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Guest editorial

Restoration of a severely impacted riparian wetland system — The Pen Branch Project

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1. Introduction

The Savannah River Swamp is a 3020 ha forested wetland on the floodplain of the Savannah River and is located on the Department of Energy's Savannah River Site (SRS) near Aiken, SC (Fig. 1). Historically the swamp consisted of approximately 50% baldcypress-water tupelo stands, 40% mixed bottomland hardwood stands, and 10% shrub, marsh, and open water. Tributeries of the river were typical of Southeastern bottomland hardwood forests. The hydrology was controlled by flow from four creeks that drain into the swamp and by flooding of the Savannah River. Upstream dams on the Savannah River have caused some alteration of the water levels and timing of flooding within the floodplain (Schneider et al., 1989).

Major impacts to the swamp hydrology occurred with the completion of nuclear production reactors and one coal-fired powerhouse at the SRS in the early 1950s. Water was pumped from the Savannah River, through secondary heat exchangers of the reactors, and discharged into three of the tributary streams that flow into the swamp. Flow in one of the tributaries, Pen Branch, was typically 0.3 $m^3 s^{-1}$ (10–20 cfs) prior to reactor pumping and 11.0 $m^3 s^{-1}$ (400 cfs) during pumping. Elevated flows continued from 1954 to 1988 at various levels. The sustained increases in water volume resulted in overflow of the original stream banks and the creation of additional floodplain. Accompanying this was considerable erosion of the original stream corridor and deposition of a deep silt layer on the newly formed delta. Heated water was discharged directly into Pen Branch and water temperature in the stream often exceeded 65°C. The nearly con-

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Table 1
Treatment zone description. site preparation and planting arrangement for the Pen Branch system (Nelson et al.. 2000)

Treatment zone	Area (ha)	Site description[a]	Site preparation[b]	Planting scheme
Upper Corridor	24	Mesic bottomland with 30-80 cm of standing water in well defined stream channels (l-2) during the growing season. Vegetation dominated by dense willow thickets	Aerial herbicide application (Sept. 1993). Controlled Burn (Nov. 1993)	747 trees ha-’ (Dec. 1993–Jan. 1994). 1078 trees ha-’ (Jan. 1995)
Lower Corridor	16	Poorly drained bottomland with water table 20-30 cm below the soil surface during the growing season. Braided stream with 4–5 flow paths. Vegetation dominated by willow thickets and grassy openings	None	747 trees ha-’ (Feb. and Mar. 1993). 549 trees ha-’ (Jan. and Feb. 1995)
Delta	46	Continuously flooded swamp except on ridges near the mouth of the stream, where water table is found 20 cm below the soil surface. Vegetation dominated by cattails (≈ 66%) and willows (≈ 33%)	Herbicide application on 12 ha of levees and alluvial deposits for willow control (Sept. 1994)	1078 trees ha-’ (Jan. and Feb. 1995). A portion (4.9 ha) was planted at 500 trees ha-’ due to standing water

[a] Description prior to restoration.
[b] Preparation for planted sections only

tinuous flooding of the swamp, the thermal load of the water, and the heavy silting resulted in complete mortality of the original vegetation in large areas of the floodplain (Fig. 2).

In the years since pumping was reduced, early succession has begun in the affected areas. Herbs, grasses, and shrubs dominate these areas. Few volunteer seedlings of heavy-seeded hardwoods or baldcypress have been found in the corridor areas. Research was conducted to determine methods to reintroduce tree species characteristic of more mature forested wetlands. Three restoration strate-

