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Application of the EPA Wetland Research Program Approach to a floodplain wetland restoration assessment

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ABSTRACT

Forested wetland restoration assessment is difficult because of the timeframe necessary for the development of a forest ecosystem. The development of a forested wetland ecosystem includes the recovery of hydrology, soils, vegetation, and faunal communities. To assess forested wetland restoration projects, measures need to be developed that are sensitive to early changes in community development and are predictive of future conditions. In this study we apply the EPA's Wetland Research Program's (WRP) approach to assess the recovery of two thermally altered riparian wetland systems in South Carolina. In one of the altered wetland systems, approximately 75% of the wetland was planted with bottomland tree seedlings in an effort to hasten recovery. Individual studies addressing hydrology, soils, vegetation and faunal communities indicate variable recovery responses. Our recovery trajectories indicate that hydrology may take 20-30 years to recover, soil carbon upwards of 60 years and 20-30 years for forest floor processes. Herbaceous vegetation and stream macrophytes appear to take 20-30 years to recover, however, trees will take considerably longer. Stream fauna appear to recover in about 20-30 years while bird populations are on 40-60 year recovery trajectory. Based on the current data, it appears that both wetland systems are on a path toward recovery and that site preparation and planting of seedlings has not accelerated the recovery process.

Keywords: Wetland, restoration, assessment, bottomland, riparian, succession, soil, hydrology, vegetation, fauna

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Development of assessment methods and associated indicators that can be used to evaluate the effectiveness of a wetland restoration is critical to determining the sustainability of restored sites. Several important constraints are placed on wetland restoration assessment methods, most notably the duration of the assessment and the ease of application (Kolka et al. 2000a). Because of time, resources and technical constraints, most assessments are of short duration and relatively simple to apply. Forested wetland restoration assessment is especially difficult because the development of a forest ecosystem may take decades if not centuries before some functions fully recover, especially those related to the vegetation and habitat.

Most approaches for assessing wetland restoration effectiveness develop indices of wetland function and compare those indices to undisturbed or reference wetlands (Stein and Ambrose 1998). The specific approach depends on the restoration goals, monitoring requirements, resources and available time. Usually the approach either focuses on the physical sciences of hydrology and soil science (e.g. Hydrogeomorphic Approach, Brinson 1993) or on biological sciences (e.g. Index of Biologic Integrity Approach, Karr 1991).

The Wetland Research Program method (WRP) uses field data from reference wetlands and wetlands that have been restored or recovering from disturbance at various time intervals to quantitatively assess recovery of specific ecosystem functions or conditions (Kentula et al. 1992). Alternatively, temporal data on individual wetlands can also be used to assess recovery. Unlike other methods, the WRP method is a quantitative, ecosystem level approach that includes both biotic and abiotic metrics. Response surfaces (Figure 1) are developed to fully characterize the temporal recovery of a wetland function, condition or indicator (Kentula et al. 1992). Metrics are selected to characterize or measure specific functions or conditions. Although considerable spatial variability may exist among reference systems, and temporal variability within a single reference system, in the long-term, the study of reference systems can provide the natural range of

conditions for specific functions over time (e.g. Reference in Figure 1). The amount of variability within the reference range will vary among different wetland properties. If an inherent property of the ecosystem is not restored to its previous state, such as hydrology, we might expect to find some functions that never fully recover (e.g. Response 1 in Figure 1). Alternatively, hydrology may be restored to a higher state than in the original ecosystem and may provide more or greater function after the impact (e.g. Response 3 in Figure 1). Some metrics, such as species richness or diversity of faunal communities, may experience an initial rise above that of the reference state and decrease as time proceeds (e.g. Response 5, Figure 1). Although there are a multitude of response surfaces that different functions can exhibit over time, theoretically we expect functions to recover over time and, at some point, approach that of the unimpacted reference system (e.g. Responses 2 and 4 in Figure 1). Active intervention strategies such as planting are expected to accelerate the recovery of wetland functions (e.g. Response 4 in Fig. 1) when compared to a naturally recovering system (e.g. Response 2 in Figure 1).

