SPECIES SELECTION TRIALS AND SILVICULTURAL TECHNIQUES FOR THE RESTORATION OF BOTTOMLAND HARDWOOD FORESTS—A 10 YEAR REVIEW

Kenneth W. McLeod, Michael R. Reed, Barbara P. Moyer, and Thomas G. Ciravolo[1]

Abstract—From 1992 to 1994, species trials were initiated in the Fourmile Branch delta to investigate the best methods of re-establishing tree species in a severely disturbed, thermally affected stream delta. Treatments examined included planting stock type, habitat, tree shelters, root pruning, and competition controls. Survival of most species, as determined in 1994 or 1996 and 2003, changed little over the past decade and was not strongly affected by the treatments within a trial, except for root pruning. Trees in many treatments have grown tremendously, but individuals with no competition controls generally grew more slowly. For example, *Taxodium distichum* Richard has had a high survival rate, regardless of whether planted as bareroot or balled-and-burlapped saplings, and have grown to 8 to 12 m in height. *Quercus lyrata* Walter, *Carya aquatica* (Michaux f.) Nuttall, *Q. nuttallii* Palmer, and *Q. phellos* L. planted in later trials also had adequate survival rates and have grown to 5+ m. Low mortality rates after the initial 3 to 4 years suggests that these species are appropriate for restoration. In contrast, survival of *Nyssa aquatica* L. and *Fraxinus pennsylvanica* Marshall have continually declined over time.

INTRODUCTION

Clewell and Lea (1989) noted that many extant wetland forest creation and restoration projects in the Southeastern United States were not being monitored. Hence the relative merits of different species and techniques were not being evaluated. In the past 15 years, many more creation and restoration projects have been initiated across the Southeast. Due to the extended length of time required for a forested wetland to develop, many current projects have not been planted long enough to determine their ultimate success or failure (Mitsch and Wilson 1996). The restoration project discussed here reports a series of species trials, planted from 1992 to 1994. Initial responses after 3 to 4 years were reported in McLeod (2000), McLeod and others (2000), McLeod and others (2001) and Reed and McLeod (1994). Five of these trials have been censused recently, and the longer term response is reported to provide data to hopefully improve the success of other restoration projects. The nomenclature and acronyms originally used in McLeod (2000) have been retained to minimize confusion. Each of the five trials reported had different objectives:

Trial VIII - determine the effects of transplant type and tree shelters on survival and growth of three tree species in stream and backwater habitats

Trial IX - determine the effects of acclimation and tree shelters on survival and growth of three tree species in stream and backwater habitats

Trial X - determine the effects of root pruning on survival and growth of three tree species planted in flooded, unconsolidated muck soil

Trial XI - determine the effects of herbaceous competition control methods on survival and growth of six tree species

Trial XII - determine the effects of willow removal on survival and growth of four tree species

Our goal was to re-evaluate the specific treatment effects and the overall project success at 10 to 12 years (7 to 9 years after the initial census).

SITE DESCRIPTION

The restoration site (Fourmile Branch delta) was impacted over 30 years (1955 to 1985) by thermal effluent from a nuclear production reactor. Initial plant colonization was from wind-dispersed plant species [*Salix nigra* Marsh. (black willow) in wet sites and *Andropogon* spp. (broomsedge) and *Pinus taeda* L. (loblolly pine) in drier sites]. No soil seed bank existed due to the chronic thermal flooding. The site could not be mechanically contoured to fit a specific planting scheme. Hence all plantings were made in the existing early successional vegetation.

Hydrology of the delta has been highly variable due to variation in rainfall and management of the Savannah River by the U.S. Army Corps of Engineers. Any extensive and long duration flooding of the delta is a result of high water levels in the Savannah River. A more complete description of the site and its hydrology can be found in McLeod (2000).

