planted with green ash, water tupelo, and baldcypress (Table 1). Planting was done in strips with unplanted, no site preparation control strips left between each planted area to assess natural regeneration (Figure 1). Species were selected based on their known tolerance to wet conditions and the hydrology of the corridor and delta (Table 1, Figure 2). Following each planting, surveys were conducted to monitor survival and growth (Dulohery et al., 1995). Understocked areas were replanted in 1995-1996. In the spring of 1996 a systematic pilot survey of seedling establishment was conducted, and the results of that survey were used to effectively design the 1997 survey.

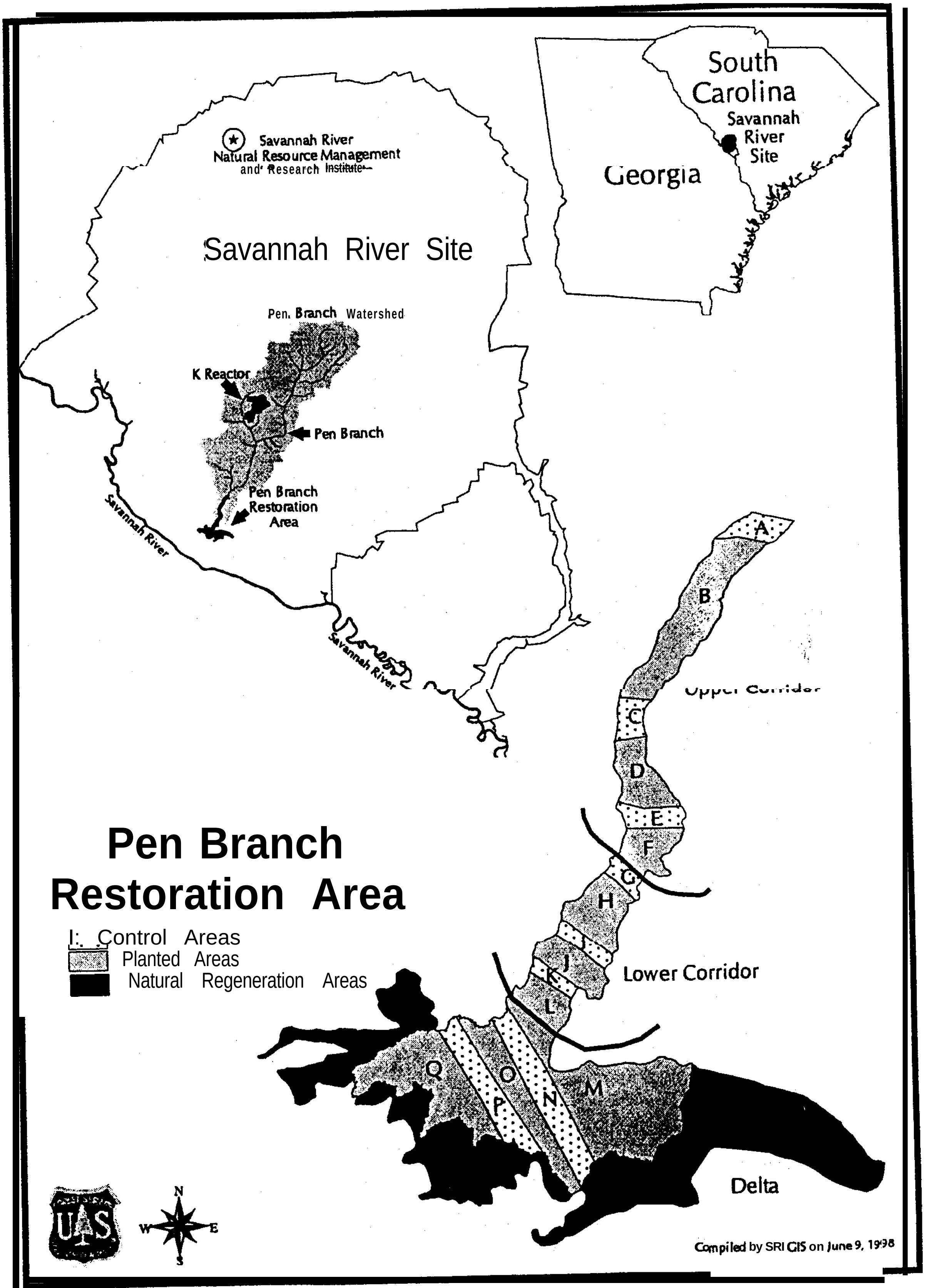

Figure 1. Location and research design of the Pen Branch Restoration Project.