The differentiating aspect of the WRP approach is that a wide diversity of ecological functions or wetland conditions that characterize both aquatic and terrestrial components are identified *a priori*, directly measured, and compared to reference conditions. This contrasts to simplistic approaches examining single wetland properties such as number of seedlings per unit area or water table depth that are merely measured out of convenience. In this work we demonstrate a) that metrics quantifying wetland properties respond differently during the recovery process, and b) how metrics can be effectively used in the WRP approach to assess a restoration and recovery of two degraded floodplain forests of two blackwater streams in the southeastern U.S. The assessment is based on a restoration objective to develop a floodplain forest with typical flora, soils, fauna and aquatic ecosystems represented by reference systems.

MATERIALS AND METHODS

Approach: Studies were initiated in 1994 and continue to the present to assess ecosystem conditions and properties. Specific studies on hydrology, soil biogeochemistry,

Figure 1. Theoretical response surfaces of functions or indicators of wetland functions (after Kentula et al. 1992). Shaded zone indicates the possible variability in reference conditions over time.

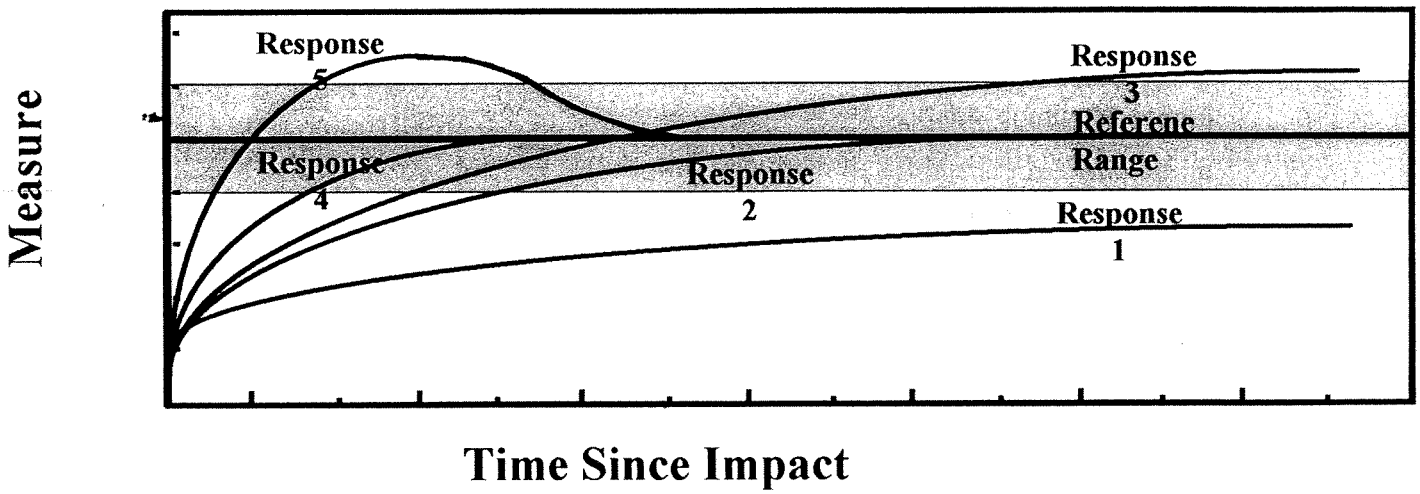
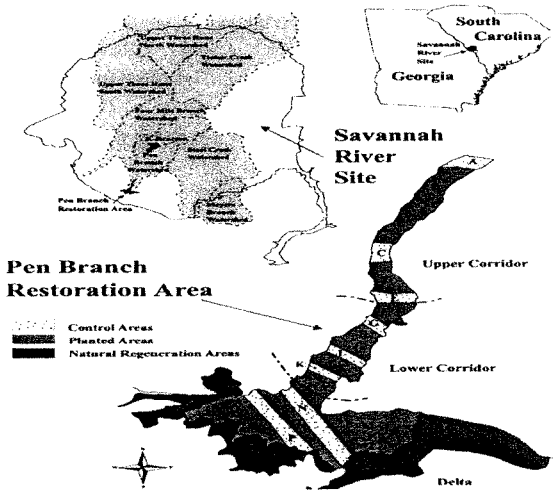


Figure 2. Location and treatment areas of Pen Branch Creek and other bottomland systems involved in wetland restoration studies on the Savannah River Site



vegetation communities, avifauna, herpetofauna, fish, and macroinvertebrates have been conducted (Nelson et al., 2000a). Those studies were designed to provide a basis for a WRP assessment, and to develop easily measured indicators for specific functions or conditions. For this paper we used results from these studies that were conducted across recovering sites and reference floodplain wetlands.

