PROJECT REPORT

The Pen Branch Project

Restoration of a Forested *Wetland* in South Carolina

by Randall K. Kolka, Eric A. Nelson, Ronald E. Bonar, Neil C. Dulohery, and David Gartner

Plantings have hastened recovery of vegetation devastated by thermal pollution.

The Pen Branch Project is a program to restore a forested riparian wetland that has been subject to thermal disturbance caused by nuclear reactor operations at the Department of Energy's (DOE) Savannah River Site (SRS), an 80,200-hectare nuclear facility located in South Carolina. Various levels of thermal discharges to streams located across the US. have occurred and continue to occur as a result of nuclear operations, electric-power production, paper production, sewage treatment and other causes. Although thermal discharges occur, we are not aware of any other wetland restoration project implemented because of thermal Impacts, mainly because impacts from these various industries are hiily regulated and relatively minimal compared to the level of disturbance that has occurred in Pen Branch.

Even though the functions that wetlands provide are widely acknowledged, losses continue at a rate of 47,000 hectares per year, much of which is occurring on forested wetlands in the Southeastern U.S. (Opheim, 1997). Techniques for restoring and monitoring bottomland forests, the major type of forested wetland in the Southeast, are undeveloped and imprecise (Clewell and Lea, 1990). Information is needed to more effectively restore, conserve and manage these valuable ecosystems. The Pen Branch Project is designed to assess the effectiveness of a number of restoration techniques. Through comparisons of planted areas with unplanted control areas and comparisons among other bottomland ecosystems at different stages of succession, we will develop indicators of wetland health that will allow us to assess the effectiveness of future wetland restorations. Here we summarize the overall project and report on what has been accomplished to date.

History

At the SRS, water was pumped from the nearby Savannah River, used as coolant for nuclear reactor operations, and died into adjacent natural river corridors. The expectation was that waters would cool to reasonable levels prior to reuniting with the Savannah River. Pen Branch, a third-order stream, was one of three river/floodplaii communities used for die of thermal effluents. Prior to reactor placement in 1954, the Pen Branch riparian vegetation community consisted of a closed canopy of baldcypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) along with other bottomland hardwood species in the floodplain riparian corridor (Sharitz et al., 1974). Natural flow in Pen Branch was typically 1-2 cubic meters per second (cms). Reactor operations raised the flow to as much as 10-12 cms, with water temperatures ranging from 40-50° C (Nelson, 1996). This high temperature and increased volume decimated the bottomland vegetation community and eliminated the seed bank and root stock from the previous bottomland forest in the floodplain and delta regions of Pen Branch. Similar levels of disturbance occur to bottomland hardwood communities in Florida as a result of phosphate surface mining.