MATERIALS AND METHODS

Trial VIII

In the winter of 1991/92, three different types of transplant units of *Fraxinus pennsylvanica* Marshall, *Nyssa aqua*tica L., and *Taxodium distichum* Richard were planted in randomly chosen locations within either backwater or stream locations. Transplant types included: (1) balled and burlapped—BB, (2) hand-bagged—HB, and (3) bareroot seedlings—SBR. Commercial BB transplant units of *N. aquatica* were not available, so we placed bareroot seedlings in top soil within a burlap bag to make hand-bagged units. All types were planted in water so that the root collar would subsequently be in 0 to 30 cm of water at time of planting. Since the balled and burlapped and handbagged treatments were planted by placing the ball on the stream bottom, the root collar of these seedlings was elevated above the stream bottom, whereas the root collar of the bareroot seedlings was actually planted at the water/sediment interface. Comparison of these three types would permit an evaluation of the response to a common root collar

[1] Associate Research Ecologist, Research Coordinator, Research Technician, and Research Coordinator, respectively, Savannah River Ecology Laboratory, University of Georgia, P.O. Drawer E, Aiken, SC 29802.

Citation for proceedings: Connor, Kristina F., ed. 2006. Proceedings of the 13th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 640 p.

location in the water column. Bareroot stock was also planted in deeper water (30 to 60 cm of water). The response of this treatment (DBR) examines both a water depth effect with bareroot seedlings and a more practical comparison of planting in a stream location of a specific water depth. Half of the seedlings in each treatment were protected with tree shelters.

Trial IX

Balled and burlapped *F. pennsylvanica* and *T. distichum* and hand-bagged *N. aquatica* seedlings were held for 60 days in water level with the root collar, in an attempt to acclimate the plants prior to outplanting into stream and backwater locations in the spring of 1992. They were planted so the root collar was 0 to 30 cm below the water surface at the time of planting. Half of the seedlings in each treatment were protected with tree shelters.

Trial X

Root systems of bareroot seedlings of *F. pennsylvanica*, *N. aqua*tica, and *T. distichum* were pruned to three levels prior to outplanting in a muck soil in the winter of 1991/92. Root pruning treatments were: (1) moderate - a bareroot seedling had all lateral roots in excess of 30 cm in length removed and the tap root was cut to a 30 cm length; (2) severe - a bareroot seedling had all lateral roots removed and the tap root was cut to a 30 cm length; and (3) cutting - the entire root system was removed by cutting at the root collar. These seedlings were planted by inserting the unit directly into the muck soil and supporting the seedling with a staked tree shelter.

Trial XI

Bareroot seedlings of *N. aquatica*, *Quercus falcata var. pagodaefolia* Ell., *Q. lyrata* Walt., *Q. nuttallii* Palmer, *Q. phellos* L., and *T. distichum* were planted in tree shelters during the winter of 1992/93. Attempts were made to control the herbaceous vegetation within the plots by chemical or physical means in July 1993 and June 1994. Treatments included: (1) herbicide the whole plot—HW; (2) herbicide only the planting row—HR; (3) control, no herbaceous control—C; (4) physical control by mowing and weedeating in the planting row only—PR; and (5) physical control by mowing and weedeating the whole plot—PW.

Trial XII

In the winter of 1993/94, containerized seedlings of *Carya aquatica* (Michaux f.) Nuttall, *Q. laurifolia* Michaux*, Q. lyrata*, and *T. distichum* were planted in plots which had (1) an existing willow canopy—control; (2) the existing willow canopy that had been cut and removed from the plot—cut; and (3) an adjacent area which was dominated by herbs and grasses with no willow present—herb.

In all trials, survival was determined on a 1 to 2 week basis for the first growing season. Thereafter, survival and seedling height were usually determined in the autumn of each year for 3 to 4 years. In 2003, survival, height, and diameter at breast height (d.b.h.) were determined. Diameter and height were well correlated. Since height had been measured in the initial time period, before d.b.h. could be determined, height is reported to illustrate trends in early growth (1994 to 1996) and late growth (2003).