The objective of this survey was to estimate the number of bottomland seedlings per hectare for each of the planted and control strips in the corridor and delta. A secondary objective was to survey the natural regeneration around the fringe of the impacted delta area.

METHODS

Statistical Design

Results of the spring 1996 regeneration survey were used as a guide to develop the statistical design of the 1997 survey. The goal of this survey was to estimate each stip mean with 90% confidence within ± 120 trees/ha (50 trees/ac). The number of plots needed is calculated using Equation 1 from Avery and Burkhart (1994),

n = 1/((E*2/(ts)*2) + 1/N) [Eq. 1]

Tablk 1. Percent distribution and total number of species planted in Pen Branch from 1993-1996. Note green ash, water tupelo and baldcypress were planted in all sections.

Species	Upper Corridor	Lower Corridor	Delta
Cherrybark Oak	22	7	0
Swamp-Chestnut Oak	7	17	0
Water Oak	18	0	0
Shumard Oak	8	0	0
Water Hickory	14	0	0
Pignut Hickory	1	0	0
Persimmon	3	0	0
Sycamore	5	0	0
Swamp Tupelo	11	25	0
Green Ash	9	25	*10*
Water Tupelo	1	*12*	60
Baldcypress	2	14	*30*
Total (seedlings/ha)	1831	1293	1012

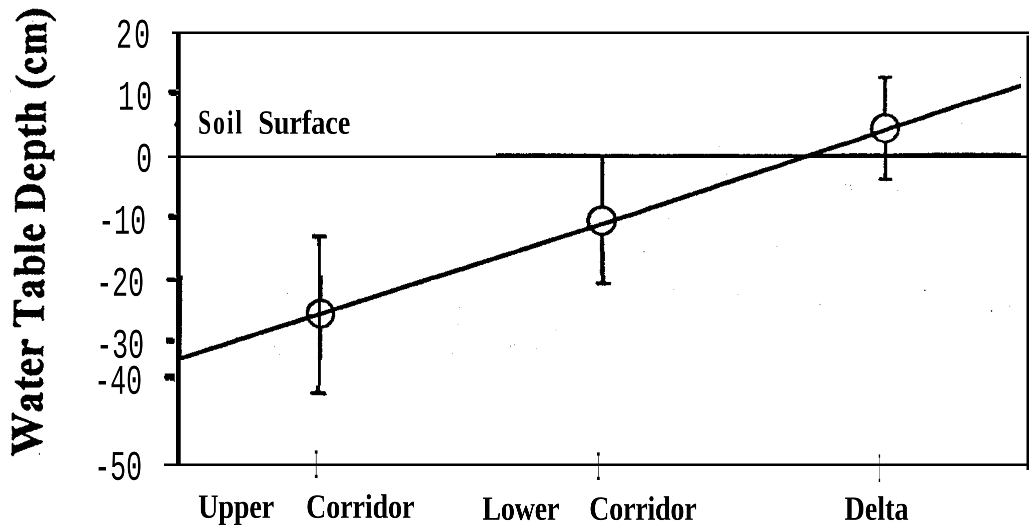

Figure 2. Hydrologic gradient in Pen Branch for 1993-1995 (± 1 SD).

where E is the allowable error (120 trees/ha), t is the t-distribution value for the given confidence level (0.90), s is the standard deviation, and N is the total number of possible plots.

The number of plots surveyed as a result of these estimates are shown in Table 2. We met our allowable error goal in all but one case (Table 2).

Although the design was developed to reach the desired level of accuracy for each strip, we also achieved a 95% CI of ± 120 trees/ha for the three planted and control section means. Results are comparisons of section means. We also sampled 63 plots in the natural regeneration zone around the fringe of the delta to assess the recovery of these less impacted areas.

Table 2. Number and location of 0.008 ha (0.02 **ac)** Seedling survey plots for 1997. Error is the actual 90% confidence interval error attained for each strip.