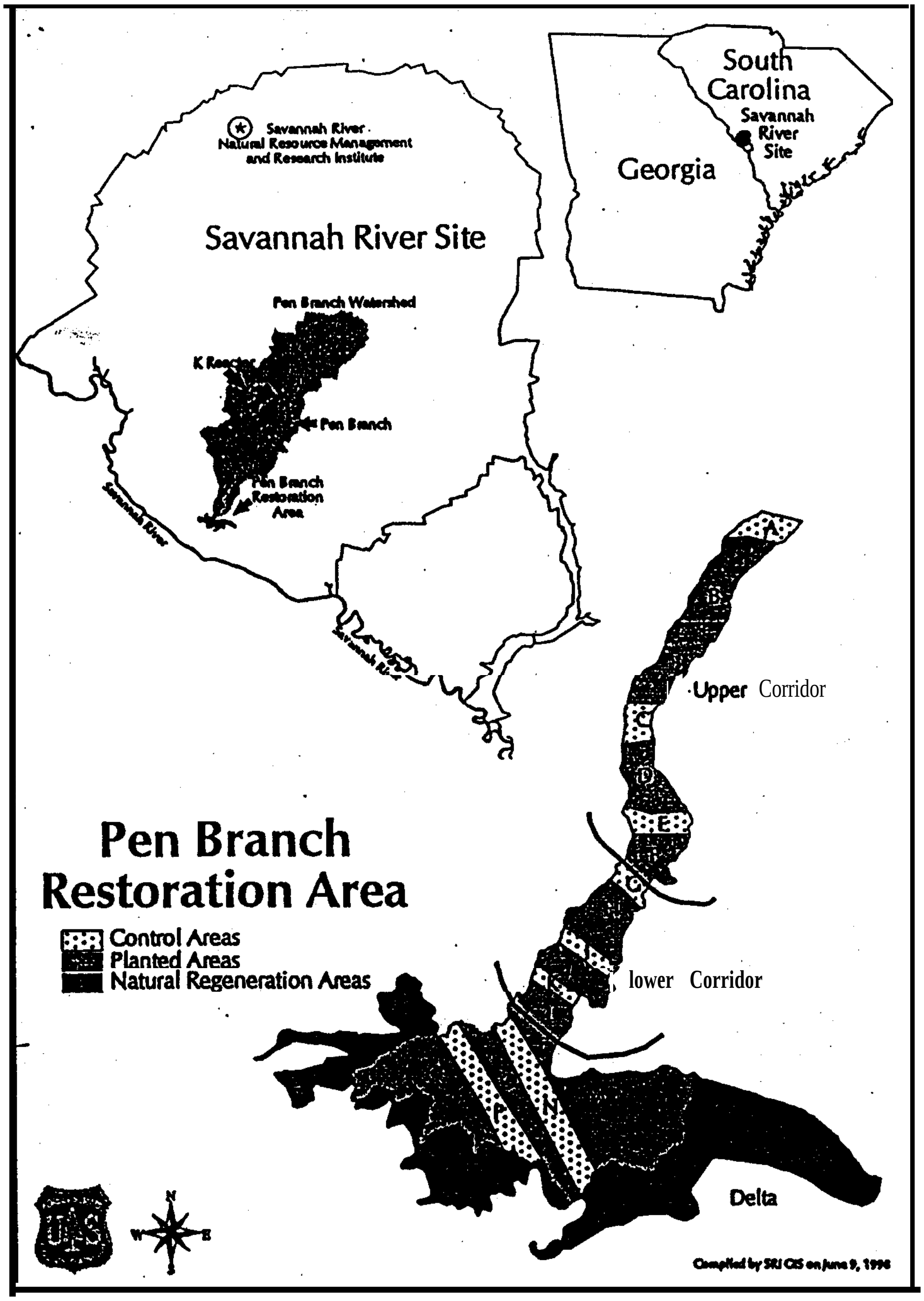


figure 1. Map of the Savanna River Siie and the Pen Branch Restoration Area.

With both types of disturbance, soils are devoid of viable seeds or root stock, but returning the natural hydrology is more difficult after surface mining. The natural hydrology returned to Pen Branch the minute the pumps were turned off in 1988.

On the basis of the Final Environmental Impact Statement (EIS), the DOE initiated restoration of those areas impacted by the thermal discharges into Pen Branch (DOE, 1991). The restoration is the result of a negotiated concession between DOE and a number of regulatory agencies including the Corps of Engineers and the Environmental Protection Agency. The restoration is an in-kind, in-place mitigation for prior damages. The Final EIS led to the development of a Mitigation Action Plan (MAP) for Pen Branch (Nichols, 1992). The MAP identified natural regeneration of the thermally impacted areas as the preferred vegetation restoration method, but also recommended the use of artificial regeneration where necessary. The Savannah River Natural Resource Management and Research Institute (a unit of the USDA Forest Service) manages SRS lands, and has the responsibility of revegetating the denuded Pen Branch wetland corridor and delta. The long-term objective of the restoration is to reestablish a bottomland hardwood community in the riparian floodplain of Pen Branch and a cypress-Npelo community in the delta.

Postdisturbance Condition

Once the thermal discharges ceased, a few early-successional species took advantage of the exposed mineral soil conditions and colonized the area aggressively. These included black willow (*Salix nigra*), smooth alder (*Alnus surrulata*), wax myrtle (*Myrica cerifera*) and buttonbush (*Cephalanthus* occident&s). Dispersed by wind and water, these light-seeded species quickly became established, and by 1992 dominated the floodplain corridor and delta.

In total, thermal discharges affected 236 hectares, including 88 hectares in the riverine floodplain and 148 hectares in the delta (Dulohery et al., 1995). When Forest Service staff assessed natural regeneration in 1992, they found that approximately 99 hectares in the lower delta fringe (see natural regenerationon map) and 48 hectares in the uppermost part of the watershed (not shown) were already sufficiently stocked with native bottomland species. The delta areas, although extensively boded, were furthest downstream from the reactor, and thermal dirges had sufficient time to cool to a level that impacted the forest community to a lesser degree. Upper reaches were less severely affected because the waterway is well channelii and the floodplain is narrow. Seed sources from the floodplain edge led to sufficient natural regeneration in these areas. The Forest Service monitored the severely damaged 49 hectares in the delta (areas M-Q on map) and the 40 hectares in the riverine floodplain (areas A-L on map) for three years. Virtually no natural recovery of native bottomland tree species occurred in these areas.

There are several reasons for the failure of natural regeneration in the Pen Branch floodplain and delta. Prolonged exposure to extremely warm water in these areas, not only killed the tree root stock, but also killed the propagules in the seed bank. Since the entire width of the floodplain was affected in this area, no native bottomland seed sources were available. Also, water flow in the delta is affected by dam operations on the Savannah River. Dam operations have virtually eliminated the naturally occurring periods of low water necessary for successful natural regeneration of swamp forest species such as baldcypress and water tupelo (Sharitz, 1993). Dominated by cattails (*Typha* spp.) and black willow, the former cypress-tupelo swamp of the delta is now inundated year-round.

Mature bottomland hardwood forest shows as a dark band along course of Pen Branch in aerial view taken in 1943, eleven years before operation of the nudear plant began.

