DEVELOPMENT OF AN ASSESSMENT FRAMEWORK FOR RESTORED FORESTED WETLANDS

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Abstract

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. An interdisciplinary approach was developed to assess how succession is proceeding on a restored bottomland site in South Carolina relative to an undisturbed reference and a naturally agrading site. Comparisons of populations and processes across successional gradients and treatments allows the effect of disturbance and restoration activities to be evaluated. Studies involving vegetation communities, organic matter and nutrient dynamics, seedling establishment and competition, and avian, herpetofauna, fish and macroinvertebrate communities have been implemented. Seedling establishment and competition studies suggest nonchemical and minimal mechanical site preparation techniques, tree shelters and root pruning should be considered as alternatives depending on restoration objectives and site conditions. The restored site contains many of the functional capabilities of a wetland with respect to fauna, however certain species tend to dominate populations in Pen Branch when compared to late successional wetlands. Fish populations show higher population densities in the restored site as compared to the reference site. A conceptual framework for integrating biotic and abiotic processes into a restoration response model will be used to synthesize ecosystem response and to identify indicators for restoration assessments.

Introduction

Wetland restoration involves re-establishment of wetland conditions and processes on a site in such way as to provide the basis for a self-sustaining vegetation community (D'Avanzo 1990; Niering 1990). Typically this is accomplished by characterizing the hydrology and soil conditions on the site and prescribing appropriate plant species (Davis 1994). Determining whether the project is a success with respect to the restoration goal is difficult to determine when the assessment period is short (e.g. 1-3 years) and indicators of desired wetland conditions or processes for recently established sites have not been developed (Clewell and Lea

1990). The common success criteria for restoration' Projects is survival of plant species. However, early survival measurements do not necessarily reflect future composition of the vegetation community on the site (Clewell and Lea 1990), nor are they a predictive indicator of the efficacy of the restoration project with respect to restoration goals involving other 'desired- wetland' conditions, like wetland plant community composition, hydrologic regime, or water quality enhancement (Erwin 1990; Niering 1990; Bartoldus 1994).

The approach that we propose is a comparison of important ecological parameters and processes on a restored site to norms established in mature and agrading wetlands. The approach measures conditions over time (stage of development) and is used to assess the effectiveness of attaining the desired wetland conditions (e.g. restoration objective). Our objective is to evaluate if the restored system is on the planned trajectory toward a recovering forested wetland. Accordingly, we are assessing whether the rehabilitated wetland has conditions that one would expect from a naturally agrading forested wetland. To accomplish this objective we compare sensitive indicators of wetland conditions in the restored, agrading, and mature forests. Those indicators are:(a) the relationship between hydrologic regime and vegetation community composition, structure and productivity; (b) stream morphology, aquatic community composition, riparian zone water quality; (c) organic matter decomposition' and nutrient dynamics; (d) fauna1 community comparisons. This study is ongoing and here we present, in most cases, preliminary results.

Study Site

For over thirty years the bottomland hardwood system of the Pen Branch corridor and delta was used for the discharge of coolant water from a nuclear reactor at the Savannah River Site (Figure 1). Prior to reactor placement, flow in Pen Branch was typically 0.28-0.57 m^3 s^- (10-20 cfs).' Reactor. operations raised the flow to as much as 11.3 m^3 s^{-1} (400 cfs) with secondary coolant water temperatures ranging from 40-65 °C (100-150 °F) (Nelson 1996). When the reactor was retired in 1989, this high-temperature, elevated flow effluent had removed virtually all vegetation and eliminated the seed bank and root stock from the previous bottomland hardwood wetland (Figures 2 and 3). Once the thermal discharges ceased, a narrow range of early succesional species including black willow *(Salix nigra)*, smooth alder *(Alms surrulata)*, wax myrtle *(Myrica cerifera)* and buttonbush *(Cephalanthus occidentalis)* took advantage of the exposed mineral soil conditions and colonized the area aggressively. Dispersed by wind and water, these light-seeded species quickly became established, and dominated the floodplain corridor and delta.

