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The Carolina Bay Restoration Project

Final Report
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Prepared by:

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Executive Summary:

A Wetlands Mitigation Bank was established at SRS in 1997 as a compensatory alternative for unavoidable wetland losses, with 16 experimentally restored Carolina bay depressional wetlands serving as the initial "deposit" to the Bank. In the experiment, two planned wetland vegetation types (herbaceous, forested) were examined in combination with two methods for upland buffer-zone management (open-canopy pine savanna, closed-canopy pine-hardwood forest). Prior to restoration activities, the 16 sites were surveyed into the SRS Site Use system to serve as a protective covenant. Pre-restoration monitoring ended in Fall 2000, and post-restoration monitoring began as restoration activities were initiated in the Winter/Spring of 2001. A total of 19.6 ha of wetland interior forest was harvested from the interiors of the 16 restoration bays. Margins of 8 bays assigned to the pine savanna margin treatment were thinned. In total, over 126 ha were included in the study areas (interior + margin). In all restored bays, natural revegetation from seedbanks was used as the primary revegetation method. In addition, initial planting of two wetland tree species and transplanting of wetland grass species in early 2001 was successful. In eight bays targeted as wetland forest restorations, approximately 2700 *Nyssa sylvatica* and 1900 *Taxodium distichum* seedlings were planted, resulting in an average planting density of ≈ 490 stems ha^{-1}. One hundred seedlings of each species per bay (where available) were marked to evaluate survivability and growth. For 12 bays, wetland grass species were transplanted from SRS donor sites to test plots that ranged in size from 100 – 300 m^2, depending on wetland size. On 0.75 and 0.6 meter centers, respectively, 2198 sprigs of *Panicum hemitomon* and 3021 sprigs of *Leersia hexandra* were transplanted.

The filling of drainage ditches was delayed approximately eight months after planting due to permitting constraints. However, most sites were effectively plugged by harvesting activities, when native soil was bulldozed into the ditch and compacted to facilitate movement of harvesting equipment. These actions, coupled with a regional drought, inhibited surface water loss through the drainage ditches. Formal actions to plug the ditches began with verification of the Section 404 Nationwide Permit 27 on December 18, 2001.. In each bay, a clay plug was installed by excavating an area perpendicular to the drainage ditch at the location of the historical wetland boundary (rim). The excavated site was at least twice the width and depth of the original drainage ditch and extended 2 to 3 meters into the upland. The material removed was used as a surface cover on the impermeable clay plug. Subsoil clays obtained from SRS borrow areas were put in the excavation, and compacted. Water levels rose in the Winter 2003 and no leaks or undercutting of the plugs have been detected since.

New shoots originating from harvested stumps were treated with a foliar herbicide (Garlon® 4) during the summer of 2001 using backpack sprayers. After all monitoring ceased, additional herbicide treatments were performed in September of 2006 for control of sweetgum (*Liquidambar styraciflua*) and red maple (*Acer rubrum*) sprouts and saplings using a foliar spray of Habitat® that was applied with a backpack sprayer equipped with a spray wand. A national ban (DOE) on prescribed burning following a Los Alamos National Lab wildfire; a Site burning ban following September 11, 2001; and extreme drought and unfavorable burning conditions combined to delay burning of pine savanna-margin bays. In 2003, site conditions improved and prescribed burning operations were re-initiated. Thus far, bays 5190, 131, 5092, 124, 126 and 5135 were burned for the first time (February - May 2003). Bays 5011 and 5184 will be burned when field conditions are acceptable. As part of the long-term management plan for these sites, the eight bays will be re-burned as soon as fuel levels permit (approx. 3 years). Bay 5204 was unintentionally burned in a wildfire in 2006.

Post-restoration monitoring of hydrologic, vegetation and fauna was performed from 2001 to 2005 . The sections following provide an overview of hydrological, vegetation,and faunal responses to the restoration actions. All studies report positive changes in metrics of wetland structure and function after five years.

For mitigation purposes, a Carolina bay restoration is deemed a success when the restored hydrologic regime has stabilized and the associated wetland community is dominated by hydrophytic vegetation more commonly found in wetlands than in the community occupying the site immediately before restoration (USDOE, 1997). Individual bay summaries of post-restoration hydrology and vegetation, and assessments of restoration success needed for calculating mitigation banking credits are found in Appendix I. For each wetland, success was evaluated in the following three categories:

1. By year 5, did hydrology and vegetation meet COE *jurisdictional* criteria?
2. By year 5, did hydrology and vegetation measures *increase* from pre-restoration (year 0) values?
3. By year 5, did hydrology and vegetation measures achieve *reference* wetland values, or show a positive trajectory toward those values?