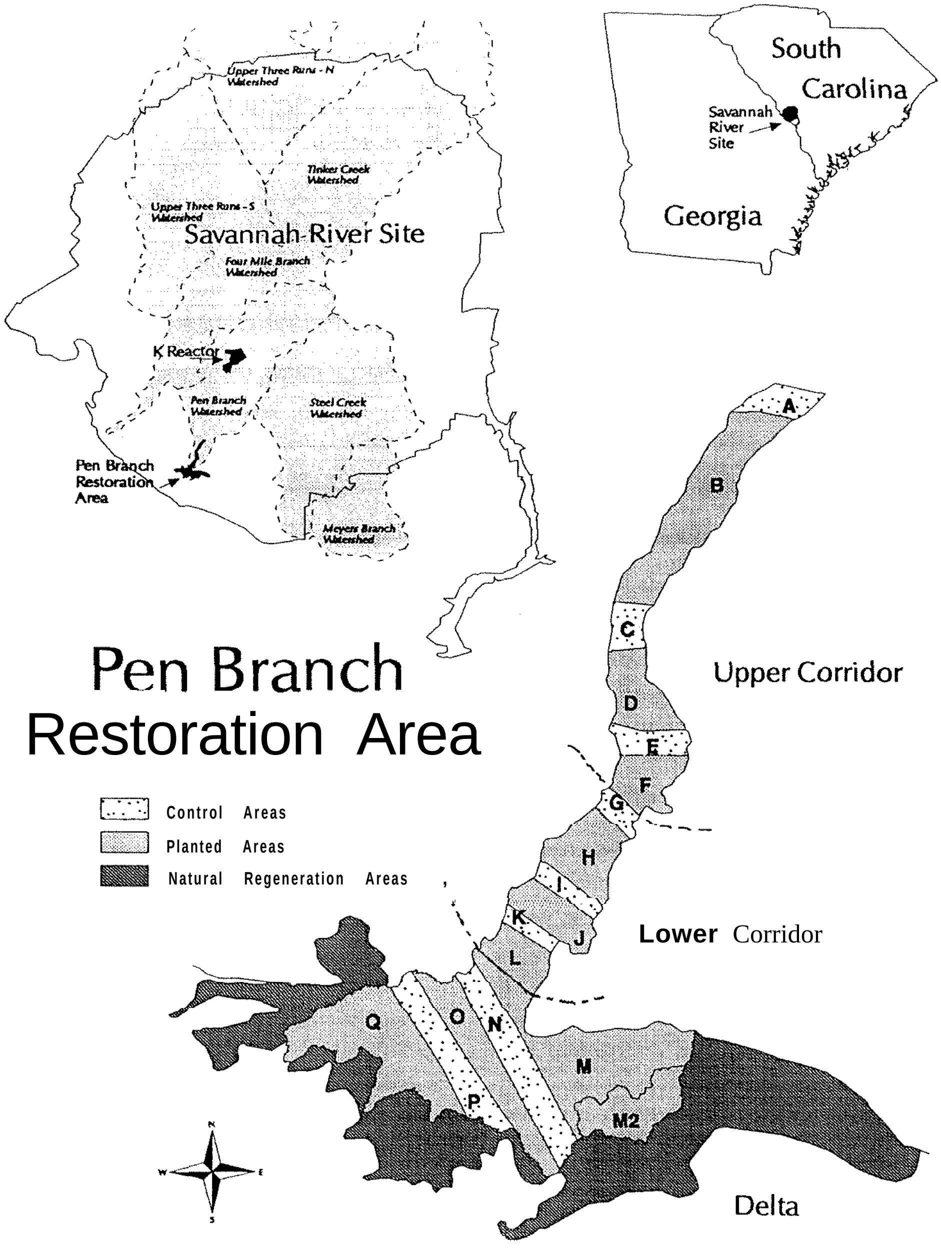

Fig. 1. Locator map for the Pen Branch study area on the Savannah River Site. SC.

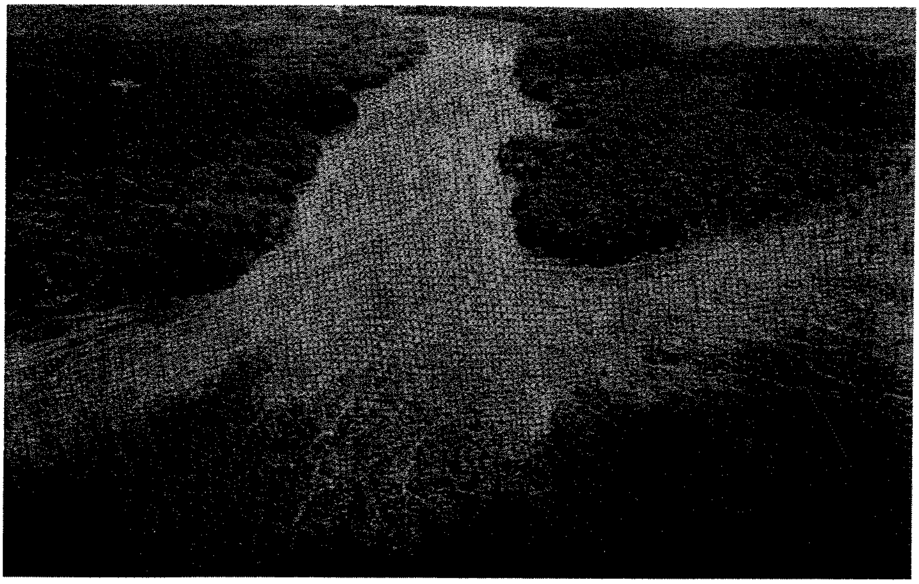

Fig. 2. Aerial view of the Pen Branch corridor prior to restoration (Nelson, 1980)