Figure 1. Location and treatment areas of Pen Branch Creek and other bottomland systems involved in **wetland** restoration studies on the Savannah River Site.

Figure 2. Aerial photo of Pen Branch prior to thermal disturbance (1943). Note the mature bottomland hardwood community in the floodplain corridor. (Photo courtesy of the Savannah River Archaeological Research Program).

Figure 3. Aerial photo of Pen Branch showing the damage of thermal effluents. (Photo by Westinghouse Savannah River Company).

In total, thermal discharges affected 236 ha (583 acres), including 88 ha (218 acres) in the riverine floodplain and 148 ha (365 acres) in the delta. Assessment of natural regeneration found approximately 99 ha (245 acres) in the lower delta fringe and 48 ha (118 acres) in the uppermost part of the watershed to be sufficiently stocked with desirable bottomland species. The Forest Service monitored the remaining 49 ha (120 acres) in the delta and the 40 ha (100 acres) in the riverine floodplain for three years. Virtually no natural regeneration of desirable bottomland tree species occurred.

Results from investigations in Pen Branch are compared, in most studies, to agrading and/or mature bottomland communities. Two agrading communities are found on the Savannah River Site, both had thermal impacts from the operation of a nuclear reactor similar to that of Pen Branch. Fourmile Creek has been in natural recovery since 1985 while Steel Creek has been in recovery since 1968. Three mature bottomland forests have been considered in studies. These three bottomland systems, Meyers Branch, Upper Three Runs and Tinker Creek, have never received thermal effluents.

Materials and Methods

In this paper we are summarizing the results of 13 studies. Materials and methods will be briefly summarized, when appropriate, for individual studies in the results section. More in depth materials and methods for individual studies can be found in the references cited (Kolka and Trettin 1997). Here, we will summarize those methods used to artificially regenerate Pen Branch.

Artificial regeneration efforts began in 1992 and were concentrated on the 89 ha (220 acres) that were most severely affected by the thermal discharges. The goal was to plant seedlings in sufficient numbers and diversity to allow the development of a mature bottomland hardwood forest in the stream corridor and a cypress-tupelo forest in the delta.

To assess the effect of active intervention, only 75% of the entire area was planted. The remaining 25% of the area was left as unmanipulated and unplanted control strips and were located between planted areas (Figure 1). Desirable bottomland species were planted using various site preparation techniques depending on site conditions (no site preparation, herbicides, herbicides+burning). Although some valuable information came from using the various site preparation techniques, they were not considered as treatments, only as the most appropriate technique for the establishment of seedlings. Seedling species for planting were selected based on soil type and expected hydrology in the floodplain corridor and delta. Following each planting, surveys were conducted to monitor survival and growth (Dulohery et al. 1995); areas understocked were replanted in the winter 1995-1996. The 1992-1996 plantings included green ash (*Fraxinus pennsylvanica*), sycamore (*Platanus occidentalis*), cherrybark oak (*Quercus falcata* var. *pagodifolia*), swamp chestnut oak (*Q. michauxii*), water oak (*Q. nigra*), shumard oak (*Q. shumardii*), water tupelo (*Nyssa aquatica*), swamp tupelo (*N. sylvatica* var. *biflora*), persimmon (*Diospyros virginiana*), water hickory (*Carya aquatica*), pignut hickory (*C. glabra*) and baldcypress (*Taxodium distichum*). In total, the upper Pen Branch corridor received approximately 1825 seedlings ha^{-1}, the lower corridor 1296 seedlings ha^{-1} and the delta 1078 seedlings ha^{-1} (Dulohery et al. 1996).