Section	Striv		Number of plots	Error seedlings/ha
Upper corridor	Control	A	17	62
	Planted	B	47	116
	Control	C	31	120
	Planted	D	46	89
	Control	E	25	118
	Planted	F	57	77
Lower Corridor	Control	**G**	14	128
	Planted	H	38	120
	Control	I	15	32
	Planted	J	32	62
	Control	**K**	11	0
	Planted	L	26	62
Delta	Planted	M	42	111
	Control	N	35	**17**
	Planted	0	29	114
	Control	P	24	14
	Planted	Q	39	35
TOTAL			528	

Field Design

The survey was conducted in April, 1997. Field crews of two or three tallied and idintified all native bottomland species, including unplanted species typical of bottomlands such as red maple (*Acer Rubrum*), **sweetgum** ***(Liquidambar styraciflua*)**, and river birch ***(Betula nigra)*** (Jones et al., 1994). Early successional species such as black willow, smooth alder (*Alnus surrulata*), ***wax*** myrtle ***(Myrica cerifera*)**, and buttonbush ***(Cephalanthus occidentalis)*** were not tallied. Plots were 0.008 ha (0.02 ac) and placed 15 m **(50 ft)** apart along transects. The starting point of the transects were located at random intervals along the wetland boundary **from** established corners between planted and control strips (Figure 1). Transect bearing was perpendicular to the floodplain in the corridor and parallel to the long axis of **strips** in the delta.

Quality Control/Quality Assurance

We resampled 5.5% of the plots and found no significant difference in number of seedlings counted (paired t-test, $p > 0.10$). Correct identification of the seedling species occurred in 98% of the cases.

RESULTS AND DISCUSSION

Overall Seedling Survival

Seedling survival varied by species and by section (Table 3). Overall seedling survival increased as soils became more inundated, from 10% in the drier upper corridor to greater than 50% in the delta (Table 3, Figure 3). This gradient of survival was probably due to several factors including more herbivory from hogs, deer, and beaver in the open upper corridor and greater competition from herbaceous species, notably blackberry (*Rubus sp.*), which quickly became established after herbiciding and burning. Oak species had poor survival in the herbicided and burned upper corridor. Soon after planting, it was discovered that feral hogs were rooting up the oaks. It appeared that full canopy removal also allowed the hogs easy access to the seedlings. No site preparation in the lower corridor apparently led to more protected conditions for the oaks, leading to considerably greater survival (Table 3).

Persimmon, sycamore, green ash, and water tupelo had good survival in the drier upper corridor (Table 3). These species, especially sycamore and green ash, are fast growing and had broken through the herbaceous competition. Except for water tupelo, these species are also less water tolerant than some of the other species planted, and we would expect them to grow well in the relatively drier upper corridor.

Baldcypress is surviving extremely well in the wetter lower corridor and inundated delta (Table 3). Nearly 100% survival of any species is somewhat surprising. The obvious potential error in survival percentages is the counting of naturally regenerated volunteers as planted seedlings. This effect should be minimal because we subtracted the species density found in unplanted control sections from those in the planted sections. Natural regeneration of planted species was extremely low for all sections. Natural regeneration accounted for 58 stems/ha of baldcypress in the delta. Natural regeneration of other species in other sections was much lower. We do acknowledge that volunteers may comprise some small fraction of what was counted in the planted areas. It is possible that planted areas had nearer seed sources then unplanted controls and/or the site preparation techniques were more conducive to the establishment of volunteers.

Table 3. Percent survival of species planted in Pen Branch from 1993-1996.

Species	Upper corridor	Lower corridor	Delta
Cherrybark Oak	4	10	NP
Swamp Chestnut Oak	3	17	NP
Water Oak	4	NP	NP
Shumard Oak	0	NP	NP
Water Hickory	1	NP	NP
Pignut Hickory	15	NP	NP
Persimmon	35	NP	NP
Sycamore	42	NP	NP
Swamp Tupelo	7	NP	NP
Green Ash	42	9	18
Water Tupelo	54	15	24
Baldcypress	13	99	98
Overall	10	33	52