Study Sites: Our study sites are located on the Department of Energy's Savannah River Site in South Carolina (Figure 2). From the early 1950's to the late 1980's nuclear reactor cooling water was discharged into several stream corridors. The cooling water was extremely warm (40-65 °C), and flows were typically one to two orders of magnitude higher than natural flows (Nelson et al., 2000b). Large areas of bottomland hardwood forest were denuded in the floodplains of these streams. We selected two thermally impacted streams (Pen Branch and Fourmile Branch), and most studies used the undisturbed Meyers Branch site as a reference. In avian studies Tinker Creek was used as a reference and Steel Creek was used as the later succession thermally impacted stream (Buffington et al. 1997), and both Meyers Branch and Upper Three Runs Creek were used as references in fish studies (Fletcher et al. 2000). A thorough description of these sites and restoration techniques are summarized in Nelson et al. (2000a). The reactor on Fourmile Branch was retired in 1985 and the reactor on Steel Creek was retired in 1974. Both bottomland ecosystems have been in natural recovery since reactor retirement. The reactor on Pen Branch was retired in 1988, and from 1992-1995 selected areas of Pen Branch were planted with bottomland hardwood tree seedlings. Other areas in Pen Branch were left as unplanted controls to assess natural vegetation recovery.

WRP Assessment: With one exception (fish species richness), we used already published work that has resulted from previous studies conducted on these floodplain wetlands. Individual methods for each study can be found in these publications. For the fish studies, multiple stream reaches in each floodplain were sampled with electroshocking. Species richness is the result of the number of fish species found within a floodplain stream system. The WRP assessment was conducted by plotting the functional response with time for the reference and recovering floodplains. There are numerous measures that

we could report, but, because of space limitations, we selected specific measures that are representative of the data sets and are related to specific functions. Two fundamental assumptions exist in our analysis. Our first assumption is that the recovering systems and the reference system were similar in nature prior to disturbance. We are confident that the two recovering floodplains and the reference floodplain were similar because: 1) the stream systems have similar watershed areas and discharge (Kolka et al. 2000b), 2) aerial photos prior to reactor establishment indicate that the floodplains along all streams were heavily forested, and 3) landscape position is similar among sites with little variation in elevation among floodplains. Our second assumption is that parameters measured were at or near to "zero" at the inception of recovery when the reactors were shut down. Photos taken of both Pen Branch and Fourmile Branch indicate little or no vegetation present and soils that were severely eroded of their organic-rich surface horizons. Considering the magnitude of the disturbance it is unlikely that any faunal communities existed within the floodplains or streams.

Statistics: From the published and unpublished work, we aggregated data to calculate means and one standard error for the variables of interest. Means and standard errors were plotted against the number of years since disturbance. For most of the studies, the number of years since disturbance was three for Pen Branch planted, 10 for Pen Branch unplanted, 14 for Fourmile Branch and 25 for Steel Creek. Trajectory lines begin at zero (see assumptions) with the exception of the litter decomposition study where the percent litter remaining after one year begins at 100%. Trajectory lines were drawn connecting the naturally recovering floodplain wetlands (i.e. Pen Branch unplanted, Fourmile Branch or Steel Creek). Means calculated for the planted section of Pen Branch were plotted separately to assess the effectiveness of planting to accelerate recovery.