Restoration

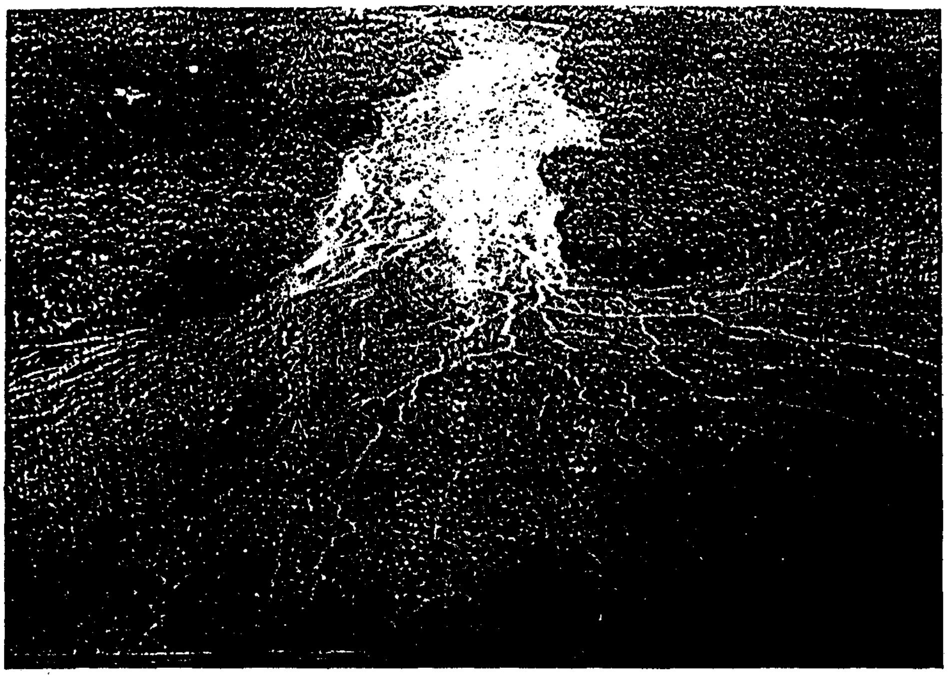
In 1992, the Forest Service's Savannah River Natural Resource Management and Research Institute began efforts to accelerate the recovery of the Pen Branch sys tern to its previous bottomland forest condition. Artificial regeneration efforts were concentrated on the 86 hectares (see map, areas A-Q) that had been most severely affected by the thermal discharges. Our goal was to plant seedlings in sufficient numbers and diversity to allow the development of a mature bottomland hardwood canopy in the stream corridor and a cypress-Npelo canopy in the delta (Table 1). Native shrub and herbaceous species were not planted. We believe that unimpacteci bottomlands located both upstream and in nearby watersheds will serve as sources of understory species for the impacted areas of Pen Branch. Also, little is known about the tolerance of understory species to shade, competition and flooding. Current conditions in Pen Branch may not support many native understory species. It may be 20-30 years before the canopy approaches closure, providing the necessary conditions for the establishment of understory species. Results of future monitoring will be used to prescribe other vegetation manipulations if necessary.

The area to be restored was divided into three sections on the basis of hydrology and vegetation present: 1) the upper corridor, the driest of the three areas, dominated by shrubs (black willow, buttonbush, wax myrtle, and smooth alder) (24 hectares [60 acres]); 2) the lower corridor, dominated by grasses and scattered black willow (16 hectares [46 acres]); and 3) the constantly inundated delm, dominated by cattails and scattered black willow (46 hectares [115 acres]).

To assess the effectiveness of active intervention, we planted only 75 percent of the study area. The remaining 25 percent of the area is a series of unplanted control strips located between planted areas. We established three planted strips and three control strips in both the upper and the lower corridor, and three planted strips and two control strips in the delta (see map). We selected seedling species that are typical of relatively undisturbed bottomland forests on the Savannah River Site (Table 1). Seedlii species were appropriate to the soil type and hydrology present in the floodplain corridor and delta. We used three site-preparation methods, also adapted to the existing conditions. The virtually unbroken thickets of black willow in the upper corridor were herbicided in

Table 1: Percent distribution and total number of species planted in Pen Branch from 1993-1 996 (Kolka et al.; 1998)

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



An aerial photo taken in 1989, shortly after flow from the reactor was halted, show delta of the Branch reduced to a vast, treeless mud pie. *Photos courtesy of Westinghouse Savannah River Company*

September 1993 with Rodeo@ (and burned in November 1993 to allow access and reduce overstory competition. In December of 1993 and January of 1994, the upper corridor was planted with cherrybark oak (*Quercus falcata* var. *pagodifolia*), swamp chestnut oak (*Q. michauxii*), water oak (*Q. nigra*), water hickory (*Carya aquatica*), persimmon (*Diospyros virginiana*), swamp tupelo (*Nyssa sylvatica* var. *biflora*), green ash (*Fraxinus pennsylvanica*), water tupelo, and baldcypress. The lower corridor was relatively open, and we planted without any site preparation under the broken black willow canopy in February and March of 1993. 'The lower corridor was planted with cherrybark oak, swamp chestnut oak, green ash, water tupelo, and baldcypress. The delta was treated with Rodeo in Sep tember 1994 to prevent competition from black willow on the ridges and cattails in the sloughs. In January and February 1995 we planted the delta with green ash on the ridges and water tupelo and baldcypress in the sloughs. All of the hardwoods and most of the baldcypress were 1-0 (that is, one year in the nursery and no years in a transplant bed) nursery-grown seedlings, from 45-120 cm in height. In 1995, some 2-O baldcypress that ranged up to 150 cm in height were planted in the deeper water areas of the delta. Planting was performed by Forest Service personnel and through contracts with **independent planters.**