RESULTS AND DISCUSSION

Trial VIII

Survival of *T. distichum* was excellent regardless of transplant type in both backwater and stream locations over all 12 years (table 1). Tree shelters decreased herbivory but did not affect survival, except for bareroot seedlings planted in shallow water at the stream site. Water depth (shallow versus deep) did not affect bareroot seedling survival. Height of *T. distichum* was greater in the backwater than the stream location (table 2). After 3 growing seasons, *T. distichum* height was not affected by the presence of shelters or by transplant type, except for bareroot seedlings planted in deeper water. Neither transplant type nor shelter affected height after 12 years.

Table 1—Trial VIII. Percent seedling survival in 1994 and 2003 after planting in the Fourmile Branch delta as affected by transplant type, location, and tree shelters

Species	Transplant type							
	BB		HB		SBR		DBR	
Habitat - Shelter	1994	2003	1994	2003	1994	2003	1994	2003
Fraxinus pennsylvanica								
Backwater - no shelter	95	90	25	10	65	45	10	10
Backwater - shelter	100	90	30	10	100	95	00	00
Stream - no shelter	45	15	30	00	45	30	00	00
Stream - shelter	75	65	30	00	85	70	00	00
Nyssa aquatica								
Backwater - no shelter	—	—	65	15	60	00	60	05
Backwater - shelter	—	—	70	35	80	10	90	25
Stream - no shelter	—	—	50	25	35	10	25	05
Stream - shelter	—	—	75	30	75	10	65	20
Taxodium distichum								
Backwater - no shelter	100	100	100	100	95	95	100	100
Backwater - shelter	100	100	100	95	100	90	100	100
Stream - no shelter	100	100	95	90	55	45	100	100
Stream - shelter	100	100	100	100	100	95	100	100

BB = balled and burlapped; HB = handbagged; SBR = bareroot seedling planted in 0 to 30 cm of water; DBR = bareroot seedling planted in 30 to 60 cm of water.

Table 2—Trial VIII. Seedling height (m) in 1994 and 2003 after planting in the Fourmile Branch delta as affected by transplant type, location, and tree shelters

Species	Transplant type							
	BB		HB		SBR		DBR	
Habitat - Shelter	1994	2003	1994	2003	1994	2003	1994	2003
Fraxinus pennsylvanica								
Backwater - no shelter	3.2	9.7	2.0	8.4	2.9	12.0	1.3	1.8
Backwater - shelter	3.2	10.3	2.6	12.0	2.7	11.0	Dead	Dead
Stream - no shelter	1.2	8.6	2.1	Dead	1.6	8.8	Dead	Dead
Stream - shelter	2.4	7.3	2.3	Dead	2.3	8.9	Dead	Dead
Nyssa aquatica								
Backwater - no shelter	—	—	1.2	6.9	0.7	Dead	1.0	2.8
Backwater - shelter	—	—	1.8	9.9	1.2	2.9	1.2	2.3
Stream - no shelter	—	—	1.3	8.0	1.3	13.0	1.2	9.5
Stream - shelter	—	—	1.4	8.3	1.2	8.5	1.2	7.6
Taxodium distichum								
Backwater - no shelter	3.3	11.2	3.1	10.9	3.2	12.3	3.2	11.5
Backwater - shelter	3.2	11.2	3.2	10.2	3.1	11.5	3.0	10.0
Stream - no shelter	2.5	10.1	2.2	10.1	2.3	8.6	2.3	8.9
Stream - shelter	3.2	11.0	3.1	11.5	2.9	10.0	2.7	9.3

BB = balled and burlapped; HB = handbagged; SBR = bareroot seedling planted in 0 to 30 cm of water; DBR = bareroot seedling planted in 30 to 60 cm of water.

Survival of *N. aquatica* was good after 3 years but unacceptable after 12 years. Sheltered trees had greater survival than unsheltered trees. Poor survival was generally also true for *F. pennsylvanica* except for good survival of BB seedlings and sheltered bareroot stock planted in shallow water. *F. pennsylvanica* also did very poorly when planted in 30 to 60 cm of water.