RESULTS

Hydrology: For wetland restorations, the recovery of hydrology is critical and the most important factor that determines overall success (Kusler and Kentula 1992). Water table elevations are slightly lower in the disturbed systems than in the reference although

ranges overlap (Figure 3a). Evapotranspiration (ET) rates are considerably lower in the disturbed sites than in the reference site (Figure 3b). Differences in ET can be directly attributed to canopy differences that have resulted from the disturbance. The trees in Meyers Branch uptake more water than the shrubs and herbs currently dominating the disturbed sites. ET rates may also be related to the water table dynamics previously discussed. Slightly lower water tables present in the disturbed systems may limit ET. Our data indicates that it will take a recovering system at least 20-30 years for ET rates to approach those of the reference site. Currently, tree planting has not dramatically affected hydrologic recovery (Figure 3). Our data suggest that ET rates are a more discerning hydrologic variable than simple water table elevations when considering recovery assessment.

Soils: Elevated flows in Pen Branch and Fourmile Branch resulted in severe erosion of the nutrient and carbon rich forest floor and upper mineral soil horizons leaving essentially sterile fluvial sands behind as the starting point of soil recovery (Kolka et al. 2000b). Forest floor responds quickly after recovery begins (Figure 4a). Over time, forest floor mass decreases, and within 15-20 years may approach that of the reference. However, the composition of the forest floor is very different among systems. Forest floor in Pen Branch is composed of only 25% woody foliage while Fourmile Branch and

Figure 3. Water table (a) and evapotranspiration (b) response during bottomland recovery (data from Kolka et al. 2000b). Error bars are standard errors. Diamonds represent naturally recovering systems and the circle represents a planted system.

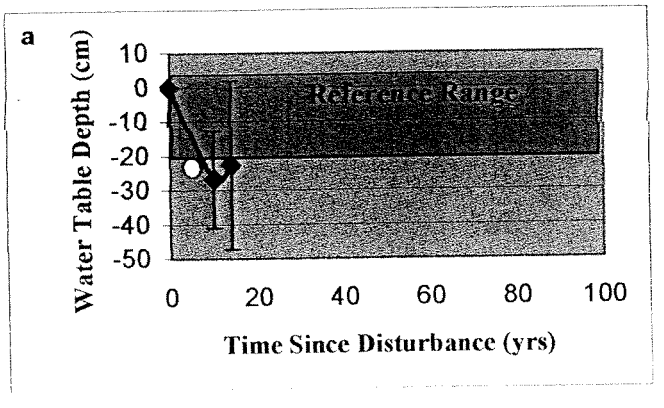
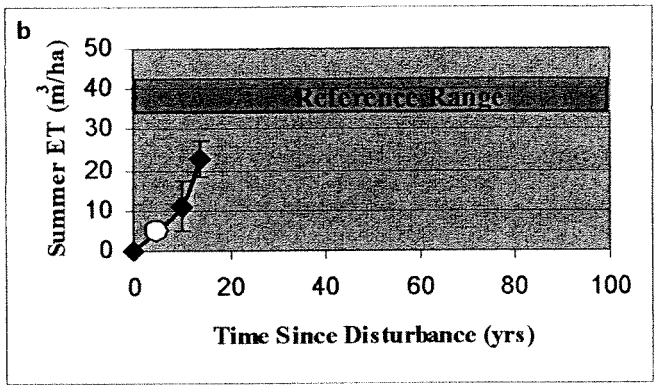
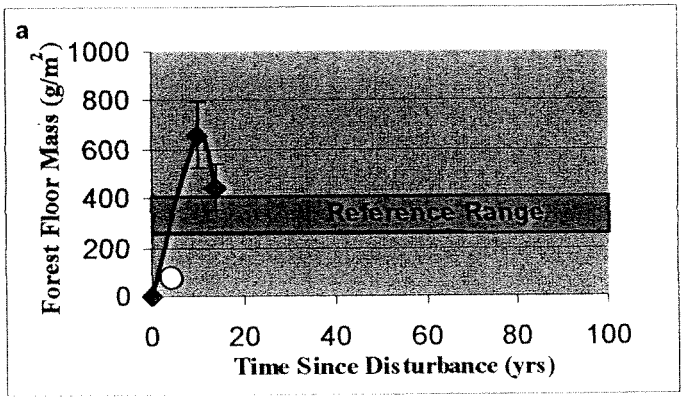