Target vegetation type (herbaceous or forested) was assigned at random to each restored bay. However, because a restored hydroperiod is constrained by basin geomorphic properties, it may be unsuited to support the assigned target. In particular, herbaceous wetlands require long hydroperiods or periodic fire for long-term persistence. Therefore, if assessments in categories 1 and 2 are positive, a restoration may be considered successful even if it does not fully match the originally targeted reference type (category 3).

The matrix system developed by COE and approved for use in the state of South Carolina (COE, 1993) provides the basis for determining mitigation credits for the DOE-SR Wetland Mitigation Bank (Barton and Singer, 2001). The information in this report shall be used as a guideline for the SC Mitigation Banking Review Team to determine the final net improvement and credits for each wetland.

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The Carolina Bay Restoration Project: Implementation and Management of a Wetland Mitigation Bank

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Introduction. A Wetlands Mitigation Bank was established at the Savannah River Site (SRS) in 1997 as a compensatory alternative for unavoidable wetland losses associated with future authorized construction and environmental restoration projects in SRS wetlands. The Bank was intended not only to hasten mitigation efforts with respect to regulatory requirements and implementation, but also to provide onsite and fully functional compensation of impacted wetland acreage prior to any impact. Restored and enhanced small isolated wetlands, as well as major bottomland wetland systems scattered throughout the nonindustralized area of SRS, were designated for inclusion in the Bank. Based on information and techniques gained from previous research on Carolina bay wetlands (USDOE 1997, Singer 2001), a project to restore degraded Carolina bays on the SRS was undertaken to serve as the initial "deposit" in The Bank. There are 343 Carolina bays or bay-like depression wetlands on the SRS, of which an estimated two-thirds were ditched or disturbed prior to federal occupation of the Site (Kirkman et al., 1996; Barton et al., 2005). These isolated wetlands range from small ephemeral depressions to large semipermanent ponds of 10-50 hectares in size. They provide habitat to support a wide range of plant species, and many vertebrates (birds, amphibians, bats). Historical impacts to the Carolina bays at SRS were primarily associated with agricultural activities. Bays were often drained, tilled, and planted to crops. The consequence was a loss in the wetland hydrologic cycle, the native wetland vegetation, and associated wildlife. Bays were abandoned from agricultural use when the SRS was established in the early 1950s; however, many retained functional ditches and developed successional forest vegetation indicative of drained sites.

The purpose of this mitigation and research project was to restore the hydrologic functions and vegetation typical of intact depression wetlands and, in doing so, to enhance habitat for wetland-dependent wildlife on SRS. Twenty small Carolina bays in the nonindustrialized management area of SRS were identified as candidates for restoration (Figure 1.1). All twenty bays possessed an active drainage ditch and nearly all had a vegetation composition characteristic of a disturbed wetland system. Pre-restoration characterizations of soil, hydrology, vegetation and wildlife were performed within each site, to be used as a baseline for evaluating restoration success. Of the twenty bays, sixteen were initially restored in 2001 and the remaining four were planned to serve as unrestored controls (one of the four was later identified as not in need of restoration). Undisturbed bays of similar size were used as reference sites. The use of reference and control systems can enhance the ability to assess responses in restored wetlands due to treatment implementation. The collaborative project was designed jointly by researchers and the management staff of the US Forest Service, Westinghouse Savannah River Corporation – Environmental Protection Division, Westinghouse Savannah River Technology Center, and the Savannah River Ecology Laboratory. Additionally, cooperators from the University of Kentucky, US Fish & Wildlife Service, Clemson University, the University of South Carolina at Aiken, the University of

West Virginia, and the University of Georgia participated in studies examining the responses of soils, hydrology, vegetation and animal communities.

Methods. To restore the wetlands, trees in the bay interior were harvested and drainage ditches were plugged with low-permeable clay to re-establish prior hydrological conditions. Several strategies for restoring the vegetation in replicated sets of these bays and their associated uplands were examined. Planned endpoints for wetland restoration were herbaceous or forested bay interiors. In bays targeted for restoration as herbaceous communities, the majority of the basin area was not planted, but efforts were taken to encourage natural succession through soil scarification and seedbank emergence. In addition, test plots were planted with wetland grass species (*Panicum hemitomon* and *Leersia hexandra)*. Bays intended for restoration to a forested community were planted on 4.5 m centers throughout the basin interior with swamp tupelo (*Nyssa sylvatica* var. *bifloura*) and baldcypress (*Taxodium distichum*). The role of the seed bank on revegetation was examined in all bays to evaluate the need for outplanting of wetland species and for further development of revegetation strategies in disturbed Carolina bays and similar depression wetlands.