Trial IX

T. distichum did well when planted late in the spring following attempts to acclimate the seedlings, except for survival in 2003 of backwater sheltered seedlings (tables 3 and 4). Acclimation did not affect survival or growth of this species. Sheltered seedlings frequently grew taller than non-sheltered plants, while stream plants were frequently taller than backwater plants. Survival of *N. aquatica* and *F. pennsylvanica* were poor regardless of acclimation, shelter, or location.

Trial X

Only *T. distichum* seedlings which had been moderately or severely root pruned survived well over the entire 12 years (table 5). Height of *T. distichum* was very good with heights of 9 to 11 m and d.b.h.s of 14 to 17 cm. Survival of *N. aquatica* was good for the first 3 years, but declined thereafter. These root pruning methods led to total mortality of *F. pennsylvanica*.

Trial XI

Q. lyrata and T*. distichum* had the highest survival rates, followed by *Q. nuttallii* and *Q. phellos* (table 6). *N. aquatica* had good survival after 4 years but declined greatly thereafter. *Q. falcata var. pagodaefolia* had unacceptable survival after 4 years. Survival declined for all species over time but generally only slightly for the more suitable species and was not affected by the herbaceous competition control treatments. Plants were generally shorter in the control plots.

Table 3—Trial IX. Percent seedling survival in 1994 and 2003 after planting in the Fourmile Branch delta as affected by acclimation, location, and tree shelters

Species	Acclimated			
	Yes		No	
Habitat - Shelter	1994	2003	1994	2003
Fraxinus pennsylvanica				
Backwater - no shelter	00	00	00	00
Backwater - shelter	00	00	05	00
Stream - no shelter	16	05	20	00
Stream - shelter	53	47	35	25
Nyssa aquatica				
Backwater - no shelter	08	00	00	00
Backwater - shelter	69	00	70	00
Stream - no shelter	15	00	00	00
Stream - shelter	54	08	70	20
Taxodium distichum				
Backwater - no shelter	100	95	100	100
Backwater - shelter	95	35	100	55
Stream - no shelter	100	95	95	95
Stream - shelter	100	100	100	100

Trial XII

Survival of *C. aquatica*, *Q. lyrata*, and *T. distichum* was good over the 10 years, but total mortality of *Q. laurifolia* occurred by the third year (table 7). Survival of the less affected species did not decline except in the plots with willows remaining, where all species declined. Survival of *T. distichum* was lower than the other two species and generally less than that observed in the other trials. This may be due to higher elevation plots used in this trial. The tallest plants were found in plots where the willows had been removed; the shortest plants occurred in the plots where willows shaded the seedlings. Reducing this shading might stimulate height growth of these seedlings.

Table 4—Trial IX. Seedling height (m) in 1994 and 2003 after planting in the Fourmile Branch delta as affected by acclimation, location, and tree shelters

Species	Acclimated			
	Yes		No	
Habitat - Shelter	1994	2003	1994	2003
Fraxinus pennsylvanica				
Backwater - no shelter	Dead	Dead	Dead	Dead
Backwater - shelter	Dead	Dead	3.0	Dead
Stream - no shelter	0.7	6.5	0.5	Dead
Stream - shelter	2.2	7.3	2.5	5.7
Nyssa aquatica				
Backwater - no shelter	0.8	Dead	Dead	Dead
Backwater - shelter	1.7	Dead	1.7	Dead
Stream - no shelter	1.1	Dead	Dead	Dead
Stream - shelter	1.6	12.3	1.3	9.8
Taxodium distichum				
Backwater - no shelter	1.6	5.2	1.6	5.2
Backwater - shelter	2.6	6.4	2.6	7.9
Stream - no shelter	2.0	8.8	1.7	7.7
Stream - shelter	2.9	10.0	2.9	10.0

OVERALL OBSERVATIONS

Treatments to control herbaceous and willow competition were not particularly effective in altering survival, but plants were generally shorter in control plots where competition was greatest. Planting of heavily root-pruned bareroot seedlings has limited applicability with only *T. distichum* doing well over the entire time period. While tree shelters did reduce herbivory, they did not generally affect survival or height growth.

