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Growth of Root-Pruned Seedlings in a Thermally Impacted Area of South Carolina

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Flooding of Pen Branch delta on the Department of Energy's Savannah River Site near Aiken, SC, by thermal effluents from 1954-1989 resulted in the death of most existing vegetation, with little re-establishment of desirable tree species since hot water discharges ceased. Re-establishment of desirable tree species may require planting. Four habitat types in the delta were identified for planting: cleared (grass cut), grass, willow, and muck. Species chosen for planting in this study were baldcypress (Taxodium distichum (L.) *Rich.), water tupelo* (Nyssa aquatica L.), *swamp blackgum* (Nyssa sylvatica *var.* biflora *(Walt.) Sarg.), and green ash* (Fraxinus pennsylvanica *Marsh.). Roots of seedlings were pruned to facilitate planting under wet conditions and to compare growth responses to seedlings with intact roots. Samples were collected at 0, 4, 7, and 14 months to determine differences in height growth and in stem and root biomass. Differences between pruned and non-pruned seedlings were variable depending on the species and area in which they were planted, but moderate pruning of roots was not detrimental to seedling growth and establishment and represents a quick and easy method of planting flooded sites.* Tree Planter's Notes 48(3/4): 76-80; 1997.

Swamp forests in the Pen Branch delta area on the U.S. Department of Energy's Savannah River Site near Aiken, SC, originally consisted of a closed canopy dominated by baldcypress *(Taxodium distichum* (L.) Rich.) and water tupelo *(Nyssa aquatica* L.). From 1954 to 1989, thermal effluents—water temperatures during times of release from nuclear reactor cooling towers ranged well over 50 °C (or 122 °F)—were discharged into the delta. High water temperatures combined with increased water levels, increased siltation rates, and anthropogenic flooding events asynchronous with natural events were considered to be responsible for the death of most of the existing vegetation on the delta (Sharitz and others 1974, 1990). Severe canopy loss occurred within 152 ha (376 ac) of swamp (alike and others 1994).

Muzika and others (1987) theorized that the restoration of a forest similar to predisturbance conditions in thermally impacted stream systems was unlikely. The re-establishment of baldcypress, water tupelo, swamp blackgum *(Nyssa sylvatica* var. *biflora* (Walt.) Sarg.), and other flood-tolerant species that were once found in the Savannah River swamp is also limited by inappropriate environmental conditions and seed dispersal problems (Sherrod and others 1980). Limited re-establishment of some flood-tolerant hardwoods on the delta was also attributed to limited seed availability because few, if any, parent trees remained following thermal discharge (Dunn and Sharitz 1987; Scott and others 1985; Sharitz and Lee 1985; Sherrod and others 1980).

Hydrology is not only important for seed dispersal (Schneider and Sharitz 1988) but also affects seedling establishment and growth. The construction of upstream dams on the Savannah River is responsible for changes in the natural flooding pattern of the delta (Sharitz and others 1990, Sharitz and Lee 1985). The natural pattern of winter flooding followed by low flow during the growing season gives seeds an opportunity to germinate. Although baldcypress and water tupelo seeds are dispersed by water, the seeds require aerobic conditions for germination and will not germinate when submerged in water (Mattoon 1916). The lack of open, moist microsites that would provide a chance for seeds to become established, allowing seedling growth without the threat of overtopping flood waters, may be attributed to anthropogenically altered hydrology of the Savannah River (Sharitz and Lee 1985).

Without natural seed sources and changes to natural seasonal flood events, recovery to former conditions may take many years without active restoration efforts. Regeneration of flood-tolerant wetland species is now possible because the reactors are inactive. Two planting strategies may improve seedling growth and survival as well as simplify the actual process of planting:

- moderate pruning of the roots to ease planting in mucky substrates where planting holes are difficult to keep open
- manipulation of the planting area such as removal of competition

Materials and Methods

The Savannah River Site, located near Aiken, South Carolina, is a 750-km^2 (290-mi^2) tract of land bordered by 37 km (23 mi) of the Savannah River along its southwestern boundary (Sharitz and others 1974). It is the property of the United States Government and is managed by the U.S. Department of Energy. The Pen Branch delta is fed by Pen Branch Creek, which enters the swamp about 5 km (3.1 mi) from the river and flows southeastward. The delta is characterized by shallow, slowly moving water that covers the experimental area year-round.