The influence of upland margin management (buffer-zones) on wetland properties and wildlife usage is widely debated and relatively misunderstood (Semlitsch, 1998; Buhlmann and Gibbons, 2000). Two principal upland landscapes on the SRS are commonly associated with Carolina bays: 1) fire-managed, open-canopy pine forest savannas, and 2) closed canopy mixed forests (principally pine-hardwoods that occur in the absence of fire). To gain a better understanding of the relationship between buffer-zone management and wetland properties, these two upland management alternatives were installed as bay margin treatments and as expected endpoints for the uplands surrounding the restored bays. The 16 restoration sites were organized in an experimental design such that the two planned wetland vegetation types (herbaceous and forested) were examined against the two buffer-zone types (open-canopy pine and closed-canopy pine-hardwood) for a total of four bay-margin communities (Figure 1.2). Bay margin treatments were applied to a 100-m buffer from the edge of each bay into the upland (i.e. essentially a 100 m radius from the bay edge). Selective harvesting of hardwoods and some pines was performed in the open-canopy pine forest savanna margins to reduce the basal area to approximately 5 $m^2 ha^{-1}$. Several young stands in this treatment group were thinned using a mechanical shredder to achieve the targeted basal area. Prescribed burning of the margins began in 2003 and will be repeated as dictated by fuel levels (approximately once every 3 to 4 years). Margins within the closed canopy mixed pine-hardwood forests were left unthinned.

Determination of whether restored systems and their accompanying buffers are moving toward planned endpoints has been accomplished by assessing trends and rates of change in biotic and abiotic metrics and comparing these to undisturbed reference bays and/or unrestored control bays. The monitoring program recorded the progress of the restoration for five years after the treatment manipulations (2001 – 2005), and will be used as a guide for determining the final net improvement displayed for each individual wetland. A Carolina bay restoration will be deemed a success when the restored hydrologic regime has stabilized and the associated wetland community is dominated by hydrophytic vegetation more commonly found in wetlands than in the community occupying the site immediately before restoration (USDOE, 1997). Table 1.1 outlines specific criteria for determining restoration success.

Results. By the end of 2002, all restoration treatments were successfully imposed (Table 1.2). Pre-restoration monitoring ended and post-restoration monitoring began as harvesting activities in the bay interiors began. The total interior harvest for the 16 restored bays was targeted at 15.5 hectares, and ultimately 19.6 ha. were cleared. Two bays (131 and 5016) were deemed too wet to harvest the entire interior with the mechanical harvester; consequently, the trees in these two bays were felled with chainsaws and left in the bay centers. Subsequent efforts were undertaken to cut these trees in small pieces, to facilitate decomposition, and to remove some of the slash from the interior for vegetation plot development. Bay 5 was too wet to perform any harvesting activities in 2001 and was not harvested until February 2002. Efforts to thin the margins in the open-canopy, pine savanna margin treatments were successful in sites that contained a mature forested stand (Table 1.3). Margins containing areas with immature forested stands (bay 5184 and portions of bays 5011 and 131) were not completely finished during the initial harvest. Two of these sites (5184 and 5011) were later thinned using a mechanical shredder in November, 2001. Additional thinning of immature trees in these areas is anticipated through mortality from future burning activities. Ultimately, over 126 hectares were included in the study areas (interior + margin).