The real key to successful restoration is using the most appropriate species for the particular habitat. *C. aquatica*, *Q. lyrata*, *and T. distichum* had overall survival in excess of 80 percent during the initial time interval (3 to 4 years since planting), while *Q. nuttallii, Q. phellos*, and *N. aquatica* had survival in excess of 50 percent (fig. 1). All of these species are good candidates for restoring this habitat, based on survival after 3 to 4 years. *F. pennsylvanica* had low overall survival but good survival in selected locations and may be carefully used for restoration. The remaining two species (*Q. falcata var. pagodaefolia* and *Q. laurifolia*) had low initial survival and should not be planted in this habitat.

Survival of numerous species in this study continued to be good 10 to 12 years after planting and are good candidates for

Table 5—Trial X. Percent survival and height (m) in 1994 and 2003 after planting in the Fourmile Branch delta as affected by root pruning treatments. Planting location was a backwater, muck soil area. All seedlings were planted in tree shelters

Species	Cutting		Severe		Moderate	
	1994	2003	1994	2003	1994	2003
Survival						
Fraxinus pennsylvanica	00	00	00	00	00	00
Nyssa aquatica	13	07	78	20	100	36
Taxodium distichum	33	33	100	93	100	100
Height						
Nyssa aquatica	1.3	8.2	1.3	6.0	1.3	6.8
Taxodium distichum	1.8	7.9	2.8	9.7	2.8	10.7

Table 6—Trial XI. Percent survival and height (m) in 1996 and 2003 after planting in the Fourmile Branch delta as affected by herbaceous competition control treatments

Species	HW		HR		C		PR		PW	
	1996	2003	1996	2003	1996	2003	1996	2003	1996	2003
Survival										
Nyssa aquatica	13	17	67	20	73	43	60	23	47	30
Quercus falcata[a]	10	13	10	13	20	13	03	00	27	20
Q. lyrata	97	97	77	70	83	80	80	73	80	77
Q. nuttallii	67	63	57	43	67	60	63	53	57	50
Q. phellos	50	43	50	50	67	63	67	63	37	37
Taxodium distichum	90	87	80	80	83	73	90	90	93	87
Height										
Nyssa aquatica	1.5	8.3	1.5	7.8	1.8	5.3	1.5	7.6	1.8	7.0
Quercus falcata[a]	1.2	3.9	1.6	6.5	1.3	7.8	1.0	Dead	1.6	7.2
Q. lyrata	3.1	7.8	2.9	7.7	2.6	6.4	2.8	7.5	2.8	7.7
Q. nuttallii	2.8	7.8	2.2	7.6	2.2	6.3	2.2	7.1	2.3	7.3
Q. phellos	2.1	8.3	2.5	7.7	2.0	6.5	1.9	6.6	2.4	7.4
Taxodium distichum	2.8	8.8	2.6	6.3	2.2	5.1	2.8	7.5	2.9	7.8

HW = whole plot treated with herbicide; HR = planting row treated with herbicide; C = not treated; PR = planting row mowed; PW = whole plot mowed.

[a] var. *pagodaefolia*

Table 7—Trial XII. Percent survival and height (m) in 1996 and 2003 after planting in the Fourmile Branch delta as affected by willow control treatments

	Cut		Control		Herb	
Species	1996	2003	1996	2003	1996	2003
Survival						
Carya aquatica	73	78	90	75	85	85
Quercus laurifolia	00	00	00	00	00	00
Q. lyrata	78	80	90	85	90	88
Taxodium distichum	75	68	95	85	70	68
Height						
Carya aquatica	1.5	5.8	1.5	4.4	1.6	5.4
Q. lyrata	1.2	4.3	1.1	3.1	1.2	4.4
Taxodium distichum	2.0	7.0	1.4	3.1	1.7	5.6

Cut = willows cut and removed; Control = willow canopy intact; Herb = herbaceous vegetation with no willow canopy.