Within the Pen Branch delta, 4 habitat types were identified for planting: cleared, grass, willow, and muck. All vegetation in the cleared area was removed using a weed eater in late January 1994, while the grass area was left uncleared. The willow area consists of an impinging canopy of black willow *(Salix nigra* L.). The muck area is characterized by less grass competition and deeper surface water than the other plots. All seedlings in the 4 areas were subject to standing water conditions and competition from surrounding herbaceous vegetation.

Two 12- x 12-m (39.4- X 39.4-ft) blocks were established in each of the areas in January 1994. Each block had 4 randomly assigned plots measuring 3 x 12 m (9.8 x 39.4 ft) containing a single species planted on a 0.6 m x 0.6 m spacing. Species chosen for planting were baldcypress, water tupelo, swamp blackgum, and green ash *(Fraxinus pennsylvanica* Marsh.). One-year-old seedlings were obtained from the USDA Forest Service at the Savannah River Site. Before planting, the seedlings were divided into 2 groups. The lateral roots of 1 group of seedlings were pruned to approximately 2.5 cm (1 in) and the taproot pruned to 20 cm (7.9 in) using anvil-style garden clippers. The second group was left unpruned. Pruned seedlings were planted by holding the seedling at the root collar and pushing them into the soil. Unpruned plants were planted using a shovel. Planting occurred the last week of February—first week of March 1994.

Height of each seedling was recorded after planting was completed. Seedlings that had pruned roots (P) and those seedlings whose roots were not pruned (NP) were harvested in May and August 1994 and in March 1995. Five root-pruned and 5 non-root-pruned seedlings of each species were harvested from each plot at each sample date. Root collar diameter and height of harvested seedlings from root collar to terminal bud were measured and seedlings were separated into root and stem components. Each sample was dried at 80 °C (176 °C) for 48 hours and weighed.

During the August 1994 harvest, light quality and quantity measurements were taken within 2 hours of solar noon (to ensure maximum sunlight) with a Licor LI-1800 portable spectroradiometer. Photosynthetically active radiation (PAR) and the red-to-far red ratio (R:FR) were computed. In each plot, 8 different locations were measured at 2 heights: low = 60 cm (2.36 in) and high = 115 cm (45.3 in). Also, the amount and type of competing vegetation in each plot were analyzed in a biomass survey (August 1994). A randomly selected 0.25-m^2 (.27-ft^2) area in the root-pruned and non-root-pruned treatment for each species in each plot was clipped and the vegetation identified, dried at 80 °C (176 °F) for 48 hours, and weighed.

Differences due to root pruning treatment were determined using ANOVA. Significance was at the 0.05 level. Variables analyzed included diameter of root collar, height from root collar to terminal bud of seedling, dry root weight, and dry stem weight.

Results

Seedling growth, There were few significant differences between pruned and non-pruned seedlings at either harvest date in any of the 4 areas. Therefore, only end-of-the-year values are discussed (table 1). Baldcypress root-pruned seedlings had significantly greater diameters (11.9 vs. 9.4 mm) and stem biomass (7.9 vs. 4.3 g) in the cleared area than did non-pruned seedlings. Root biomass of green ash seedlings in the willow area was significantly less than non-pruned seedlings (24.4 vs. 34.2 g). Root-pruned seedlings of water tupelo in the muck and willow areas were significantly shorter (74.1 vs. 80.8 cm and 79.0 vs. 99.1 cm, respectively) than non-pruned seedlings. Other than these differences, there was no definite pattern *of* pruned seedlings being greater or less in diameter, height, root biomass, or stem biomass after 1 year in the field (table 1).

Competition and light. Eight different genera were identified as competing vegetation: *Scirpus cyperinus* (L.) Kunth, *Boehermia cylindrica* (L.) Schwartz, *Polygon um* spp., *Salix* spp., *Ludwigia* spp., *Panicum* spp., *Juncos* spp., and *Typha* spp. Although it depended on the plot as to which genus was the most abundant, *Scirpus* was usually the major component of biomass samples. On the other hand, *Ludwigia* and *Panicum* appeared most frequently in the samples even if they were only a small portion of the total sample weight. Competing vegetation biomass differences between areas are presented in figure 1. By the end of the summer, herbaceous vegetation was taller than planted seedlings.

There was no significant difference between areas for variables measured except for PAR measured at the upper level (115 cm). The cleared area mean was significantly different $(P < 0.05)$ than the willow area mean according to the Ryan-Einot-Gabriel-Welsch multiple F-test for the upper level PAR. Both levels (115 and 60 cm) of R:FR as well as the low level of PAR were not significantly different between these areas.