Figure 3 Continued



Meyers Branch litter is composed of 40 and 70%, respectively (Wigginton et al. 2000). These differences in the quality of the litter may also be important determinants in the functional recovery of the floodplain soils. Litter decomposition rates are fastest in the late successional system (Meyers Branch) although the data suggests that rates recover within 15-20 years (Giese et al. 1999, Figure 4b). Slower decomposition rates in the naturally recovering systems allow forest floor to accumulate (Figure 4a). Slower decomposition in the recovering wetlands is likely the result of differences in moisture and temperature regimes when compared to the reference. The data suggests that site preparation and tree planting has slowed the accumulation of forest floor and sped up decomposition (Figure 4a and 4b), possibly in response to the warmer temperatures in the planted zones after opening the canopy.

Figure 4. Forest floor biomass (a), litter decomposition (b), and soil carbon (c) response during bottomland recovery (data from Giese et al., 1999 and Wigginton et al., 2000). Error bars are standard errors. Diamonds represent naturally recovering systems and the circle represents a planted system.



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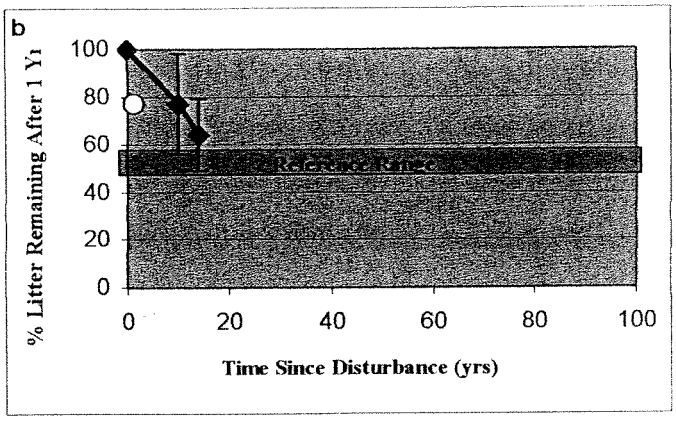
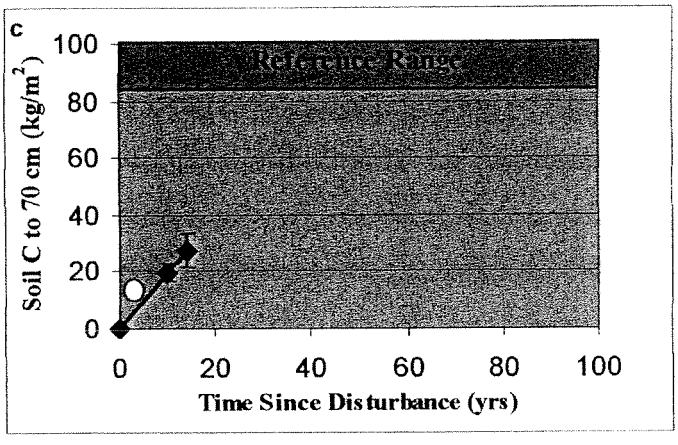




Unlike the forest floor, the soil carbon content of the mineral soil will take considerably longer to reach predisturbance levels (Figure 4c). Soil carbon content in the upper 70 cm of the recovering sites are approximately 25% of those of the reference site (Wigginton et al. 2000). If the trajectory continues, soil carbon content should approach that of the reference range in approximately 50-60 years. Wetland functions associated with the mineral soil, such as carbon and nutrient cycling, will likely be affected for the same time period. Tree planting does not appear to have dramatically affected soil carbon content.

Vegetation: Vegetation communities have developed from the denuded conditions present after thermal flows. Vegetation in the two recovering sites is mainly composed of early successional herbaceous and shrub species. Herbaceous biomass increased rapidly after the disturbance and is decreasing over time, already approaching that of the

reference site in 15-20 years (Figure 5a). However, tree biomass will take considerably longer to recover (Figure 5b). Although difficult to project, the data suggests that a forest canopy will not be fully developed for 40-60 years. Like the mineral soil, functions related to the presence of a forest canopy, such as wildlife habitat, will likely be affected for this time period. Site preparation in the tree planted zones has increased herbaceous biomass and the newly planted trees have yet to accumulate much biomass (Figure 5a and 5b). Stream macrophytes increased initially after the disturbance as a result of the open conditions (Figure 5c). As the canopy closes near the streams, macrophyte cover is decreasing. Like herbaceous biomass, macrophyte cover is greater in the planted sections of the floodplain than in the naturally recovering systems.