gies were formulated to address the differing conditions of the Upper Corridor, Lower Corridor, and the Delta regions of the impacted area (Fig. 1). Site preparation began in 1992 and planting followed in the lower corridor during Feburary and March of 1993 (Table 1). The upper corridor and the delta were planted in January of 1994 and January and Feburary of 1995, respectively. Portions of the upper and lower corridors were replanted in 1995 to compensate for mortality (Dulohery et al., 1995). Approximately 25% of the restoration area was reserved for nontreated, nonplanted control strips (Nelson et al., 2000).

Approximately 8700 seedlings were planted in the lower corridor (16 ha) at a target density of 747 trees ha^{-1} without any site preparation. The upper corridor (24 ha) was planted after the application of a wetland-approved herbicide and a prescribed burn, also at a target density of 747 trees ha^{-1}. Herbicide application and prescribed burning were performed to control a dense black willow (*Salix nigra)* overstory and to clear brush and vines from the planting area. The delta (12 ha) was planted after the application herbicide, without burning, at a target density of 1078 trees ha^{-1}. Replantings in the upper and lower corridors were performed at a density of 1078 and 549 trees ha^{-1}, respectively. Tree species included in the plantings were overcup oak (*Quercus lyrata),* swamp chestnut oak *(Quercus michauxii*), nuttall oak (*Quercus nuttallii*), willow oak (*Q. phellos*), cherrybark oak *(Quercus pagodaefolia),* water hickory (*Carya aquatica),* persimmon (*Diospyros virginiana),* green ash (*Fraxinus pennsylvanica*), sycamore (*Platanus occidentalis),* swamp blackgum *(Nyssa sylvatica* var. *biflora*), water tupelo *(Nyssa aquatica),* and baldcypress *(Taxodium distichum*). Species composition and selection were based on the hydrological gradient from the upper corridor to the delta.

Because of the operational design of the restoration project, a research program was developed to document ecosystem response. Information pertaining to the impact of disturbance and effects of restoration on Pen Branch were evaluated through studies that examined the following parameters: stream hydrology, seedling survival and competition, aquatic insect community dynamics, revegetation techniques, fish ecology and stream habitat, autotroph and macroinvertebrate characterization, organic matter decomposition and nutrient mineralization, and terrestrial vertebrate distribution. In most of these studies, measurements were made in both the restored system and in one or more minimally disturbed reference systems (Meyers Branch, Upper Three Runs Creek and Tinker Creek). Some studies also included control systems (Fourmile Creek and Steel Creek), which experienced a thermal impact similar to that of Pen Branch, but were hydrologically restored at an earlier date. Findings from many of these research efforts were presented at the Pen Branch workshop. The highlights and key points of the workshop are detailed in the following sections.

2. Hydrology

Water levels in the Savannah River Swamp are influenced by the stage height of the Savannah River, local drainage, groundwater seepage, and inflows from four tributaries; namely, Beaver Dam Creek, Fourmile Creek, Steel Creek, and Pen Branch. The ability to predict water levels within the swamp was deemed necessary for the development of a restoration strategy for Pen Branch, particularly for the selection of suitable vegetation species. Chen (1999) discussed the use of the TABS-MD modeling system to evaluate water levels and hydrological influences in the swamp. Based upon boundary conditions from sediment transport, roughness coefficients, in-channel flow, and groundwater flow, water levels in the swamp were predicted for a range of flow conditions in the Savannah River and discharges from Pen Branch. Subsequently, the model provided a more precise indicator of flooding susceptibility within the restoration area.

Kolka et al. (2000a) examined the hydrologic conditions in a restored section of Pen Branch, two disturbed but recovering systems, and in the Meyers Branch reference site to evaluate the influence of restoration on hydrology. Water table elevations in the uplands and bottomlands of the reference site were found to be significantly higher than that of the disturbed sites. Throughfall and evapotranspiration were elevated in the reference system over that of the naturally recovering sites, and to an even greater extent over the restored area. Enhanced canopy closure across the successional gradient is likely responsible for these differences. Results from the study indicated that the industrial hydrology effect is still impacting Pen Branch, but the system appeared to be rebounding. Kolka (1999) noted that restoration of the natural hydrology cannot be fully achieved until lost soil functions and properties are regained.