The level of competition measured in *each* plot (none, light, or dense competition) may help explain the lack of significance in light measurements. Biomass of competi-

Table 1—*Diameter, height, root biomass, and stem biomass of root-pruned (P) and non-pruned (NP) seedlings after 1 year*

Area & treatment	Diameter (mm)	Root height (cm)	Stem biomass (g)	biomass (g)
Baldcypress				
cleared, P	11.9 (0.8)*	70.7 (4.1)	7.9 (1.4)	7.9 (1.6)*
cleared, NP	9.4 (0.6)	66.1 (3.8)	5.4 (1.0)	4.3 (0.6)
grass, P	13.2 (0.9)	75.0 (4.1)	9.0 (1.5)	9.3 (1.1)
grass, NP	13.3 (1.2)	77.9 (3.4)	10.8 (2.1)	10.5 (1.7)
muck, P	12.6 (0.9)	71.6 (8.1)	6.8 (0.7)	9.9 (2.3)
muck, NP	12.0 (0.8)	75.5 (3.7)	8.3 (1.7)	8.8 (1.4)
willow, P	11.1 (0.7)	74.2 (4.3)	6.5 (0.9)	6.9 (0.9)
willow, NP	12.0 (0.7)	85.4 (3.9)	7.6 (1.1)	7.3 (0.7)
Green ash				
cleared, P	16.7 (1.2)	107.4 (6.2)	18.4 (3.3)	33.0 (5.1)
cleared, NP	16.6 (1.1)	117.0 (6.4)	26.7 (3.8)	36.7 (6.2)
grass, P	16.1 (1.3)	100.3 (8.3)	19.7 (3.9)	33.6 (8.5)
grass, NP	16.6 (1.0)	109.9 (5.1)	27.8 (4.8)	37.3 (6.2
muck, P	17.9 (1.3)	121.1 (4.4)	17.5 (2.6)	45.5 (7.0)
muck, NP	16.4 (1.1)	113.7 (5.3)	15.6 (2.4)	34.0 (5.3)
willow, P	19.5 (1.0)	138.8 (9.5)	24.4 (2.2)*	54.0 (6.6)
willow, NP	21.3 (1.1)	129.6 (7.7)	34.2 (3.2)	57.4 (6.5)
Swamp blackgum				
cleared, P	14.4 (0.6)	67.7 (6.8)	7.6 (1.0)	10.0 (1.8)
cleared, NP	13.0 (0.4)	80.7 (4.7)	8.7 (0.9)	11.3 (0.9)
grass, P	12.0 (0.3)	73.9 (5.9)	4.2 (0.5)	8.7 (0.8)
grass, NP	12.5 (1.1)	64.4 (6.2)	5.6 (0.8)	7.9 (1.5)
muck, P	15.0 (1.0)	80.9 (6.3)	6.2 (0.9)	13.1 (2.0)
muck, NP	12.7 (1.3)	75.4 (7.8)	7.2 (2.1)	9.0 (1.0)
willow, P	14.0 (0.7)	90.0 (7.7)	5.8 (0.5)	13.0 (0.7)
willow, NP	13.1 (0.9)	87.0 (6.9)	6.8 (1.2)	10.8 (1.3)
Water tupelo				
cleared, P	11.4 (0.4)	76.7 (1.2)	5.1 (0.8)	8.1 (0.8)
cleared, NP	12.3 (0.7)	78.4 (2.9)	6.9 (1.2)	8.6 (1.0)
grass, P	13.1 (0.8)	75.8 (3.0)	7.1 (0.9)	9.7 (1.2)
grass, NP	12.4 (0.5)	70.6 (3.4)	8.5 (1.0)	9.8 (0.9)
muck, P	13.4 (0.6)	74.1 (2.3)*	5.2 (0.5)	9.4 (0.8)
muck, NP	15.0 (1.2)	80.8 (2.0)	8.9 (1.7)	12.0 (1.8)
willow, P	13.5 (0.8)	79.0 (4.4)*	6.9 (1.1)	11.1 (1.2)
willow, NP	14.5 (1.0)	99.1 (6.3)	8.5 (1.2)	13.5 (1.6)

Note: Number in parentheses represents 1 standard error; * = a significant difference between root treatments within an area at the P = 0.05 level; 1 mm = .04 inches; 1 cm = .4 inches; 1 g = .04 ounces.