Results

Veaetation Establishment

Results of a seedling survey conducted in 1996 indicated good survivalship of planted seedlings. The upper Pen Branch corridor averages 716 $\pm$ 158 stems ha^{-1} (290 $\pm$ 64 stems ac^{-1}, mean $\pm$ standard error), the lower corridor 555 $\pm$ 109 stems ha^{-1} (225 $\pm$ 44 stems ac^{-1}) and the delta 1358 $\pm$ 198 stems ha^{-1} (550 $\pm$ 80 stems ac^{-1}) of desirable species (Kolka and Trettin 1997). Approximately 12% of the desirable stems counted were species that had not been planted, most notably red maple and sweetgum (*Liquidambar styraciflua*). These stocking levels compare favorably to a nearby mature bottomland hardwood community (Upper Three Runs) with 593 stems ha^{-1} (240 stems ac^{-1}) (Keeland and Sharitz 1995).

Herbaceous competition can effect seedling survival and growth (McKevlin and Dulohery 1997). Initial results from studies addressing the effect of herbaceous competition on growth and survival of seedlings indicate that the four overstory competition control treatments (no control; intermediate control, stems left in place; complete control, stems left in place; and complete control, clearcut) resulted in significant differences in 1) diurnal fluctuations in depth to the water table, 2) light environment of the seedlings both in terms of quantity and quality,. and 3) biomass of herbaceous competition. Larger diurnal fluctuations in the water table are found in treatments where the willow canopy was undisturbed. As expected, light transmittance is directly related to the level of canopy manipulation in the treatments. Greater light transmittance in the clearcut plots has led to greater herbaceous competition in these plots. Analysis of seedling height growth and survival data is currently being conducted. Initial results suggest differences in both height growth and survivalship among species and among treatments. It appears that a sparse to moderate willow canopy can ameliorate the stresses of growth limiting hydrology and herbaceous competition and be beneficial to the establishment, growth and survival of tolerant bottomland hardwood species. Future reforestation efforts in bottomland hardwood wetlands should consider alternative site preparation techniques that minimally alter the early successional vegetation.

In the Pen Branch delta the feasibility of planting wetland species was examined (Conner et al., 1996). Species chosen for planting were baldcypress, water tupelo, swamp tupelo and green ash. On four sites seedling roots were pruned to compare responses to non-pruned roots. Additionally, tree shelters were placed on a portion of the seedlings to evaluate effects on seedling response. Differences between root pruned and non-root pruned seedlings were variable depending on the species and area in which they were planted. Highest survival was found for baldcypress and water tupelo. Root pruning does not seem to significantly affect growth of these species, and in some cases may stimulate root growth. With enough sunlight, root pruned seedlings could be used to revegetate disturbed swamp areas where natural regeneration has not occurred. Tree shelters significantly improved survival and height growth of all four species. Although tree shelters may be cost prohibitive on a large scale project such as the Pen Branch reforestation, they may be cost effective in areas where seedling establishment is deemed critical. If stream stabilization and stream community recovery are primary restoration objectives, assuring seedling survival adjacent to streams with tubes may be a viable alternative. In a relatively short period of time, these seedlings will stabilize the banks and provide the light conditions necessary for stream biota recovery.

To assess physiological and morphological responses of seedlings to flooding, baldcypress, water tupelo, swamp tupelo and green ash seedlings were planted in the Pen Branch delta (Rozelle and Hook 1996). Seedlings were lifted from plots at periodic intervals and roots were tested for viability with tetrazolium dye and activity with alcohol dehydrogenase (ADH). Staining by tetrazolium dyes suggested that a smaller percentage of green ash roots were alive than the other three species. Activity of bald cypress roots averaged about 0.035 units per mg dry weight whereas the other three species averaged less than 0.01 units per mg dry weight. All four species showed a strong seasonal response for ADH activity with the rate being highest in the spring and rapidly decreasing to near zero during late summer. Baldcypress, water tupelo, and swamp tupelo showed recovery of ADH activity in the fall or maintained a low level of activity whereas green ash ADH activity fell to zero in August and did not recover. The combined results suggest that green ash is more susceptible to prolonged flooding than are baldcypress, water tupelo and swamp tupelo. Prolonged soil saturation and inundation are typical conditions in the Pen Branch delta and other stream deltas in the area. Future reforestation in deltas or other areas that experience prolonged floods should choose species that are consistent with these findings.