NP = species not planted

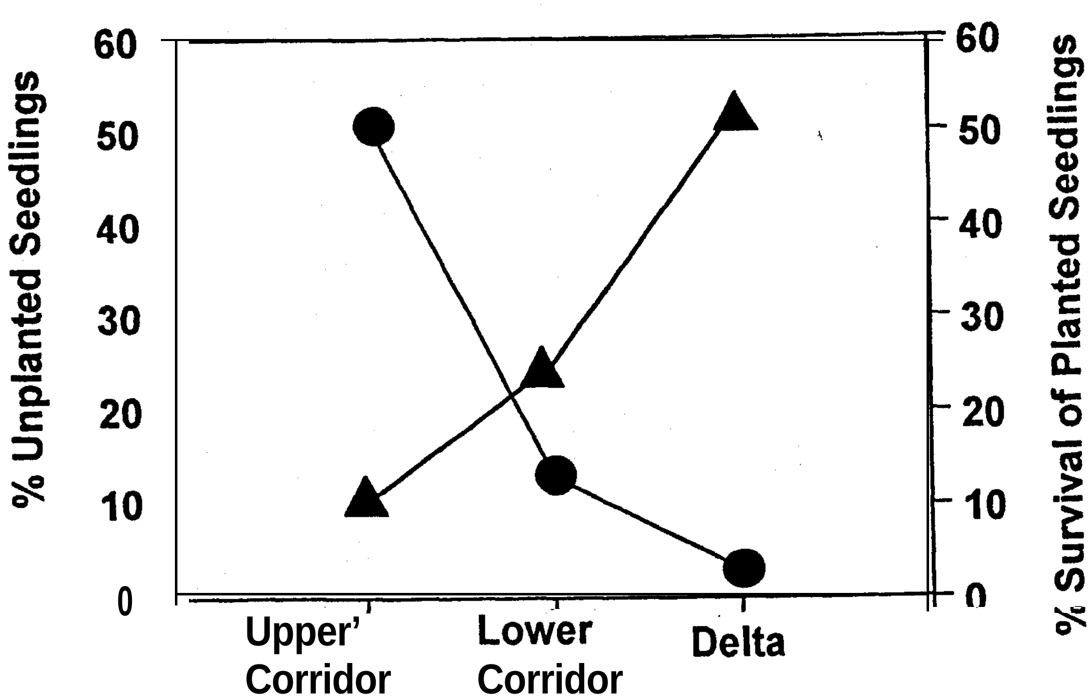

Figure 3. Distribution of unplanted seedling species (circles) and distribution and survival of planted seedlings (triangles).

Red maple was virtually unaffected by the herbicide and burning treatment in the upper corridor. It appears that site preparation in the upper corridor actually released red maple seeds. Red maple density was significantly greater in the upper corridor than in the lower corridor and delta (t-test, $p < 0.10$). Natural regeneration of red maple, sweetgum, and river birch is desirable and were counted as part of the overall bottomland seedling establishment. These species comprised about 50% of the bottomland species established in the upper corridor (Figure 3) of which, red maple represents the majority (95%) of unplanted seedlings. The percentage of red maple lessens as conditions become wetter, however it is not possible to differentiate the effects of site preparation techniques or nearness of seed sources from the hydrology.

Overall seedling establishment, including both unplanted native species and planted species, is significantly greater (t-test, $p < 0.10$) in the planted sections than in the unplanted control sections (Figure 4). We would certainly expect this result as much effort has been put forth to establish the planted seedlings. Bottomland seedlings established in the unplanted control sections included mainly red maple (51%) with river birch (17%), baldcypress (12%), sweetgum (6%) and sycamore (5%) also as important components. In planted sections, there were au average of 443 stems/ha, which falls within the range (330-900) reported for tree densities in unimpacted bottomland systems located on the Savannah River Site (Megonigal et al., 1997). Although we expect some seedling mortality to occur in the future, the 3-5 year old seedlings were well established, are above the herbaceous competition, and are growing vigorously. The main threat to their survival at this stage is from beavers. Often we observed planted seedling stumps that had been chewed by beavers.

Natural regeneration of the less impacted areas around the margin of the delta is highly variable. Mean stem density is 1750 ± 2410 stems/ha (1 SD), with a range of 0 to almost 10,000 stems/ha. Natural regeneration is comprised of mainly baldcypress (56%) with water tupelo (18%), red maple (16%), and sweetgum (8%) also as important components. Nearness to seed sources is obviously playing a very important role in the natural regeneration of the delta margin.

Survival of Baldcypress, Water Tupelo and Green Ash

Baldcypress, water tupelo, and green ash were planted in all three sections of Pen Branch. Comparison of these species within sections indicated no significant differences in survival in the upper corridor, however, baldcypress survival was significantly greater than either water tupelo or green ash in the lower corridor and delta (Figure 5).

Comparison of individual species across sections indicated no significant differences in survival of water tupelo or green ash. Baldcypress survival is greater in the lower corridor and delta than in the upper corridor (Figure 6). Although baldcypress is very tolerant of wet conditions (Hook, 1984) and survival increases as conditions become wetter, we can not attribute these differences to the hydrologic gradient alone. If hydrology was the only effect leading to survival, we would also expect water tupelo, a species also very tolerant to wet conditions (Hook, 1984), to have increased survival as conditions become wetter. We would also expect green ash, a species not as tolerant as baldcypress and water tupelo to wet conditions (Hook, 1984), to have a decreasing gradient of survival from the upper corridor to the delta.