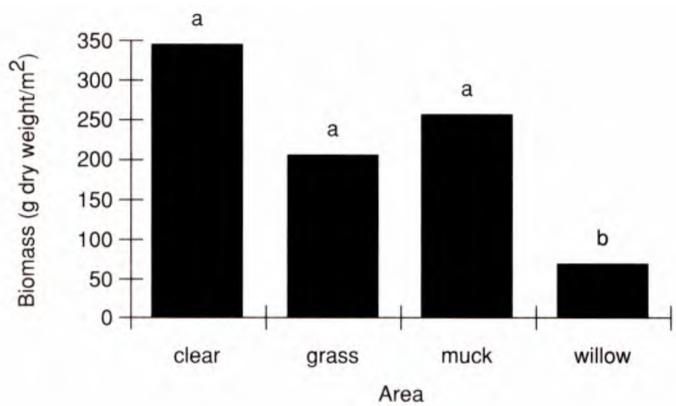

Figure 1—*Biomass of competing herbaceous vegetation in 4 areas planted with wetland species.*

tion differed by area as did light quantity (PAR) at the upper level. High-level PAR measurement differences explain differences in amounts of competition. The lower level PAR measurements indicated how the amount of light available to planted seedlings is affected by competition. Herbaceous biomass and PAR were related (figure 2).

A relationship was apparent between R:FR and biomass for the cleared, muck, and grass area (figure 3). An increase in biomass was related to a decrease in the R:FR for these areas. The willow area R:FR was lower than other areas even though its biomass was not as great as the other areas due to the impinging vegetative canopy of *Salix* species, which filtered out most of the red light.

Discussion

Based on data from the U.S. Geological Survey, water depth was at or above the soil surface for most of the study period, with increased flooding during August 1994 and February and March of 1995. Flooding during the growing season has been shown to be detrimental to roots of some trees. Coutts and Nicoll (1990) reported that the roots of Sitka spruce *(Picea sitchensis* (Bong.) Carr.) subjected to waterlogging in the fall suffered substantial dieback. The reason given for the dieback and poor survival of the spruce was that roots were still active when flooded out of season (usual flooding occurs in the winter and so seedlings were affected detrimentally because they still required oxygen transport).

Root pruning to ease planting in the delta is probably not detrimental in that seedling survival and performance is more likely affected by herbivory, the level of competition, and the duration and depth of flooding events. Similar results were reported by Conner and Flynn (1989), who reported 3-year survival rates of 70%

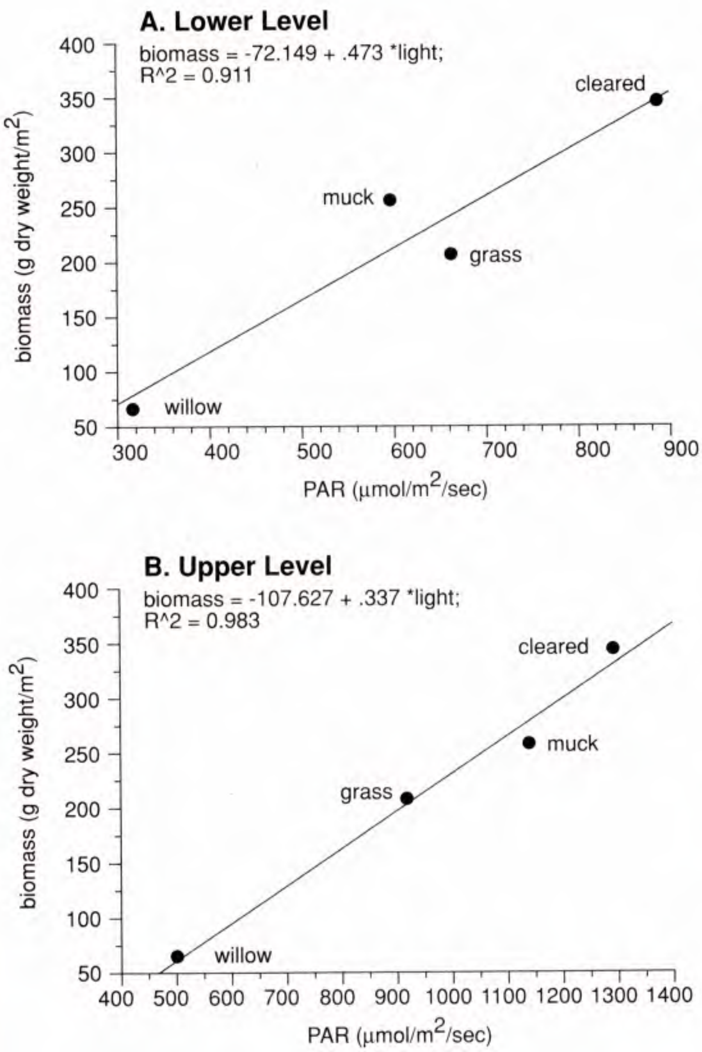

Figure 2—*Relationship between biomass of competition and photosynthetically active radiation (PAR) at lower* (A , *60 cm) and tipper* (B, *115 cm) levels.*