New studies are currently being initiated to compare vegetation community structure and production among planted and control areas in Pen Branch, Fourmile Creek and Meyers Branch (see later).

Stream Communities

The availability of fast decomposing biomass that is currently in the Pen Branch corridor and stream is leading to high rates of instream fauna1 activity. Preliminary analysis indicates that removal of the low willow/shrub canopy has greatly increased aquatic macrophytes and fish abundance in the Pen Branch planted areas (Fletcher et al. 1997).

The effects of past effluent release on present day fish communities are being addressed using Fourmile Creek and Pen Branch as replicate sites impacted by past thermal effluents and flow augmentation, and Upper Three Runs and Meyers Branch as replicate unimpacted control sites (Fletcher et al. 1997). Preliminary analysis indicates that the impacted steams have a least as many species of fish as control streams, and two to five times the densities of individuals. Even though species richness is similar, distribution of individuals among the species differs greatly. Impacted streams are heavily dominated by a few taxa of fishes, including suckers, mosquitofishes, minnows, and sunfishes, a characteristic of disturbed areas. Unimpacted streams have a more even distribution of individuals among species, characteristic. of more natural sites. Community compositions also differ, indicating a possible change in the functional organization of these communities. Past disturbances appear to be having long-term effects on the community structures in these streams.

Coordinated with fish community studies is an ongoing study addressing stream autotroph and macroinvertebrate populations (Lakly and McArthur 1996). Preliminary results indicate that insect densities in Pen Branch are significantly higher than in late successional systems and those populations are dominated by early successional species (Lakly, personal communication).

Studies are concluding comparing stream structure and morphology among Pen Branch, Fourmile Creek, Meyers. Branch and Upper Three Runs (Reichert and Dean 1997).

Terrestrial Vertebrate Co-

The assessment of avian communities included Pen Branch, Steel Creek and Tinker Creek. Results indicated that there are few differences in the avian community among treatments (Miller and Chapman 1997). However, plots in Pen Branch that were herbicide treated, burned, and planted tended to have greater richness in 1994 and abundance in 1995 ($P < 0.05$). Bird species composition differed slightly among treatments. Abundance of individuals was lower in the Steel Creek bottomland compared to Pen Branch and did not differ between Pen Branch and Tinker Creek. Species richness differed among all sites (lowest in Pen Branch, highest in Tinker Creek). Bird species diversity was greater in the Tinker Creek bottomland compared to Pen Branch. Short-distance migrants and species associated with forest edge/scrub habitats were more common in the early successional bottomland (Pen Branch) compared to the other sites. Neotropical migrants and interior species were most common in the late successional habitat (Tinker Creek).

A small mammal sampling program was conducted in the Pen Branch restoration area during the summer of 1996 (Wike et al. 1997). Trapped animals were identified, sexed, weighed, and ear tagged. One hundred and ninety two traps operating for 18 nights provided 3,456 trap-nights of effort. Four hundred and eight captures occurred for a success rate of 11.8%. Species captured included cotton rats *(Sigmodon hispidus,* **151),** rice rats *(Oryzomys palustris,* **117),** cotton mice *(Peromyscus gossypinus,* **107),** Southeastern short-tailed shrew **(*Blarina carolinensis*, 8),** and single captures of Golden mouse *(Ochrotomys nuttalli),* wood rat *(Neotoma **floridana**),* and Star-nosed mole *(Condylura cristata).* Cotton rats, rice rats, and cotton mice are considered species that are associated with early successional systems (Wike, personnel communication). These species represented 92% of the captures. Currently,. trapping is also being conducted in Meyers Branch to develop data sets for control systems.