Following each planting, surveys were conducted to monitor survival and growth (Dulohery et al., 1995). The combination of herbicide + burning eliminated about 95 percent of the overstory and understory. Red maple (*Acer rubrum*), a native bottomland hardwood species (Jones et al., 1994) and a component of the target ecosystem, whose density was low enough not to pose a competition problem for the planted hardwoods, was virtually unaffected **by the herbicide** treatment. Although the combination site preparation technique allowed for much easier and efficient planting, it **also opened the site to** nuisance animals. Though mice, rabbits, beaver, and deer did little damage to the newly planted seedlings, feral hogs caused unexpected and unacceptable damage in areas cleared by burning and herbiciding, destroying two-thirds of the upper corridor seedlings, preferring oaks over other species (WSRC, 1995). In spring of 1995, we replanted the herbicide + prescribed-bum areas in the upper corridor with cherrybark oak, water oak, shumard oak (*Quercus shumardii*), green ash, sycamore (*Platanus occidentalis*), pignut hickory (*Carya glabra*), water hickory and swamp tupelo. By 1995, the herbicide+ bum areas had regained some early-successional herbaceous vegetation cover, and no extensive feral hog damage has occurred since.

Outcome

We conducted a seedling establishment **survey** in April of 1997. Field crews tallied and identified all native bottomland species in 0.008 hectare plots, including unplanted species typical of bottomlands such as ted maple, sweetgum (*Liquidambar styraciflua*) and river birch (*Betula nigra*)

Table 2:. Percent survival of species planted in Pen Branch from 1993-1996 **(Kolka et al., 1998)**

Species	Upper Corridor	lower Corridor	Delta
Chenybark 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

Hip deep in muck and loaded with planting stock, silvicultural technician Charlie Possee makes his way to planting area on the delta of Pen Branch in western South Carolina. An effort is underway to restore forested wetland on the site, devastated by thermal pollution from a nudear facility between 1954 and 1988. Photo courtesy of USDA Forest Service

(Jones et al., 1994). In total, 528 plots were measured in planted and unplanted areas of the floodplain corridor and delta. We also measured 63 plots around the fringe of the delta in the natural regeneration areas. Early-successional species such as black willow, smooth alder, wax myrtle and buttonbush were noe tallied. Results from our 1997 seedling establishment survey suggest that Pen Branch is on a trajectory toward a mixed bottomland hardwood forest in the riverine floodplain, and a cypress-tupelo swamp in the delta (Table 2, Figure 1). Planted areas in the upper Pen Branch corridor average 401 ± 43 stems/hectare (mean ± standard error), the lower corridor 405 ± 34 seems/hectare and the delta 522 ± 34 stems/hectare of native bottomland species (Kolka et al., 1998). Our seedling establishment in Pen Branch falls within the range (330-900 seems/hectare) of those reported for tree densities in unimpacted bottomland systems located on the Savannah River Sire (Megonigal et al., 1997). We expect seedling mortality to occur in the future, but the 3-5 year old seedlings are well established, and most are above herbaceous competition. Nearly 50 percent of the seedlings established in the upper corridor are unplanted volunteers, mainly red maple. Unplanted volunteers comprise only 12 percent of the seedlings established in the lower corridor and three percent in the delta.

Although water tupelo, sycamore, green ash and persimmon have faired well in the drier upper corridor, overall survival of planted seedlings is poor (Table 2). These species, especially sycamore, green ash and persimmon, are fast growing and have broken through the herbaceous competition. Baldcypress is surviving extremely well in the wetter lower corridor and inundated delta (Table 2). Nearly 100 percent survival of any species is somewhat surprising. The obvious potential error in survival percentages is the counting of naturally regenerated volunteers. Thii effect should be minimal, however, because we subtracted the species density found in nearby unplanted control sections from the those in the planted sections. However, it is possible that planted areas, because of natural variability, had nearer seed sources than unplanted controls, or chat the site-preparation techniques used in planted areas were more conducive to the establishment of volunteers,

Seedling establishment in unplanted areas is much lower than in planted areas, averaging 115 stems/hectare in the corridor and delta (Figure 1). Bottomland seedlings established in the unplanted control sections were comprised mainly of mainly red maple (51 percent), with river birch (17 percent), baldcypress (12 percent), sweetgum (6 percent) and sycamore (5 percent) also as important components (Kolka et al., 1998).

Natural regeneration of the less impacted areas around the margin of the delta is highly variable. Average stem density is 1750 ± 2410 stems/hectare, with a range of 0 to almost 10,000 stems/hectare (Kolka et al., 1998). Naturally recovering stands ace comprised mainly of baldcypress (56 percent), with water tupelo (18 percent), red maple (16 percent), and sweetgum (8 percent) also as important components. Nearness to seed sources is obviously play ing a very important role in the natural regeneration of the delta margin.