Faunal Communities: Fish species richness is an example of a metric that can be abnormally elevated by some types of disturbances (Figure 6a). Richness was higher in Fourmile Branch than the naturally covering portion of Pen Branch. Because of complex interactions controlling fish species richness, we cannot be sure of the long-term trend. We predict that richness will decrease as the riparian vegetation community matures. The increased number of species is likely due to inflated fish abundances in the disturbed systems after the canopy was opened and to increased heterogeneity in the recovering systems. This illustrates why great care must be exercised when using species richness based metrics for assessment of wetland condition. Similarly, macroinvertebrate density increases initially after disturbance (Figure 6b). The macroinvertebrate data suggest that the stream fauna will approach that of the reference system in about 20-30 years. At least in the short-term, site preparation and tree planting appears to have had a negative effect on the stream fauna. Fish density and macroinvertebrate abundance are similar or greater in the planted sections of the floodplain than in the naturally recovering systems. Avian diversity is lower in the recovering systems than in the reference system (Figure 6c). Our trajectory suggests that it may take 40-60 years before avian diversity will be comparable among recovering and reference systems. It does not appear that tree planting has had an effect on the trajectory.

Figure 5. Herbaceous biomass (a), tree biomass (b), and stream macrophyte cover (c) response during bottomland recovery (data from Giese et al., 2000 and Fletcher et al., 2000). Error bars are standard errors. Diamonds represent naturally recovering systems and the circle represents a planted system.