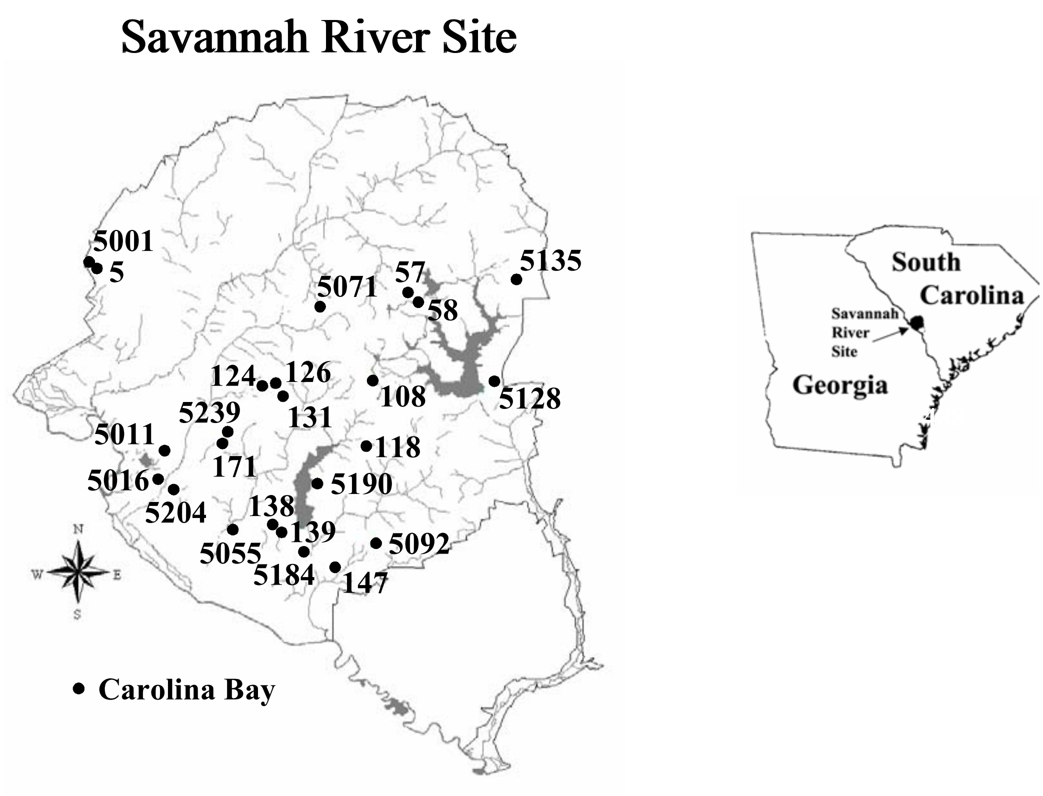
Initial planting of the two wetland tree species and the transplanting of wetland grass species was successful. The exact number of either *Nyssa sylvatica* or *Taxodium distichum* actually planted in the bays was difficult to ascertain owing to methods employed by the contracted planting crew. The total number of trees planted at each site was estimated by the number of seedling bags utilized at the site (50 and 100 seedlings per bag of cypress and tupelo, respectively) and the number of seedlings claimed planted by the contractor. From subsequent field surveys, it was estimated that approximately 2700 *Nyssa sylvatica* and 1900 *Taxodium distichum* seedlings were planted in the eight bays. One hundred seedlings of each species per bay (where available) were marked and measured and were utilized throughout the study to evaluate survival and growth. In 12 bays, wetland grass species were transplanted as rooted sprigs from SRS donor sites into test plots that ranged in size from 100 – 300 m^2, scaled to correspond to the size of the wetland. On 0.75 and 0.6 meter centers, respectively, 2198 sprigs of *Panicum hemitomon* and 3021 sprigs of *Leersia hexandra* were transplanted (Table 1.4). Annual surveys were performed in these plots to evaluate transplant survival and growth.

The filling of drainage ditches was intended to begin immediately after all planting had been completed; however, plug installation was delayed approximately eight months due to permitting constraints. Most of the sites were “effectively” plugged by harvesting activities, where native soil was dozed into the ditch and compacted so as to facilitate movement of mechanical harvesters and skidders in the wetland interiors. These actions, coupled with a regional drought, inhibited surface water loss through the drainage ditches at all sites during the year with the possible exception of bay 124, which may have drained actively for a portion of April/May 2001. With the verification of the Corps of Engineers 404 permit (Nationwide Permit 27), received December 18, 2001, actions to plug the drainage ditches began. A clay plug was installed by excavating an area perpendicular to the drainage ditch at the location of the historical wetland boundary (rim). The excavated site was at least twice the width and depth of the original drainage ditch and extended two to three meters into the upland. The material removed from the ditch was set aside and reused as a surface cover on the impermeable clay plug. Once the excavated area was established, subsoil clays obtained from SRS borrow areas were dumped into the pits and compacted using a backhoe. The total amount of material used for each plug is presented in Table 1.5. Erosion-control practices (seeded annual ryegrass and installed coconut/straw stitched erosion control blankets) were implemented at each site with the completion of the plug installation. Continuation of the regional drought through the 2002 calendar year inhibited our ability to evaluate the integrity of the plugs as surface water levels remained well below the discharge level of the historical drainage ditches. Water levels ultimately rose during the winter/spring of 2003, and no leaks or undercutting of the plugs were detected. Annual checks of the plugs were performed each year and they remained stable.