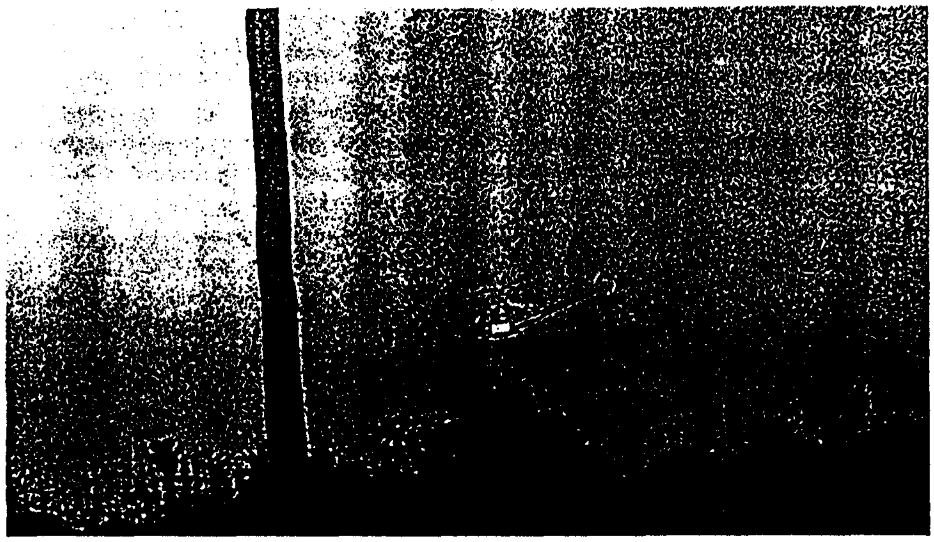
At thii point, it appears likely that the future forest canopy of Pen Branch will be similar in composition to the pre-disturbance canopy (Sharitz et al., 1974). We will monitor seedling survival through the year 2000, or until we have reasonable assurance that we have enough established seedlings to assure a self-sustaining system. Beyond that, our plans call for periodic revisitation over the next 20 years to confirm the development of a functioning bottomland ecosystem. Such long-term monitoring is essential to assess the outcome of this project.

Research

The majority of wetland restoration performed in the Southeast involves either coastal or inland marshes or mangrove ecosystems. The results of vegetation establishment on these sites are evident relatively soon after restoration is initiated, in one to five years for marshes, and five to 15 years for mangrove swamps. Because of the longevity of forest species and the uncertainty associated with long-term survival, it takes at least 20 to 40 years to truly evaluate the results of a forested wetland restoration. Determining whether a forested wetland restoration project is a success is difficult when the assessment period is short (typically one to five years) and indicators of desired wetland conditions for recently established sites have not been developed (Clewell and Lea, 1990). Development of an assessment framework and associated indicators that can be used to evaluate the effectiveness of a wetland restoration is critical to demonstrating the sustainability of restored sites.

Our research objectives are todevelop best-management techniques for forested-wetland restoration and to develop monitoring methods to assess restoration effectiveness within the first one to five years after restoration. To meet theseobjectives, the Savannah River Natural Resource Management and Research Institute, in cooperation with the Westinghouse Savannah River Technology Center has initiated 13 collaborative Pen Bran&studies with several Federal agencies, including the Corps of Engineers and the USDA Forest Service's Center for Forested Wetlands Research, and eight universities, including Auburn University, Clemson University, University of Georgia and the Savannah River Ecology Lab, the University ofSouth Carolina, the University of South Carolina-Aiken, and Virginia Polytechnic University.

Several of these studies have already led us to improved reforestation techniques for bottomland hardwood systems.



The team applied herbicides aerially . . .

Seedling establishment appears to be hampered in open conditions, like those we created in the upper corridor by herbicideing and burning. Open conditions promote dense growth of herbaceous competition by species such as blackberry, and allow access by herbivores such as hogs and beaver. Studies assessing canopy and herbaceous competition suggest that the highest probability for seedling survival is where a broken black willow shrub cover is present (McKevlin and Dulohery, 1996). Where shrubs are too dense to allow easy access and are likely to cause future competition problems, we found that killing approximately 60 percent of the shrub layer by stem injection of herbicide leads to good survival and growth of seedlings. Although shading might slow seedling growth to some extent, thii effect is offset by protection from herbaceous competition and herbivory. Restorationists undertaking reforestation efforts in bottomland hardwood wetlands should consider alternative site-preparation techniques, such as planting directly under shrubs, that minimally alter the early successional vegetation.

. . . and used a combination of herbicides and prescribed burns in the upper corridor to knock back early-successional competition. Photo courtesy of USDA Forest Service

We have ongoing experiments assessing the use of tree tubes or tree shelters for protection against herbivory. Seedling survival and establishment is much greater when tree tubes are used (Conner et al., 1996). Although tree shelters may be prohibitively expensive on a large-scale project such as the Pen Branch reforestation, they may be cost effective in areas where seedling establishment is deemed especially critical. If, for example, stream stabilization and recovery are primary restoration objectives, it may be worthwhile to use tree tubes adjacent to streams. In a relatively short period of time (three to five years), these seedlings will stabilize the banks and provide the light conditions necessary for stream biota recovery. Also, if it is known prior to restoration or even shortly after planting that an area is susceptible to herbivory, tree shelters may be a cost-effective measure that would ensure seedlihg survival.