3. Vegetation establishment and competition

Vegetation studies were performed in the Savannah River Swamp and adjacent watersheds to assess reforestation efforts and to identify parameters which may benefit future restoration activities. McLeod et al. (2000) examined the use of 24 tree species for restoring a bottomland forest in the thermally impacted Fourmile Creek. Results indicated that only the most flood-tolerant species, such as baldcypress and water tupelo, were capable of surviving in areas occasionally inundated with 1-2 m of water. Green ash, water hickory and overcup were also found to exhibit high survivability (> 90% in one experiment), but only in sites that were not permanently flooded. Three additional oak species (*Q. michauxii*, *Q. nuttallii*, and Q. *phellos*) were shown to have good survival in areas with a slightly higher elevation. Survival of the least expensive planting stock, bareroot saplings, was nearly equivalent to that observed for balled and burlapped trees. However, McLeod warned that the bareroot stock height must exceed that of the water level during the growing season. In addition, operational problems associated with excessive root pruning and the mishandling of stock under such unfriendly (mucky) conditions may have resulted in some losses. Tree shelters were recommended in areas with high herbivore pressure, but other silvicultural techniques, such as fertilization or herbicide application, were not deemed necessary. When asked what was responsible for the lack of effect when the herbaceous competition was controlled, McLeod (1999) suggested that algae accumulation on herbaceous vegetation while flooded would weigh down the herbs and reduce the deleterious influence on tree growth.

The use of tree shelters in Pen Branch was examined to assess the effect of herbivory on reforestation and to further identify measures for the enhancement of seedling survivability. Seedlings of baldcypress, water tupelo, swamp blackgum, and green ash were planted in four areas within the Pen Branch delta. Fifty percent of the seedlings were protected with 1.5-m tall tree shelters. After 5 years, Conner et al. (2000) reported survival rates from 67 to 100% for seedlings in tree shelters and 2-90% for those without the shelters. High mortality of the seedlings without tree shelters was attributed to beaver damage. Resprouting of baldcypress seedlings that were clipped by the beavers was observed, and the new shoots often exceeded growth levels exhibited by undamaged plants. However, seedlings of other species tended to die once clipped. Elevated height by sheltered seedlings was detected during the first year, but growth differences declined thereafter such that the two groups were approximately equal by the fifth year. Although the use of tree shelters will add to the cost of reforestation (approximately $2 per tree), Conner (1999) suggested that the shelters not only provided excellent protection from herbivory, but also aided in reducing competition effects from herbaceous plants. Moreover, the use of shelters to increase survivability in sensitive or important areas, such as the stream banks, may justify the extra expense.

Dulohery et al. (2000) examined the effect of an undisturbed, partially thinned, and completely removed black willow canopy on four bottomland tree species (green ash, baldcypress, swamp chestnut oak, and water tupelo) that were planted in the Pen Branch and Fourmile Creek corridors. Seedlings in the control area (willows remaining) exhibited elevated growth during the first year, but treatment differences were not evident in the following 4 years. Alterations to the willow canopy also had no effect on seedling survival, however, mortality differences between the selected species was observed. By age 5, over half of the baldcypress and green ash seedlings were alive, while most of the swamp chestnut oak (73%) and water tupelo (83%) had perished. Dulohery (1999) noted that the high mortality may be attributable to the use of genotypes that were not well suited for growth in the study area, or possibly to herbivory. The influence of an intact willow canopy on hydrology, soil temperature, and herbaceous competition may have provided some ‘nurse crop’ growth benefits during the first 2 years. As a result, Dulohery suggested that overstory competition should not be removed until after the second growing season.

The status of canopy coverage and macrophyte abundance in treated (restored) and untreated sections of Pen Branch, a naturally recovering section of Fourmile Creek, and in two relatively undisturbed reference streams (Upper Three Runs and Meyers Branch) were evaluated by Fletcher et al. (2000). Results indicated that the level of canopy cover increased across the successional gradient. A fully open herbaceous canopy was observed in the Pen Branch treatment section, while the post-thermal control systems exhibited a moderately closed canopy of herbaceous plants, shrubs, and willows. The undisturbed systems, on the other hand, displayed a relatively closed hardwood tree canopy. The aquatic macrophyte abundance in these systems was inversely related to the degree of canopy closure. For example, macrophyte abundance was highest (82% coverage) in the Pen Branch treatment system, which had the least amount of canopy coverage, and lowest (< 2%) in the fully closed reference sites. However, canopy closure in the control section of Pen Branch was higher than that observed in Fourmile Creek, which exhibited a lower macrophyte abundance. This may be explained by the presence of submergent macrophytes in Pen Branch that were absent in Fourmile Creek. Fletcher (1999) also suggested that differences in seed dispersal within the two corridors may reflect macrophyte abundance. In addition, differences in canopy closure in the controls may be indicative of a successional change from the dense willow species in Pen Branch to the more sparse river birch found in Fourmile Creek.