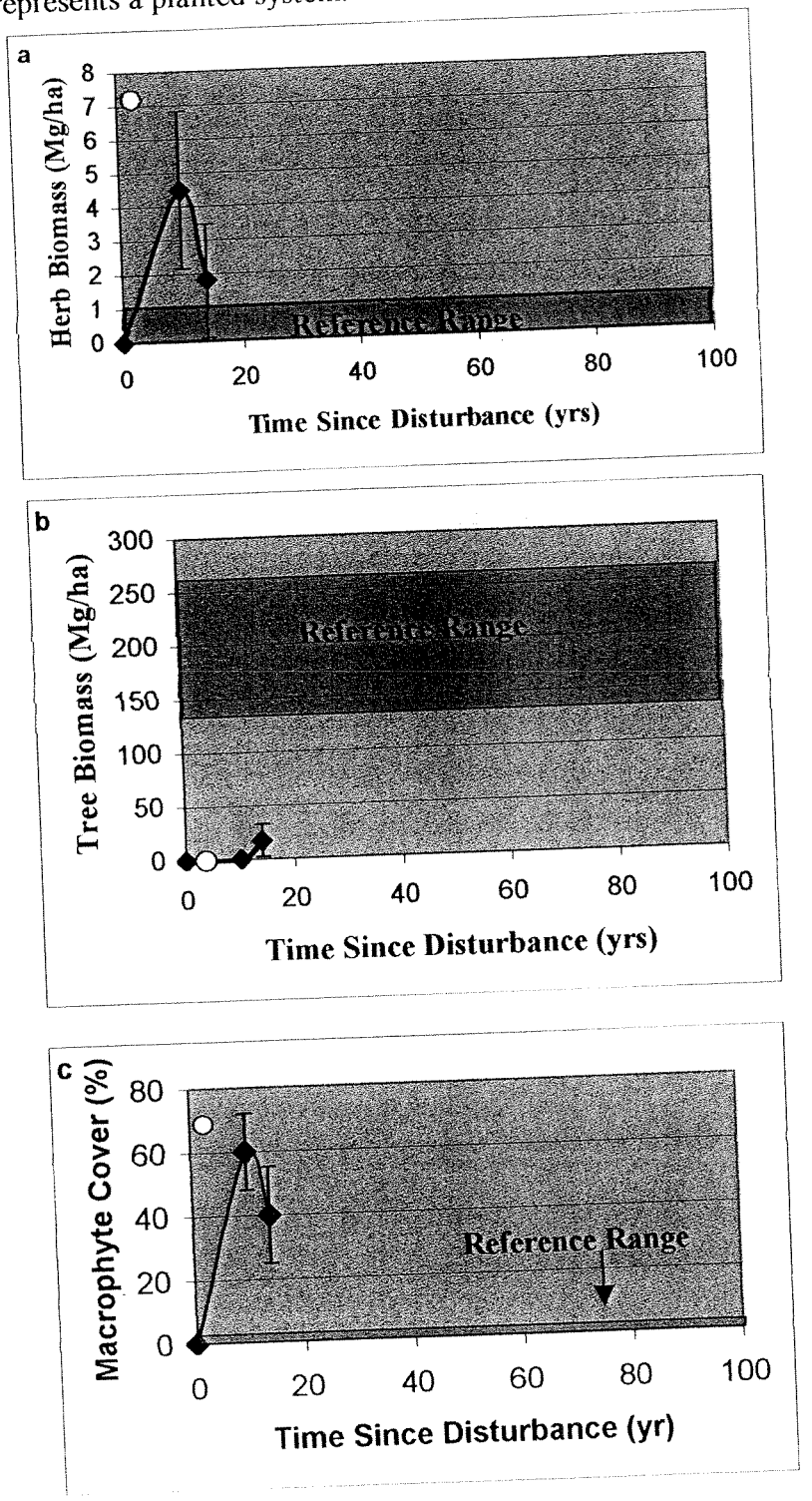
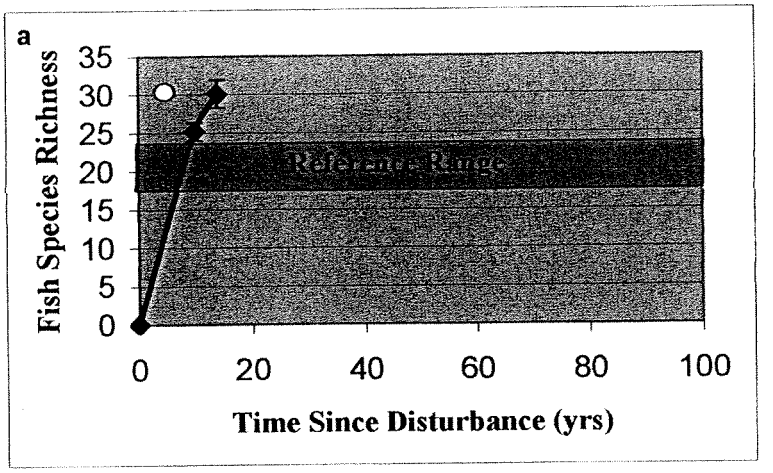
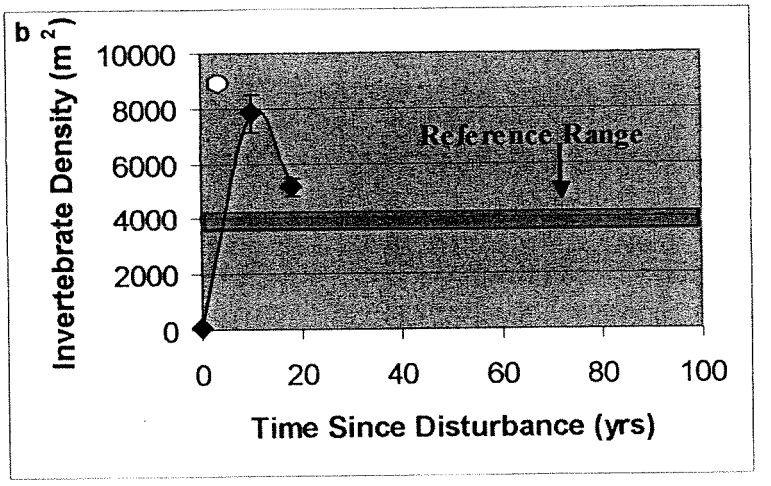
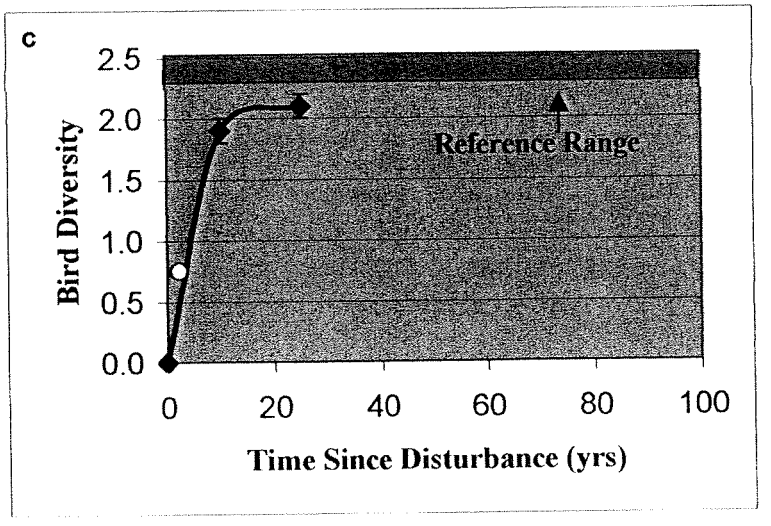