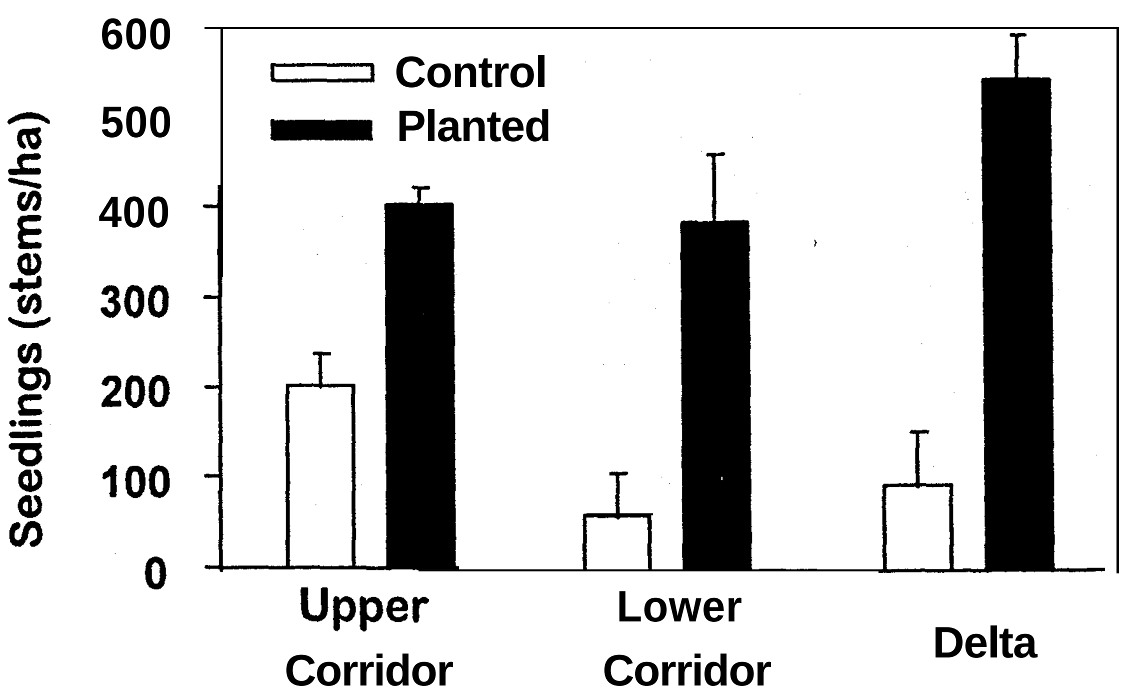

Figure 4. Overall seedling densities in the Pen Branch corridor and delta (error bars = 1 SD). Densities include unplanted bottomland species (red maple, river birch, and sweetgum).

The results indicate that hydrology is not the only factor controlling seedling survival of baldcypress, water tupelo, and green ash in Pen Branch. Herbivory and competition are also controlling survival. The effect of herbivory and competition were variable across sections depending on the site preparation method applied. Water tupelo is not as tolerant as baldcypress and green ash to shaded conditions (McKnight et al., 1981), and this may explain the low survival of water tupelo in the lower corridor. The lower corridor was planted directly under the scattered black willow canopy. However, green ash, a species tolerant of shaded conditions (McKnight et al., 198 1), also had poor survival in the lower corridor. Degree of herbivory possibly explains the bulk of the variability in survival for these three species. Unfortunately, our study did not differentiate seedling mortality from the effects of hydrology, competition and herbivory.