4. Instream fauna

An assessment of the recovery status of the lower food chain community in Pen Branch was discussed by Lakly and McArthur (2000).

Macroinvertebrate faunal assemblages (using natural substrates), organic matter availability, and instream structural complexity were examined in Pen Branch, both above and below the zone of thermal impaction, and in Meyers Branch. The study revealed that the abundance and diversity of the lower food chain community has recovered substantially since cessation of the thermal effluents. However, the resultant communities remain structurally and functionally distinct due to the differences in instream structural components and energy inputs in each stream. In Pen Branch, the macroinvertebrate community relied on the high densities of aquatic macrophytes, while the communities in Meyers Branch were associated with high concentrations of coarse woody debris. Pen Branch also differed from the reference streams in morphometry, canopy cover, litter inputs, and floodplain interaction, which resulted in distinct compositions of macroinvertebrate species and instream habitat.

Comparisons between the current conditions at Pen Branch and those observed 15 years after thermal effluents ceased in Steel Creek; however, revealed that the systems are distinct from the reference system in form and function but on similar trajectories for recovery (Kondratieff and Kondratieff, 1985; Lakly and McArthur, 1999). Notably, Lakly and McArthur (2000) found that the functional differences between the systems were not detected using popular biotic indices; however, the relative distribution of functional groups across streams was useful in determining differences in resource utilization and processing by stream biota. When asked whether or not coarse woody debris should be added to the impacted stream as a method to advance the restoration process, the speaker replied with an acknowledgment of its potential benefits as a substrate material, but warned that it may invoke some deleterious side effects to the stream hydrology. Moreover, she reiterated that the distinction between macroinvertebrate abundance and diversity and their function in the ecosystem should be important to establishing relevant mitigation plans and endpoints for future restorations.

Parker et al. (1999) also examined macroinvertebrate recovery and similarly indicated an increased species abundance and diversity in Pen Branch over that observed in Meyers Branch. Parker noted that that the insect community within Pen Branch meets the definition of being ‘restored’, but cautioned whether stream communities provide an accurate metric for the measurement of restoration success.

Fish assemblages in Pen Branch, Fourmile Creek, Upper Three Runs Creek, and Meyers Branch were examined to assess differences between the recovering and undisturbed streams, and to determine if such comparisons could be used as a metric for the evaluation of restoration success. Nonparametric multivariate statistical methods and the Index of Biotic Integrity (IBI) were employed to identify potential differences in fish assemblage structure. Lesions, malformations, and parasites on individual fish species were also recorded as an indicator of ecosystem health. Significant differences in fish assemblage structure between the recovering and disturbed streams was demonstrated using the multivariate techniques. An elevated species density, a more open canopy, and more aquatic vegetation in Pen Branch and Fourmile Creek may have contributed to the differences. With the exception of one section of Fourmile Creek, however, the IBI did not differ between the recovering and disturbed sites. Streams that were in early stages of succession displayed IBI values that are normally found in intermediate to mature communities. According to Reichert et al. (2000), results indicate that the impacted systems may be considered ‘healthy’ in their present state of recovery even though development is not yet complete. Reichert also indicated that a combination of multivariate and IBI techniques may provide a more accurate representation of restoration success than either technique alone.

5. Terrestrial vertebrates

An assessment of the diversity and abundance of reptile and amphibian species in unplanted and planted sections of the Pen Branch corridor, and in adjacent unimpacted riparian zones was evaluated. During the period of thermal effluent discharge from the reactors, the Pen branch corridor likely supported no reptile or amphibian species. However, over 12 000 individuals representing 72 species were captured in the 21 month survey that occurred approximately 8 years after the thermal discharges had ceased. Amphibians comprised a majority (≈ 85%) of the captures, and recapture of all species was limited (12%). Successful reproduction was documented for 48 species (67%), which indicated that the wetland was functioning as a suitable habitat for these individuals. Results also suggested that the planting regimes and treatment design (burning or herbicide application) had little influence on herpetofaunal species assemblage. However, the unimpacted riparian zone supported a more diverse population of amphibians and reptiles than the corridor. Hanlin (1999) attributed these differences to the enhanced canopy cover and litter accumulation found within the riparian zone, and noted that the species will likely migrate as the plant community within the corridor further develops into a mature forest.