Planting in the Pen Branch delta was difficult because of the deep, mucky soils present in places. We found that planting holes closed quickly and it was difficult to get the entice coot mass properly placed in the holes. Because of these problems we cuccently have a study assessing coot pruning to facilitate planting of seedlings under these conditions. Root pruning is simply cutting off the most of the lateral roots to make it possible to insert seedliidicectly into mucky soils without making a planting hole- Although our results ace preliminary, it appears that root pruning of transplant stock does not have a detrimental effect on seedling survival in mucky conditions, at least for the four species in our study-baldcypress, water tupelo, swamp tupelo, and green ash (Conner et al., 1996). We will continue to follow this study over the first five years of seedling establishment. If the long term results support our initial impression, it will be possible to achieve dramatic improvements in planting efficiency inthesediicult conditions.

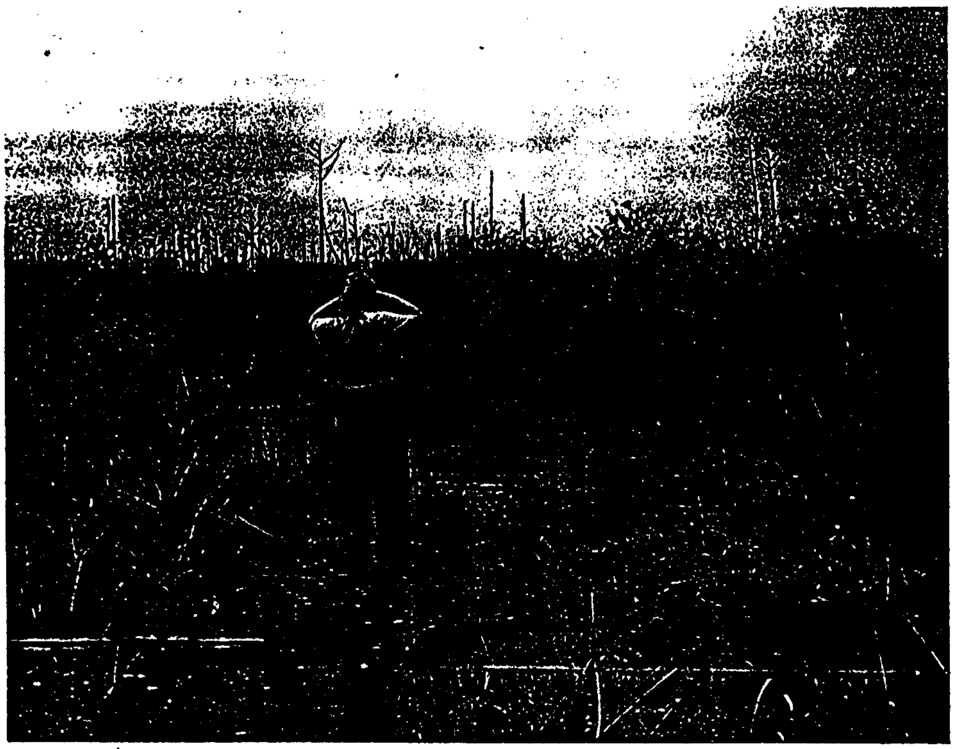
Hydrology, of course, is a critical factor when assessing seedling survival. We have found, for example, that green ash is more vulnerable to prolonged flooding than are baldcypress, water tupelo and swamp tupelo (Rozelle and Hook, 1996). Prolonged soil saturation and inundation are typical conditions in the Pen Branch delta and other stream deltas in the area, and restorationists will want to take this into consideration when selecting species for planting in areas that have different hydrology.

our restoration-assessment studies compare important ecological parameters and processes on a restored site (Pen Branch) to norms established in unimpacted and naturally recovering wetlands on the SRS. We ace using sensitive indicators of wetland functions across the successional gradient to determine whether Pen Branch is on the planned trajectory coward a recovering forested wetland. Those indicators are: (a) the relationship between hydrology and the composition, structure and productivity of the plant community; (b) stream morphology, aquatic community composition, water quality in the riparian zone; (c) organic-matter decomposition and nutrient dynamics; (d) responses of the animal community.

Currently, the vegetation in the Pen Branch corridor and delta is dominated by early successional hecbaceous species, especially blackberry and various grasses, in planted areas, and a shrub canopy of black willow with an understory of similar herbaceous species in the control areas. Instream vegetation is dominated by dense mats of maccophytes. Open conditions created by the thermal diicges and by site preparation favored the establiihment of these early successional species. The flush growth of both terrestrial and instream vegetation has resulted in a large quantity of herbaceous and small woody detritus, which is decomposing rapidly and supporting a large and diverse community of vertebrate and invertebrate animals.

Ed Olson of the Savannah River Institute measures two years of growth of a planted baldcypress seedling.