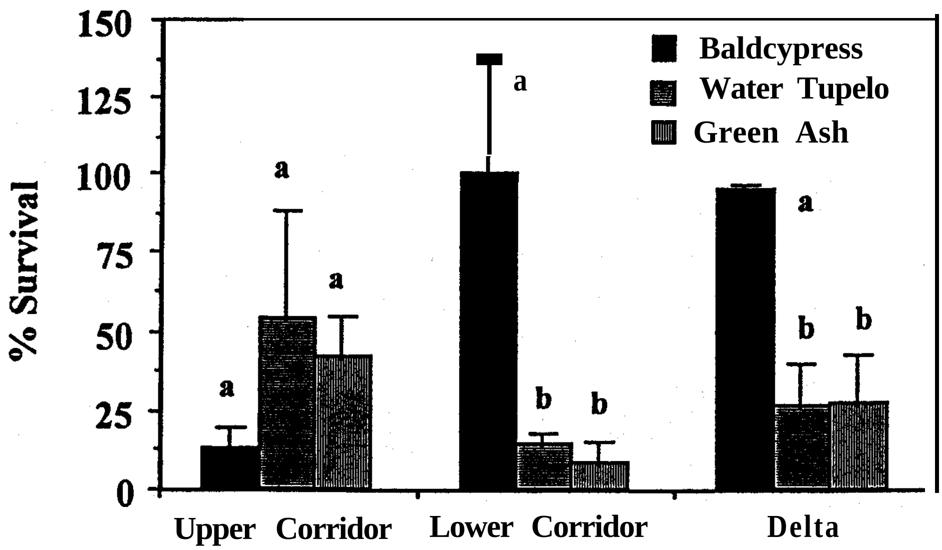

Figure 5. Comparison of species survival within sections of the Pen Branch corridor and delta. Error bars ± 1 SD, significance at the 0.10 level (t-test).

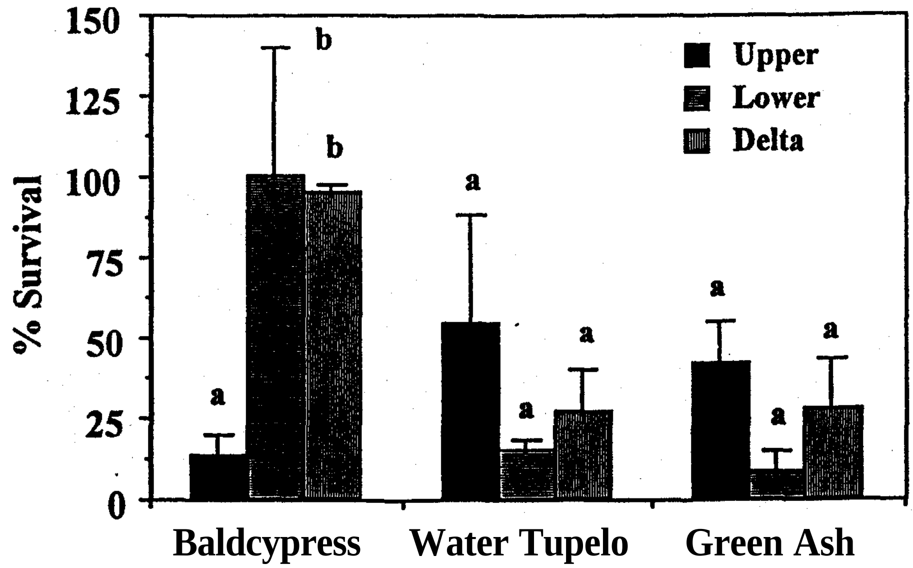

Figure 6. Comparison of individual species survival **across** sections of the Pen Branch corridor and delta. Error **bars ±** 1 SD, significance at the 0.10 level (t-test).

CONCLUSION-FURTHER RESEARCH

Seedling establishment in Pen Branch is variable depending on a number of factors. Hydrology is undoubtedly very important when considering seedling establishment, but site preparation methods, as they relate to competition and herbivory effects, are also important. We were not able to differentiate the effects of hydrology from competition and herbivory on seedling establishment in Pen Branch.

We have two ongoing studies designed to assess the effects of herbivory and competition on seedling survival and growth. In our study of competition effects, we replicated treatments of various canopy removal levels. Baldcypress, green ash, water tupelo, and swamp chestnut oak seedlings were planted under fill mechanical removal of overstory, full herbicide removal of overstory, 60% removal of canopy, and intact black willow canopy (control). Plots were fenced to minimize herbivory. We recently took our fifth and final year of measurements on these plots. Preliminary analysis indicates that, the mid-level, 60% canopy removal treatment had greatest survival and growth. It appears some canopy removal is desirable to allow light penetration to the seedlings without stimulating dense growth of herbaceous species which overtop the seedlings.

A second study is assessing the use of tree shelters on the survival and growth of baldcypress, green ash, water tupelo, and swamp tupelo seedlings. Tree shelters provide protection from herbivory. Replicated plots with and without tree shelters are in their fifth year of growth. Preliminary results suggest that tree shelters positively affect survival and growth of seedlings. Characterizing the magnitude of the positive response will allow us to assess the effect of herbivory on seedling survival. Results obtained from the competition and tree shelter studies will allow us to separate the effects of herbivory and competition from the effect of hydrology on seedling establishment.

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