The effect of restoration on breeding bird communities in undisturbed (control), partially thinned and replanted, and completely removed and replanted sections of the upper and lower Pen Branch corridor were examined. During the 2-year study, no significant differences in the avian communities were observed among the Pen Branch treatments. Dead vegetation, new herbaceous growth, and some scattered hardwoods, however, provided many singing perches and nesting sites in the upper corridor treatment sections. According to Buffington et al. (2000), Indigo Buntings (*Passerina cyanea*) preferred these sites over the control plots, while the White-eyed Vireos (*Vireo griseus*) and Red-winged Blackbirds (*Agelaius phoeniceus*) were found to be more prevalent in the lower corridor and control areas. Censusing in later successional bottomland areas (Steel Creek and Tinker Creek) was also performed to provide an index of species expected to occur in Pen Branch as the vegetation community develops. From this research, Kilgo (1999) noted that species richness and diversity increased along the successional gradient, but abundance was negatively related to forest age. Pen Branch was dominated by short-distance migratory birds, while Tinker Creek was primarily occupied by neotropical migratory birds. The mid successional Steel Creek (20 years older than Pen Branch and 30 years younger than Tinker Creek) exhibited a mixture of both migratory groups. Thus, avian diversity and abundance is expected to change as the Pen Branch forest matures.

The influence of wetland restoration activities on small mammal populations has not been widely examined. However, monitoring of mammal populations within these systems may prove to be a useful indicator of ecosystem health and restoration success, since these animals eat plants and are themselves eaten by larger carnivores. Hence, live trapping of small mammals was conducted on six transects at Pen Branch and three transects at Meyers Branch to evaluate community dynamics in response to the restoration effort. The rice rat, cotton rat, wood rat, and cotton mouse exemplify species that were frequently caught using the employed trapping procedure. Of these species, only the rice rat primarily occupies wetland areas, however, both the wood rat and cotton mouse utilize bottomlands and swamps. Even though habitat use and movement differed among the species, no significant differences were found in capture rates between treatment types and among transects of a particular stream. Wike et al. (2000) indicated that the proximity of transects to each other may have been too small to fully encompass the habitat range of these species.

Fliermans et al. (1999) further examined the before-mentioned small mammal population in an effort to assess microbiological diversity in the impacted and relatively undisturbed stream systems. Microbiological samples from 296 specimens collected at 18 traps in Meyers Branch and 46 traps in Pen Branch were analyzed using Biolog™ technology for the identification of bacteriological isolates. Results indicated that a greater diversity of bacterial species were found in the cotton mice, than in rice rats or wood rats. The data also indicated that the rodents in Meyers Branch were host to a greater diversity of pathogens than those from the Pen Branch area. The differences are likely attributable to the vegetative variation between the systems, which comprise the rodent's diet. Diversity differences between the sites could converge if the Pen Branch system matures to a state similar to that currently found in Meyers Branch.

6. Soils and carbon

Organic carbon is considered to be a key energy source for forested ecosystems. Carbon accumulation within the soil is derived from litter fall, root turnover, and microbial organisms. Understanding spatial and temporal biotic-abiotic interactions within a riparian forest may provide insight into past disturbance activity and may also be used as an indicator of functional recovery. Giese et al. (2000) examined carbon storage patterns in Pen Branch, Fourmile Creek, and Meyers Branch to evaluate the role of successional status and micro-topography on riparian ecosystem restoration. Results showed that the mean productivity between each of the riparian forest and associated uplands were not significantly different. Although productivity did not differ across the successional gradient, Giese (1999) pointed out that qualitative differences between the systems reveal that functional recovery has not been fully achieved. Soil carbon was found to be higher in Meyers Branch than the restored Pen Branch system, and bottomland areas generally contained more soil carbon than the adjacent uplands in all systems studied. As expected, organic carbon concentrations in soils increased as soil moisture increased. Although successional processes appear to be moving slowly in the disturbed areas, aboveground biomass and soil carbon data suggest that these systems are advancing toward conditions exhibited by the later successional forests.