We have initiated studies assessing organic carbon and nutrient cycling across the succession gradient. Soil organic matter (SOM) is a critical interface for the exchange of nutrients between vegetation and soil, and is directly linked to patterns of forest productivity. Studies ace addressing SOM development by assessing forest-floor processes along the successional gradient (Lockaby and Wiiton, 1997). The mass of organic matter on the forest floor increased rapidly during early succession, reaching a maximum of 657 g/m^{-2} in Pen Branch (early succession) and decreasing to 338 g/m^{-2} in the late-successional system of Meyers Branch. The herbaceous fraction declinedsteadily through succession, from 74 peccent in the earliest stage to less than 1 percent in the latest stage of succession- Conversely, the amount of woody foliage increased from 6.7 percent in the earliest stages of succession to over 70 percent in late succession- Other studies have begun to investigate carbon and nutrient pooh and fluxes along the successional gradient (Kolka and Tcettin, 1997). In our studies of carbon and nutrient fluxes, we ace combining hydrologic monitoring with data on soil water, precipitation, throughfall, and stream-water chemistry to determine whether carbon and nutrient transport processes vary with the stage of succession. In the closely related study investigating carbon and nutrient pools, we are assessing both aboveground and belowgcound pools and the turnover of these pools along the identical successional gradient (Aust and Giese, 1997). Within the scope of this study ace individual studies addressing net primary productivity, standing biomass, vegetation community stcuctuce, soil and forest-floor carbon and nutrient content, littecfall production and decomposition, lateral litter transport, inscceam biomass, and instream litter transport. We will



Ground truth: Damage from hot effluent in the lower corridor is assessed by Marilyn Buford, project leader for the Forest Service's Center for Forested Wetlands Research.

integrate the two studies in an attempt to characterize the processes that affect-carbon and nutrient allocation and transport in bottomland-hardwood wetlands. Dirences in carbon and nutrient allocation and transport processes across the successional gradient will be used as one set of indicators to establish **a framework for assessing** the effectiveness of wetland restoration techniques.

It appears from the data that Pen Branch is performing many of the functional capabilities of a wetland with respect to animals. For some animal species, especially those adapted to disturbed conditions, such as mosquitofish *(Gambusia affinis)*, the eastern narrow-mouthed toad *(Gastrophryne carolinensis)*, red-winged blackbirds *(Agelaius phoeniceus)* and cotton rats *(Sigmodon hispidus)*, it appears thae Pen Branch is providing greater opportunity for establishment and survival than do late successional **systems (Fletcher et al.,** 1997; Hanlin and Guynn, **1997;** Buffington et al., 1997; Wike et al., 1997). Although species abundance and in some cases diversity are higher in Pen Branch than in unimpacted, mature systems, the community structure is very different. Our **results indicate that just a few** species dominate populations in Pen Branch, in contrast with late-successional systems **where we find a wide variety of species more evenly** represented. Ongoing and future **monitoring of animal communities and** the functions that control animal communities, **will allow us to plot the animal recovery trajectory for bottomland wet**lands. We expect that over time, as the **plant community matures, differences in** animal-community structure between Pen Branch and late-successional model systems will lessen and **that the system will gradually assume the character of a mature bottomland** hardwood system.

Pen Branch is recovering from 34 years of thermal disturbance. We hope that planting native tree species will accelerate recovery. We will continue **to monitor seedling** establishment, plant **communi**ties, soil and hydrology variables, and response of the animal community until we have ensured a self-sustaining bottomland hardwood wetland ecosystem.

With the use of unplanted control areas, and comparisons to similar systems at various stages of succession, we are assessing the effect of our restoration efforts. Knowledge gained from our monitoring and systematic studies will enable future restoration efforts to be more efficiently and effectively performed and evaluated.

Note

The mention of trade names or a commercial product doe.5 not constitute endorsement by the **USDA** or the US DOE.

References

Aust, M., and Giese. L 1997. Distribution and function of organic matter pools among systems of different successional stages. In Kolka, R.K. and CC Trettin (Eds.), Wetlands Research Related to the Pen Branch Restoration Effort on the Savannah River Site. WSRC-TR-97-00273: 19-20.

Buffington, J. M., J. C Kilgo, R. A. Sargent, K. V. Miller, and B. R. Chapman. 1997. A comparison of bird communities in bottomland hardwood forests of different successional stages. The Wilson Bull. 109(2): 314-319.

Clewell, A.F. and R. Lea. 1990. Creation and **restoration of forested wetland vegetation in the southeastern United States. pp. 195-**232. In: J.A. Kusler and M.E. Kentula, (eds.), Wetland **Creation ad** Restoration: The Status of the Science. Island Press, Washington, DC.

Conner, W.H., LW. inabinette, and EL Funderburk. 1996. The use of root pruning and tree shelters in regenerating forested wetlands in Pen Branch. In: Nelson, E. (Ed.), Proceedings of the Restoration of Pen Branch **Symposium,** Savannah River Site. WSRC-MS-96-0257X: 20-21.

Department of Energy. 1991. Record of decision: **continued operation** of K, L, and P **reactors, Savannah River Site, Aiken, SC** Federal Registry 56(28): 5584- 5587.

Dulohery, N.J., **CS. Bunton, CC Trettin** and W.H. McKee. 1995. **Reforestation,** Monitoring, and Research at Pen Branch: Restoring a Thermally-Impacted Wetland Forest Establishment Report USDA Forest Service. 55 pps.