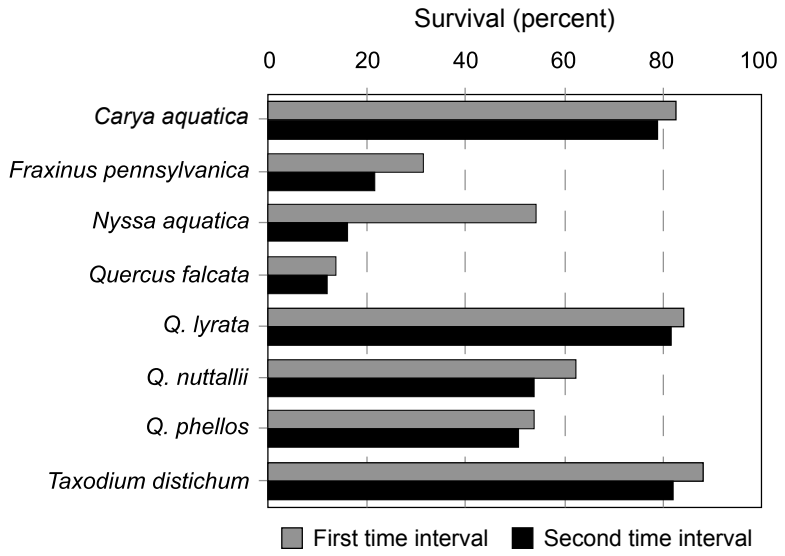

Figure 1—Mean survival (percent) of tree species from all 5 trials during the initial time interval (first 3-4 years) and secondary time interval (next 8-10 years).

restoration. However the continual decline in survival of *N. aquatica*, and to a lesser extent *F. pennsylvanica*, through the entire 10 to 12 year interval suggests that these species are unsuitable for restoration, at least in this habitat or under these conditions. Survival of *N. aquatica* was anticipated to be similar to *T. distichum*, due to their similar habitat requirements. Their dissimilar outcomes may be due to poorer nursery stock of *N. aquatica*, which has not had as much commercial horticultural interest as *T. distichum*. These results would also suggest that for at least seven of these species, survival after 3 to 4 years is indicative of future survival in bottomland/swamp forest restoration projects.

ACKNOWLEDGMENTS

This research was supported by the Savannah River Technology Center (Westinghouse Savannah River Company) and the Environmental Remediation Sciences Division of the Office of Biological and Environmental Research, U. S. Department of Energy through Financial Assistance Award Number DE-FC09-96SR18546 to the University of Georgia Research Foundation. Support of E. A. Nelson and L. D. Wike (technical representatives at SRTC) was critical.

LITERATURE CITED

Clewell, A.F.; Lea, R. 1989. Creation and restoration of forested wetland vegetation in the Southeastern United States. In: Kusler, J.A.; Kentula, M.E., eds. Wetland creation and restoration: the status of the science, volume I: Regional reviews. EPA/600/3-89/038: 199-237.

McLeod, K.W. 2000. Species selection trials and silvicultural techniques for the restoration of bottomland hardwood forests. Ecological Engineering. 15(Supplement 1): S35-S46.

McLeod, K.W.; Reed, M.R.; Nelson, E.A. 2001. Influence of a willow canopy on tree seedlings establishment for wetland restoration. Wetlands. 21: 395-402.

McLeod, K.W.; Reed, M.R.; Wike, L.D.; Nelson, E.A. 2000. Elevation, competition control, and species affect bottomland forest restoration. Wetlands. 20: 162-168.

Mitsch, W.J.; Wilson, R.F. 1996. Improving the success of wetland creation and restoration with know-how, time, and self-design. Ecological Applications. 6: 77-83.

Reed, M.R.; McLeod, K.W. 1994. Planting unconsolidated sediments with flood-tolerant species. In: Webb, F.J., ed. Proceedings of the 21st annual conference on wetlands restoration and creation. Tampa, FL: Hillsborough Community College: 137-146.