Wigginton et al. (2000) examined the processes responsible for soil organic matter formation, carbon sequestration, and soil structure development across a successional gradient. Results indicated that forest floor organic matter increases rapidly during early succession, but declines thereafter. The composition of forest floor material was shown to change from a herbaceous dominated system in early succession (Pen Branch) to one consisting primarily of woody foliage in later stages (Meyers Branch). Aggradation of soil carbon was observed in the thermally impacted systems, however, regressional analysis indicated that it would require over 30 years before Pen Branch soils reached carbon levels equivalent to 50% of that currently found in Meyers Branch. Soil structure characterization also exhibited differences across the successional gradient. Pen Branch was found to have a disproportionate percentage of microaggregates than the later successional sites, but Wigginton (1999) pointed out that microbial influenced macroaggregate formation is likely to increase as a result of the high organic matter concentrations found in Pen Branch.

7. Implications for riparian wetland restoration: attendee perspective

Following the workshop, a questionnaire was distributed among the attendees to provide them with an opportunity to further evaluate the restoration project and to contribute additional insight that may not have been captured in the presentations and/or journal articles. The following is a synthesis of responses and common themes from the questionnaire. Although a consensus was not achieved for each question, the responses reflect the multitude of personal opinions and uncertainties associated with a project of this magnitude from both a management and ecological standpoint.

7.1. What were the lessons learned from the Pen Branch Restoration?

7.1.1. Major problems

- The site itself represented one of the major obstacles encountered by all researchers. Limited accessibility to research plots combined with the complications associated with performing research in an often uncompromising area added significantly to the time required to perform simple tasks. Plot development and sampling strategies often had to be altered or customized to overcome these unexpected difficulties and likely had a profound effect on the final results of the study.

- Beaver damage to planted seedlings proved to be a major factor in seedling survival rates. The degree of herbivory observed at Pen Branch was not anticipated, however, valuable information pertaining to site preparation techniques was gained as a result of the destruction.
- Inclusion of Steel Creek as a middle succession site and the use of larger unplanted 'control' areas may have provided valuable information to further assess the role of parameters such as carbon cycling, nutrient availability, and hydrology on reforestation. Increasing the size of treatment and control areas may also have benefited studies on terrestrial vertebrates. With few exceptions, the normal ranges of movements of these animals (reptiles, amphibians, mammals, and birds) are such that no individual would have a territory confined to the limits of one of the plots. Thus, habitat differences between the control and experimental zones were difficult to ascertain.
- The hydrologic characteristics of Pen Branch have become very unpredictable due to flood control dams on the Savannah River and streambed disturbances from past reactor operations. Uncertainties associated with the current hydrology forced a conservative approach to restoration, which may have been restrictive to the restoration effort.
- The acquisition of appropriate planting stock (genotypes, size, species) was also problematic for an operation of such magnitude.

7.1.2. Aspects overlooked

- Tree shelters should have been used in areas considered sensitive or important.
- The role of natural seed dispersal methods to assist colonization of gaps that exist in the stream deltas was not examined.
- Characterization of the soil/litter microbial community may have provided useful information on decomposition at different successional stages.
- More detailed hydrology and soils data (pre- and post-restoration) could have aided our development of planting strategies and provided insight into the degree of disturbance and post restoration recovery.
- Although not anticipated, examining the influence of herbivory on seedling survival may have resulted in valuable information pertaining to the revegetation effort.
- A thorough study examining the effects of coarse woody debris (CWD) in bottomlands and streams, and the influence CWD has on structural stability, carbon and nutrient cycling, and biota could have provided some insight into community structure at different stages of succession.

7.2. What do we expect Pen Branch to look like in 50 years?

- From a vegetation standpoint, responses to this question were highly varied and ranged from a marsh-like system with scattered trees to that of a mature forest. A consensus was apparent, however, that the degree of disturbance to the soils and unpredictable nature of the hydrology will likely influence species composition and recovery rates. The appearance of canopy gaps is anticipated in the Delta where reestablishment of species is not fully achieved.
- In respect to overall diversity of terrestrial vertebrates, the vegetative species necessary to support a fauna similar to that of Meyers Branch is currently existing in the Pen Branch corridor such that the two systems would likely function similarly in 50 years.
- Studies of soil carbon show that more carbon is being added to the soil in disturbed systems over that of the reference. Through incorporation and time, soil carbon levels will eventually resemble that of the mature forest. Based upon the studies presented at this workshop, soil carbon and nitrogen in Pen Branch may reach approximately 75% of the reference level (Meyers Branch) in 50 years.
- Although a wide diversity of herbaceous species are present in the Pen Branch delta, tree species diversity is limited and may remain so due to the wet conditions and limited topographical variation.

- Assuming that the Pen Branch riparian zone continues to develop at a rate similar to the present, increased instream shading and subsequent alterations in instream structure should result in a reduction of aquatic macrophytes and associated macroinvertebrate communities.