Efforts to curtail stump sprouting immediately following the interior harvest were not undertaken, as it had been anticipated that sprouting might be inhibited by rising water levels. This did not occur owing to the drought conditons. However, new shoots originating from the stumps were treated with a foliar herbicide (Garlon® 4) during the summer of 2001 using backpack sprayers. Dieback of the sprouts was apparent within a week of the applications, but the treatment proved ineffective as evident by the numerous shoots that reappeared and persisted in subsequent growing seasons. Additional herbicide treatments were performed in September of 2006 for control of sweetgum (*Liquidambar styraciflua*) and red maple (*Acer rubrum*) sprouts and saplings using a foliar spray of Habitat® that was applied with a backpack sprayer equipped with a spray wand. Assessments performed after application indicated that the herbicide was initially effective, although the long-term effect is unknown. Planned burning of the open-canopy, pine savanna margin bays was postponed in both 2001 and 2002 due to a variety of reasons that included a national ban on prescribed burning following a wildfire incident at the Los Alamos National Lab in NM, a Site burning ban in response to terrorist activities of September, 11, 2001, and extreme drought and unfavorable burning conditions. The consequence of the delay on the vegetation and overall restoration response is difficult to ascertain, though possibly it contributed to the lack of early control of woody resprouts. After soil moisture levels increased in response to rainfall in 2003, site conditions improved and prescribed burning operations were re-initiated. Bays 5190, 131, 5092, 124, 126 and 5135 were burned for the first time between February and May of 2003. With the exception of bay 5190, fires did not carry from the margins into the flooded wetland interiors. Efforts will be taken to burn bays 5011 and 5184 when field conditions are acceptable. The eight bays will be reburned as soon as fuel levels are re-established to a point that will support the activity (approx. 3 years). Bay 5204 was unintentionally burned in a wildfire in 2006.

Details on the response of hydrology, vegetation, and faunal communities to the restoration activities are presented in the following summaries. Individual bay summaries of post-restoration hydrology and vegetation, and assessments of restoration success needed for calculating mitigation banking credits are found in Appendix I. Photographs outlining the progress of the project are presented in Appendix II.

Figure 1-1. The Savannah River Site and location of Carolina bay restoration study sites.



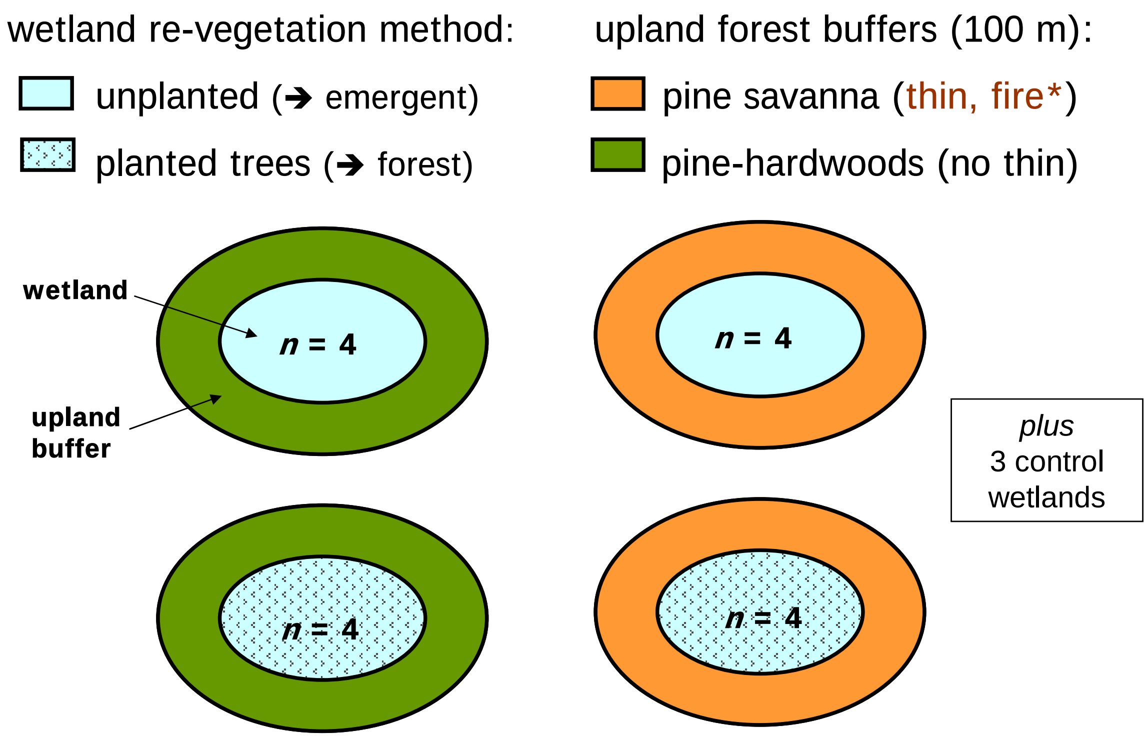


Figure 1-2. Treatment pairs for the Carolina bay restoration project at SRS.

Table 1.1. Success Criteria Summary

Action #	Mitigation Action	Success Criteria
1	Habitat Protection	Areas are incorporated into the DOE-WSRC Site Use Program
2	Hydrological Restoration	Ditch plugs are installed and permanently stabilized. Water levels show an increase over baseline conditions and the depth and duration of flooding and/or groundwater saturation is comparable to the target reference ecosystems.
3	Vegetative Restoration Forested	Bay interiors are planted with appropriate wetland tree species at the density of 500 trees/hectare (200 trees/acre) with a 50% survival rate after 5 years. Plant species density and diversity are comparable to the target reference ecosystem.
4	Vegetative Restoration Herbaceous	Wetland emergent vegetation from plantings and/or natural seeding is established. Plant species and density and diversity are comparable to the target reference ecosystem.