Fletcher, D., D. Wilkins, and G. Meffe. 1997. Ecological risk **assessment and stream restoration relative to** thermal flow disturbance. In Kolka, RK. and CC Trettin (Eds.), **Wetlands Research Related to the** Pen Branch Restoration Effort on the Savannah Riyer Site. WSRC-TR-97-00273: 6-a.

Hanlin, H. and D. Guynn. 1997. Reptile and **amphibian characterization of the** Pen Branch corridor at the beginning of restoration. In Kolka, R.K. and C.C. Trettin (Eds.), Wetlands Research Related to the Pen Branch Restoration Effort on the Savannah River Site. WSRC-TR-97-00273: 9-10.

Jones, R.H.. R.R. Sharitz, S.M. James, and P.M. Dixon. 1994. Tree population dynamics in seven South Carolina mixed species forests. *Bulletin of the Torrey Botanical Club* 121(4): 360-368.

Kolka, R.K., C.C. Trettin, E.A. Nelson, and W.H. Conner. 1998. Tree seedling survival across a hydrologic gradient in a bottomland hardwood restoration. In Proceedings: Annual Conference on Ecosystem Restoration and Creation, Tampa, FL Submitted.

Kolka, R.K. and C.C. Trettin. 1997. Wetlands Research Related to the Pen Branch Restoration Effort on the Savannah River Site. WSRC-l-R-97-00273.

Lockaby, G., and J. Wigginton. 1997. Soil organic matter development and characterization: Successional patterns on a forested floodplain. In Kolka, R.K. and CC Trettin (Eds.), Wetlands Research Related to the Pen Branch Restoration Effort on the Savannah Rivet Site. WSRC-TR-97-00273: 17-18.

Nelson, E. A. 1996. The Restoration of Pen Branch: Defining and Measuring the Progress of a Thermally Impacted Stream Becoming a Functional Wetland Ecosystem. Abstracts from Symposium held on Feb. 13, 1996, Savannah River Site. WSRC-MS-96-0257X.

McKevlin, M.R. and N. Dulohery. 1996. Optimum overstory condition for survival and growth of late-successional seedlings. In: Nelson, E. (Ed.), Proceedings of the Restoration of Pen Branch Symposium, Savannah River Site. WSRC-MS-96-0257X: 11.

Megonigal, J.P., W.H. Conner, S. Kroeger, and R.R. Sharitz. 1997. Aboveground production in Southeastern floodplain forests: A test of the subsidy-stress hypothesis. Ecology 78(2): 370-384.

Nichols, D.M. 1992. Program implementation plan for mitigation action plan: 1992 annual update. Westinghouse Savannah River Company, Reactor Environmental Management, Aiken, SC RRD-OAM-911515.

Opheim, T. 1997. Wetland losses have continued but have slowed. *National Wetlands Newsletter* 19(6): 7.9.

Rozelle, A-L, and D.D. Hook. 1996. Comparison of biomass partitioning and use of physiological parameters in determining long term survival of four wetland tree species (abstract). In: Nelson, E. (Ed.), Proceedings of the Restoration of Pen Branch Symposium, Savannah River Site- WSRC-MS-96-0257X: 22-23.

Sharitz, RR 1993. Coarse woody debris and woody seedling recruitment in southeastern forests. p. 29-34. In: J.W. McMinn and D.A. Crossley, (eds.), Proceedings of the Workshop on Coarse Woody Debris in Southern Forests: Effects on Biodivenlty. U-S. Department of Energy and USDA Forest Service. Athens, GA.

Sharitz, R.R., J.E. Irwin, and E.J. Christy. 1974. Vegetation of swamps receiving reactor effluents. Oikos 25: 7-13.

Wih, L, E. Stieve, T. Parker, and J. Gass. 1997. Pen Branch small mammal program-1997. In Koika, R.K. and CC. Trettin (Eds.), Wetlands Research Related co the Pen Branch Restoration Effort on the Savannah River Site. WSRC-TR-97-00273:13.

WSRC. 1995. Savannah River Site Environmental Report For 1994. WSRC-TR-95-075, Westinghouse Savannah River Company, Aikcn, SC.

Dr. Randall K. Kolka is a Research Soil Scientist with the USDA *Forest* Service, *Center for* Forested *Wetlands Research, Savannah River Ecology Lab, 737A, Drawer* E, *Aiken, SC* 29802. Phone: *(803) 725-7283*, Fax: *(803) 725-3309, Email: kolka@srel.edu.*

Dr. Eric A. Nelson is a Principal Scientist with the Savannah River Technology Center, Westinghouse Savannah River Company, Aiken, SC *29808.*

Ronald E. Bonar is the Timber Staff Officer at the USDA *Forest* Service, *Savannah River* Natural *Resource Management and Research Institute, Box 710, New Ellenton, SC 29841.*

Neil C. *Dulohery* is the *Nutrition Research* Project *Leader* at *International Paper* company, 719 *Southlands Rd, Bainbridge, GA 31717.*

David Gartner is a Statistician at the USDA Forest Service, Center for Forested *Wetlands* Research, *2730 Savannah Hwy., Charleston, SC, 29414.*