7.3. What are our recommendations for the future of this and other restoration projects?

- Utilize the lessons learned from this experiment and identify the techniques and metrics which were vital to the outcome of the restoration. From these parameters a comprehensive package for future restorations and long-term monitoring can be established in a much more efficient and cost effective manner.
- Given the influence of herbivory on seedling success, planting is a necessity in order to restore the Pen Branch delta to forested conditions. The use of tree shelters and vegetative species of a genotype suited for the particular environment may enhance restoration success.
- Periodic reexaminations of the sites and some scaled-down monitoring will be beneficial in maximizing the information obtained to date, and as a method of continuously reevaluating ecosystem function in the restored system.
- Other restorations may benefit by applying the specific techniques and metrics which were deemed essential in the Pen Branch restoration. On the other hand, parameters that remain a mystery, such as the influence of hydrology and water quality on vegetation reestablishment, will require further examination and should be scrutinized in future restoration projects.

7.4. Are we naïve in our use of Meyers Branch as a reference wetland, and in our expectation to reach an endpoint similar to that of the reference system?

- According to McLeod (1999) an endpoint will be reached, the question remains as to whether this endpoint is desirable. Any endpoint will provide some degree of ‘services’. The endpoint ecosystem will provide some services different than the pre-SRS ecosystem, but maybe these services will be more beneficial than those previously provided or might have been provided by the undisturbed ecosystem. As such, we are not even sure what the undisturbed ecosystem would have looked like if the SRS never existed. The appropriate question may not be ‘will it look and function like Meyers Branch?‘, but instead ‘does it look and function like we want it to?’ The reason for rephrasing the question differently is that the Meyers Branch model may not give us the services we currently desire. We do not currently build cars to look and work like they did in 1950, we build them to provide the features that we currently think are important. So we may have to add features if the system does not provide the services we want, but first we must decide what those services are.
- Meyers Branch may not be the perfect reference, according to Kolka (1999), but it was the most representative system onsite or in the vicinity of Pen Branch. A better reference would have been Fourmile or Steel Creek if unimpacted, since they reside at a landscape position more similar to Pen Branch. All things considered, however, both were fine controls as points on the succession continuum. From an animal and plant perspective, Meyers Branch was an excellent reference. From a hydrology, soils, carbon and nutrient cycling perspective, a better site may have been utilized. Small differences in landscape position can likely have a drastic impact on energy inputs resulting in varying soil development and hydrology. Wigginton (1999) suggested that similarities in soil morphology and taxonomic classifications between the soils in the two systems make Meyers Branch an acceptable reference system. If the forest canopy was removed in Meyers Branch, soil carbon levels would likely change to resemble those observed in the disturbed system.
- The choice of Meyers Branch was pragmatic and not naïve, according to Martin (1999), so long as we admit that localized conditions may have effects for which we cannot account. If we had several comparison sites available (not

truly controls but as close as we can get) we might have been able to pick out the localized conditions which lead to differences. However, having no experimental replicates, we have no idea about the variance or sources of variance there which might mask or emphasize differences between the experimental and control systems.

- According to Lakly and McArthur (1999) addressing the concepts of the desired endpoint, Meyers Branch as a reference system, and appropriate species in our recommendations is vital. Care should be taken not to insinuate that our only goal is the creation of a carbon copy of Meyers Branch with exactly the same species and metrics. A more appropriate goal would be the re-establishment of an evolving, dynamically stable, self-sustaining, functionally diverse system that is well adapted to its current hydrologic regime and inputs. This concept allows for successive changes in metrics like macrophyte biomass, riparian development, bank stability, and biotic function in relation to current capacities and developmental histories (Ebersole et al., 1997). Additionally, by combining this with our other goals of restoration, we incorporate our current characterization of the ecological effects of thermal effluent while indicating which response variables may be important indicators of future recovery.

8. Conclusion

Information from the above studies will be utilized in developing a quantitative assessment method for evaluating riparian wetland restoration success (Kolka et al., 2000b). It is evident from the research that Pen Branch is currently functioning as a viable wetland. The degree of function and level of recovery, however, is subject to debate. By utilizing biotic and abiotic metrics obtained from research in hydrology, soils, vegetation, carbon and nutrient cycling, and faunal communities, predictions of wetland function in response to the restoration activity may be ascertained. As succession proceeds and research continues in the restored and relatively unimpacted reference sites, information shall be accumulated to validate our predictions and further contribute to the development of this assessment procedure. As a consequence, these efforts may serve as a template for future wetland restorations.

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