Table 1.2. Status of milestones for the Carolina Bay Restoration Project.

Event	Begin Date	Finish Date
Bay Selection	1998	December, 1999
Restoration Plan	January, 1999	December, 1999; Rev. 1, November, 2001
COE 404 Permit (NW 27)	April, 2001[3]	January, 2002
Pre-restoration Monitoring	January, 2000	November, 2000
Harvest Trees	November, 2000	February, 2001[4]
Interior Tree Planting	February, 2001	March, 2001
Interior Herbaceous Planting	April, 2001	May, 2001
Sprout Control	September, 2001	September, 2001[5]
Ditch Plugging	January, 2002	February, 2002[6]
Post Restoration Monitoring	February, 2001	December, 2005
Burn Pine Savanna Margins[1]	February, 2003	2003[7] (repeat as soon as fuel levels permit)
Foliar Herbicide Treatment	September, 2006	September, 2006
Thin and Plant MPH Margins[2]	2006	On-going (as needed)
Final Report	October, 2006	November, 2007

[1]Open-canopy pine savanna margin.

[2]Closed-canopy mixed pine/hardwood margin.

[3]Submitted "Pre-construction notification for the Carolina Bay restoration project- Nationwide Permit 27" to US Army Corps of Engineers. Permit approved January, 2002.

[4]Bay 5 could not be harvested at that time due to wetness. Trees removed from Bay 5 in February, 2002.

[5]Sprout control was performed using a foliar herbicide (Garlon 4), which proved inefficient for effective treatment of the resprouts. Additional sprout control efforts was implemented in 2006.

[6]Bay 5016 was not plugged at this time due to wetness and an inability to get equipment to the location where the plug was to be installed. The plug was subsequently installed at Bay 5016 in December 2002.

[7]Bays 5190, 131, 5092, 124, 126, 5135 burned between the dates of 2.12.03 and 4.22.03, respectively. Bays 5011 and 5184 have not been burned (to date) due to inappropriate site conditions and weather patterns.

Table 1.3. Total area of restoration sites and adjacent margins after treatment application.

Bay	Harvested Interior Area (ha)	Interior + Margin Area (ha)
	Thinned Margin	
124	1.36	7.15
126	1.72	9.71
131	1.06	5.50
5011	1.08	7.69
5092	1.16	7.85
5135	0.79	6.43
5184	1.22	7.73
5190	1.29	8.18
Total (thin)	***9.68***	***60.24***
	Intact Margin	
5	1.68	14.21
171	1.67	9.44
5001	0.57	7.69*
5016	0.70	7.68
5071	1.16	7.71
5128	1.65	10.74
5204	1.13	8.29
5239	1.42	7.82
Total (intact)	***9.98***	***73.58***
Grand Total	**19.66**	**126.13**

*Margins of 5 and 5001 overlap, so 7.69 ha is inclusive of both sites and factored only once in total area calculation.

Table 1.4. Final number of wetland grass transplants per site and plot size.

Bay	Block Size (m^2)†	# Panicum Transplants‡	#Lersia Transplants*
5204	180	156	195
5071	200	169	225
171	300	247	345
5239	300	247	345
124	200	169	225
5092	300	247	345
5190	162	144	196
126	300	247	345
5128	200	169	225
5001	162	144	196
5135	112	90	154
5011	200	169	225
Total	**2616**	**2198**	**3021**

†Each block was divided into two equal-area split-plots (one plot per species).
‡Planted on 0.75 m centers.
*Planted on 0.6 m centers.

Table 1.5. Volume of fill material used to plug drainage ditches.

Bay #	Ditch Area at Bay Rim (m^2)	Fill Volume (m^3)†	Clay Fill (cy)†
5	1.13 and 0.71	5.7 and 3.59	12.1
124	0.88 and 0.66	4.45 and 3.31	10.2
131	0.43	2.20	2.8
5001	1.82 and 1.71	9.11 and 8.6	23.2
5011	1.40	7.05	9.2
5016	0.67	3.35	4.4
5071	1.14 and 1.09	5.75 and 5.50	14.3
5092	2.99	14.98	19.6
5135	1.51	7.58	9.9
5184	0.39	2.02	2.6
5190	1.14	5.75	7.5
5204	0.24 and 0.53	1.29 and 2.69	5.2
Total	***18.44***	***92.92***	***121.0***

†Volume as cubic yards required for 404 permit.