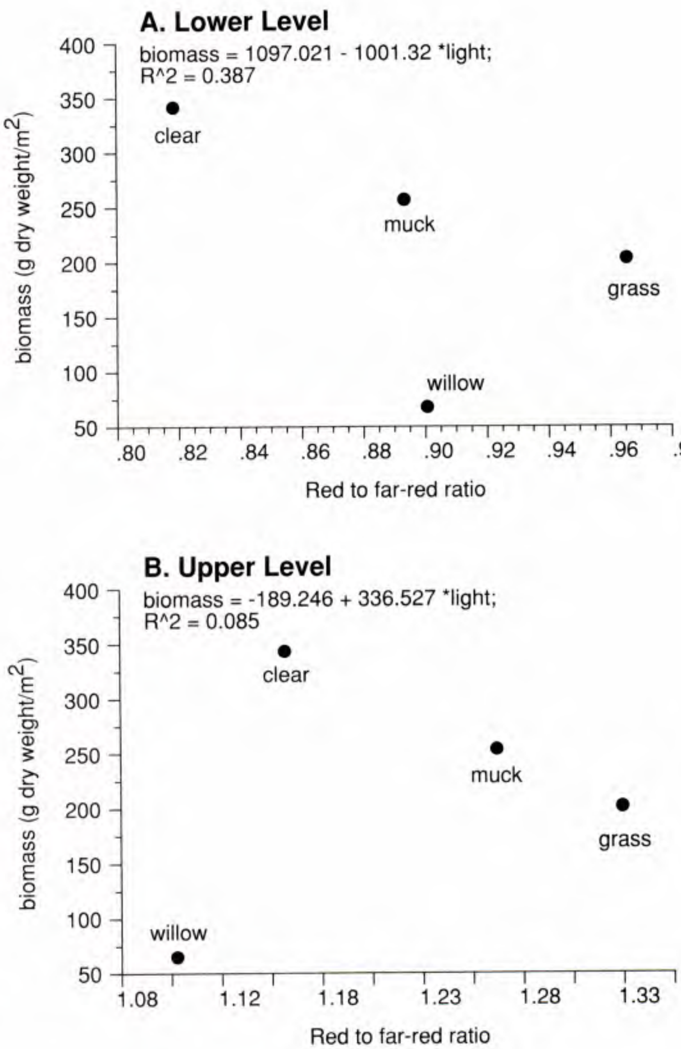

Figure 3—*Relationship between biomass of competition and red-to-far red light (R:FR) at lower* (A, *60 cm) and tipper (B, 115 cm) levels.*

for root-pruned baldcypress that were protected from herbivory. In another study, survival rates for root pruned baldcypress seedlings ranged from 80 to 100% after 2 years (Conner 1993). McLeod and others (1996) also concluded that moderate root pruning of seedlings to be planted in mucky substrates is successful for baldcypress and water tupelo. Furthermore, they suggested that the limiting factor for success is the relative flood tolerance of a species.

Differences between pruned and non-pruned seedlings were not great for any of the field harvest dates. The pruned ash seedlings allocated more biomass to above-ground parts than the other species at the final harvest date. Root systems of plants that are continuously flooded have low root—shoot ratios and shallow root systems (Megonigal and Day 1992). With a decrease in root—shoot ratio of seedlings in flooded conditions, the demand for oxygen is decreased and tolerance to waterlogged soils is increased (Keely 1979). Even with a shallow rooting zone, baldcypress is able to allocate more carbon to above-ground biomass when continuously flooded if ample nutrients are present (Megonigal and Day 1992).

All 4 species planted in this experiment had a decrease in the root—stem ratio from the first harvest (May 1994) to the second harvest (August 1994) regardless of root pruning treatment. The root—stem ratio held constant from the August 1994 harvest to the 1-year harvest in March 1995. After the initial dieback of roots under continuously flooded conditions, loss of main roots was compensated for by the formation of water roots. However, water roots did not increase the root-stem ratio. Increasing root mass was not necessary for growth of seedlings planted on Pen Branch delta as nutrients were readily available (judging from the healthy appearance of harvested seedlings) and water was not limited. It may be inferred that all 4 species in this experiment with pruned roots will establish and grow as well as those seedlings that are not pruned as long as nutrients and water are available. However, long-term studies are needed to determine if root-pruned seedlings will continue to perform as well as non-pruned seedlings.

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