A study of recolonization by reptiles and amphibians in Pen Branch was initiated in **1995** (Hanlin and Guynn 1997). A total of 11,802 individual reptiles and amphibians representing 70 species **were** captured in 221,126 trap nights between January 1, 1995, and June 30, 1996. Total captures equaled 13,834 of which 12% were recaptures and 3% escaped. The most frequently captured species was the eastern **narrow-**mouthed toad **(*Gastrophryne* *carolinensis;*** 3601 individuals captured) making up 30.5% **of the** total captures. The other **top** four species captured were: southern toad *(Bufo terrestris;* **19.1%),** southern leopard frog **(*Rana*** *utricularia;* **16.7%),** marbled salamander **(*Ambystoms opacum*; 6.7%),** and slimy salamander **(*Plethodon*** *glutinosus;* 6.02%). **These** five species represented about 79% of the total captures. Of the 70 species captured, snakes were represented by 24 species (524 individuals), anurans by 16 species (8281 individuals), salamanders by 13 species (1818 individuals), turtles by 9 species (459 individuals), lizards by 8 species (718 individuals), and crocodilians by 1 species (2 individual American alligators). Eastern narrow-mouthed toad, southern toad, and southern leopard frog are species that inhabit early successional systems. Like **small** mammals, these species dominated the herpetofauna representing 66% of the captures. Currently, discussions are ongoing to develop data sets for a mature bottomland hardwood system.

Results from terrestrial vertebrate studies indicate the avifauna, small mammal and herpetofauna communities are well established **in Pen Branch.** For some fauna1 communities, it appears that Pen Branch is providing greater opportunity for establishment and survival than in late successional systems. Although species abundance and in some cases diversity are higher in Pen Branch than in mature control systems, the community structure is very different. The initial results suggest -that certain species dominate populations in Pen Branch and the distribution of species is very different than in late successional systems.

Organic Carbon and Nutrient Dynamics

Studies have begun investigating organic carbon and nutrient cycles in Pen Branch, Fourmile Creek and Meyers Branch. 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 have been initiated to examine SOM development by assessing forest floor processes along the successional gradient (Lockaby and Wigginton 1997). Forest floor organic matter mass was found to' increase 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 steadily declined through succession from 74% in the earliest stage to less than 1% in the latest stage of succession. Conversely, the amount of woody foliage increased from 6.7% in the earliest stages of succession to over 70% in late succession. Carbon and nitrogen estimates reflect patterns of increasing concentration during early succession, reaching an equilibrium during the later stages of succession. Carbon and nitrogen ratios were relatively constant throughout all stages of succession, ranging from 41 to 48. Measures of the rate of transformation of litter to soil organic matter using the lignocellulose index were not significantly different between stages of succession. Higher ratios of lignin to lignin+cellulose are predicted in later stages of succession due to the expected increase in a refractory lignin component over time. The hydrologic dynamics of floodplains, in conjunction with the warm climates of the southeastern U.S., may prevent the application of this procedure to studies of succession in floodplain forests.

Studies have begun investigating carbon and nutrient dynamics along the successional gradient of Pen Branch, Fourmile Creek and Meyers Branch (Kolka and Trettin 1997). To perform this study we have separated two main components; 1) carbon and nutrient fluxes and, 2) carbon and nutrient pools. In studies investigating carbon and nutrient fluxes, we are combining hydrologic monitoring with soil water, precipitation, throughfall, and stream water chemistry to determine if carbon and nutrient transport processes vary by successional state.

In a closely related study investigating carbon and nutrient pools, we are assessing both *insitu* pools and the turnover of these pools along the identical successional gradient (Aust and Giese 1997). Within the scope of this study are individual studies addressing net primary productivity, standing biomass, vegetation community structure, soil and forest floor carbon and nutrient content, litterfall production and decomposition, lateral litter transport, instream biomass, and instream litter transport.