Restoration of Carolina Bays on the Savannah River Site: Hydrological Response

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Introduction. Hydrology is generally considered to be the primary controlling factor for the development and persistence of wetlands. However, characterizing wetland hydrology is difficult to perform and often compromised due to constantly changing hydrological/environmental conditions and to potential error associated with water budget accounting. Carolina Bays are shallow elliptical depressions found in the Atlantic Coastal Plain that are not only poorly understood with respect to hydrology, but have also been severely altered by human activity. Historical impacts to the Carolina bays at the Savannah River Site, SC were primarily associated with agricultural activities. Bays were often drained, tilled and planted to crops. The consequence was a loss in the wetland hydrologic cycle, the native wetland vegetation, and associated wildlife. Although speculations have been fabricated as to the effect that filling drainage ditches may have on bay vegetation and fauna at SRS, an increased hydroperiod will likely be the most definable constituent associated with any restoration activities. Considering that abiotic and biotic metrics of wetland function are greatly influenced by hydrology, an attempt must be established to thoroughly quantify and characterize bay hydrology so that an assessment for current and future restoration projects involving Carolina bays may be evaluated. As such, a study has been initiated to investigate hydrogeochemical processes in altered, restored and unimpacted bay systems and to use the hydrological data to assess the effectiveness of restoration practices within the current Carolina Bay restoration project. In addition, an overall evaluation of hydrology response to restoration activities is being monitored to fulfill reporting requirements for the Bank.

Methods. Bay hydrology was monitored bimonthly using a combination of piezometers, wells, and water level gages. Hydrological transects were established that traverse bays from the center of the bay to the upland in a perpendicular fashion following the long and short axis. Each transect was equipped with well nests within the bay interior, upland zone and a transitional point (hydric soil boundary or abrupt vegetation change) that is likely to exhibit hydromorphic change in response to filling the drainage ditch. The well nests were comprised of a shallow monitoring well at a depth of 200 cm and four piezometers at 50, 100, 200 and 300 cm depths. Information pertaining to the types of monitoring equipment installed and location within the bays was presented in the first SRS Mitigation Bank Status Report (Barton, 2003). Piezometers were constructed of 2.5 cm diameter schedule 80 PVC pipe with perforations drilled at the submerged end and covered with geofabric. Borings for the piezometers were drilled by hand using a 8.5 cm bucket auger. Washed sand was packed from the base of the borings to approximately 25 cm above the screened area and the remaining annulus will be filled to just below the surface with a slurry created from the bore cuttings. A plug of bentonite was placed at the surface to prevent short circuiting. Shallow wells were constructed in a similar fashion using 5.0 cm diameter schedule 40 PVC pipe that has been slotted along its entire length. Development of the shallow wells was achieved by purging with a bailer to remove water and any dislodged sediment. Water depths within the wells and piezometers were measured using a portable water level indicator. Surface water level (pond stage) was monitored using staff gages and semi-continuously recording monitoring wells (WL-40 capacitance monitors and In-Situ pressure transducers recorded level at 6-hr. intervals). The saturated water depth, piezometric surface, and bay hydroperiod were determined from measurements accumulated with the above monitoring devices. Open precipitation and throughfall were measured in bay margins and interiors of each site. Other meteorological variables (net solar radiation, air temperature, humidity, wind speed) were provided by the SRS Weather Center. Surface evaporation within the bay interiors was determined using a modified Penman-Monteith equation.

Results. Pre-restoration hydrology of the bays revealed that most of the treatment bays exhibited a very low hydroperiod (ponded < 10% of year), although some were ponded for a significant portion such as bays 5 and 124 (Table 2.1). After restoration, the hydrological response to the treatments was initially complicated by a prolonged regional drought. For the three-year period 2000-2002, average monthly rainfall fell below the 50 year precipitation average at SRS (Figure 2.1). However, a positive change in hydroperiod (% time ponded per year) was detected in most (81%) of the treatment bays during that period (Figure 2.2). The control bays responded to the initial drought conditions with hydroperiods that were lower than those exhibited prior to restoration in the treatment bays. This response was likely due to timing and number of precipitation events. Water levels in the bays were high at the beginning of 2000, due to a wet period at the end of 1999. A few large precipitation events were recorded in 2001 and 2002, but they occurred during summer months when the control bays were dry and evapotranspiration was at its highest. The initial increased hydroperiod in the treatment bays; however, was most likely the result of changes to the water budget via tree removal and subsequent lowering of water demand in these systems from transpiration. Physical compaction of soils in the treatment bays from log skidding may have contributed to decreased infiltration and ponding. Similar findings pertaining to the role of forest harvesting on wetland hydrology have been noted elsewhere (Sun et al. 2000). One study indicated that the water table rise associated with harvesting is most expressed during periods when the water tables were low (Riekerk 1989), which was the case in this study.