Figure 6. Fish species richness (a), stream macroinvertebrate density (b) and avian diversity (c) response during bottomland recovery (Fletcher, unpublished data; Lakly and McArthur 2000, Buffington et al. 1997). Error bars are standard errors. Diamonds represent naturally recovering systems and the circle represents a planted system.







We have numerous measures from our array of studies on these wetland systems. The focus of our assessment is on ecosystem processes or functions that change as succession proceeds. For restoration to be considered effective, wetland functions must be restored or at least on a trajectory where restoration of those functions is probable (Figure 1). We recognize that the recovery of wetland functions (or indicators of functions) is a complex process that is time dependent and that different response patterns may result from different types of disturbances. Biological interpretability will be enhanced by directly measuring functions within a variety of system components (e.g. biotic and abiotic; aquatic and terrestrial) rather than inferring them from characteristics of a single component. It is not ecologically justifiable to develop one qualitative number that defines the status of a wetland recovery. Simply stating that some functions have recovered and that others are or are not on their planned trajectory is a rational approach. Subsequently, identification of the status and trajectory of specific functions may provide more suitable guidance for future restoration efforts.

Based on the WRP approach, both Pen Branch and Fourmile Branch bottomlands appear to be on a trajectory towards being functional wetlands. However, important differences still exist, such as species composition of the forest canopy, which may or may not allow complete recovery. Only time and future monitoring will confirm whether the initial response will be indicative of future conditions. Planting of bottomland tree species should shorten the trajectories and hasten recovery (Figure 1, response 4 vs. response 2) although currently it appears that it is too early to judge the long-term effectiveness of site preparation and tree planting. To date, it has had either a negative or negligible effect on recovery.

Based on early trajectories, predictions of time to recovery were made for several metrics. For the naturally recovering bottomland systems, our data suggests that hydrology may take at least 20-30 years to fully recover. Similarly, forest floor and decomposition appear to take 20-30 years to recover, but it may take more than 60 years

for soil carbon content to be comparable to reference sites. Herbaceous vegetation and stream macrophytes communities appear to take 20-30 years to recover as canopies begin to close. Tree biomass will take much longer as they replace the herbaceous and shrub communities currently dominating the recovering sites. Some characteristics of stream fauna are recovering much faster (20-30 years) when compared to avian species (40-60 years). Stream fauna recovery is likely more influenced by canopy closure, whereas avian recovery is more dependent of forest composition and structure.

CONCLUSION

In this paper we present examples of possible biotic and abiotic metrics for recovery assessment. We hope to continue to monitor wetland processes over the long-term to develop response surfaces that will allow us to describe the state of recovery of various wetland functions. We understand that regulatory agencies or private firms cannot afford the time or expense of the comprehensive approach we developed. However, after response surfaces of indicators of wetland function have been developed for different types of systems, others will be able use the established metrics and their knowledge of the type of disturbance affecting the wetland to *a priori* select the most relevant metrics to more efficiently conduct an assessment.

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