The two studies will be integrated to develop a holistic approach to the dynamic processes that affect carbon and -nutrient allocation and transport in bottomland hardwood wetlands. Differences in carbon and nutrient allocation and transport processes among and within systems will be used as one set indicators to establish a framework for wetland restoration effectiveness.

Discussion/Conclusion

For restoration to be considered effective, wetland functions need to be restored or at least on a trajectory where restoration of those functions is probable (Figure 4). The problem arises when predicting the effectiveness of restoration efforts in forested systems because of their longevity. Methodologies need to be developed to predict the effectiveness of restoration efforts within the first few years after restoration. Through the use of naturally agrading systems and unimpacted control systems we expect to develop wetland function response curves such as those shown in Figure 4.

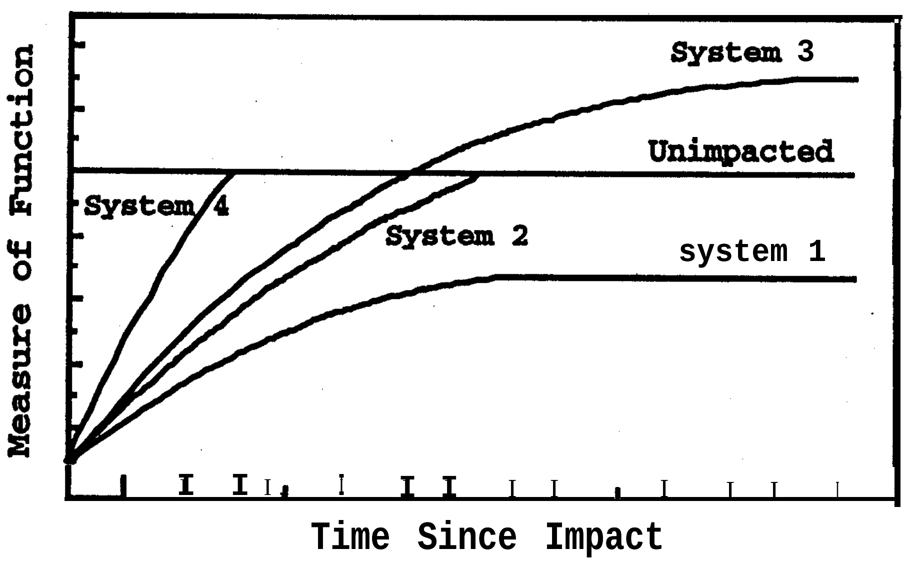

Figure 4. Theoretical response curves of wetland functions after an impact.

Response curves of specific parameters can be variable depending the parameter and the magnitude of the impact (Figure 4). Unimpacted systems have relatively constant rates of providing specific functions over time. If an inherent property of the ecosystem is not restored to its previous state, such as hydrology, we might expect to find some functions to never fully recover (System 1 in Fig. 4). Alternatively, other inherent ecosystem properties may be restored to higher state than in the original ecosystem and may provide more or greater functions after the impact (System 3 in Fig. 1). Although there are a multitude of -response surfaces that different functions can exhibit over time, theoretically we expect functions to agrade over time and, at some point, approach that of the previous unimpacted system (Systems 2 and 4 in Fig 4). By using active intervention strategies such as planting, we expect to accelerate the recovery of wetland functions (System 4 in Fig. 4) when compared to a naturally agrading system (System 2 in Fig. 4).

As shown by the breadth of research being conducted in association with the Pen Branch wetland restoration, the focus is on the assessment of ecosystem level processes that are occurring as succession proceeds. Comparisons of populations and processes across successional gradients and treatments allows the effect of disturbance and restoration activities to be evaluated. Knowledge gained from the above studies will enable future restoration efforts to be more efficiently and effectively performed and evaluated. Once all the results of past, ongoing and planned research are integrated, we will have a holistic view of the biotic and abiotic parameters that have the most promise as wetland function indicators.

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