Table 2.1. Annual hydroperiod (portion of year bay is ponded) data for treatment bays* .

	Treatment Bays															
Bay	**5**	**124**	**126**	**131**	**171**	**5001**	**5011**	**5016**	**5071**	**5092**	**5128**	**5135**	**5184**	**5190**	**5204**	**5239**
2000	0.74	0.56	0	0.44	0.10	0	0.01	0.35	0.02	0	0.01	0.01	0	0	0.12	0.01
2001	0.79	0.67	0.33	0.81	0.23	0.38	0.40	0.41	0.01	0.15	0.67	0.05	0.24	0.28	0.65	0.47
2002	0.81	0.44	0.04	0.51	0.15	0.09	0.02	0.29	0.02	0	0.55	0.04	0.13	0.01	0.52	0.01
2003	1.0	0.88	0.85*	1.0	0.99	0.74	0.87	1.0	0.60	0.83	1.0	0.72	0.98	0.83*	1.0	0.75
2004	1.0	0.51	0.38*	0.71*	0.62	0.31	0.59	1.0	0.23	0.20	0.89	0.32	0.39	0.16*	0.92	0.36
2005	1.0	0.65	0.52	0.75	0.49	0.45	0.63	1.0	0.13	0.38	0.83	0.23	0.67	0.45	0.88	0.37

*WL-40 damaged, hydroperiod estimates from manual sampling of A-well and observations of whether or not water was present during this period.

By 2003 above-normal rainfall patterns were observed at SRS and all bays responded with long duration annual and growing season hydroperiods (Tables 2.1 and 2.2). Normal precipitation levels followed in 2004 and 2005. With this reversal in precipitation volume, mean hydroperiod change for the entire study period became positive for all treatment and control bays (Figure 2.2). The mean hydroperiod change for the treatment bays; however, was twice as high as that observed for the controls (0.38 versus 0.16). All treatment bays except 124 exhibited an increased hydroperiod change over that of the mean control after restoration. If the mean change in control value is utilized as the reference point for assessing hydrological response, then 15 of the 16 hydrologic restorations were "successful". Considering that the pre-restoration period was only one year and that it occurred during a drought, use of hydroperiod change as a metric for evaluating hydrologic response may not be appropriate. An such, an examination of the hydroperiod data was performed to determine whether or not the sites met the minimum hydrology criteria for wetland delineation as described in the 1987 COE Wetlands Delineation Manual (with reference to the 1991 interagency revisions). For this interpretation we determined that a site met the minimum hydrology criteria if inundation continues for 11 consecutive days during the growing season for most years (3 out of 5) after restoration (2001-2005). Using this criteria, all bays exhibited wetland hydrology (Appendix I). A comparison of mean post restoration hydroperiod was also compared to undisturbed reference bays on SRS (Lide, unpublished data). Using this approach, all bays except

5001, 5071, 5135 and 5190 were found to exhibit a similar range in hydroperiod as the reference condition.

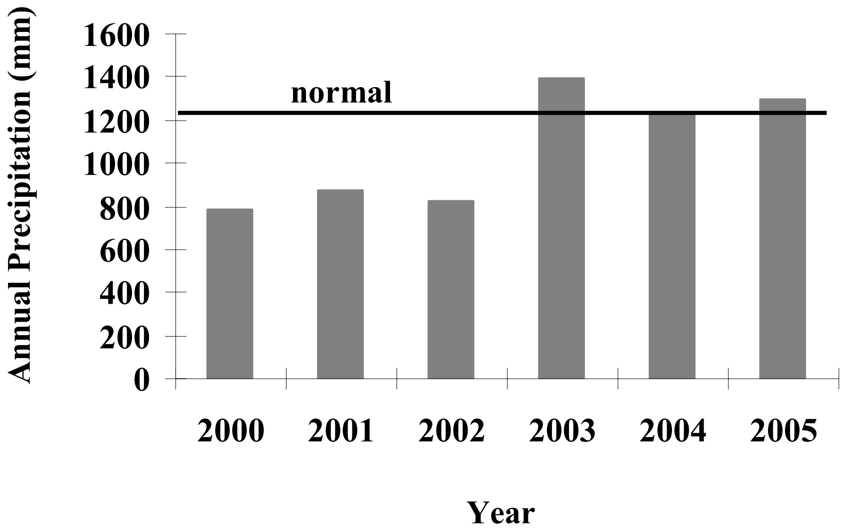

Figure 2.1. Annual rainfall deviation from 50 year mean precipitation levels acquired by the C-Area weather station.

Table 2.2. Bay hydroperiod (portion of year bay is ponded) during growing season (April 1 – November 1: 214 days).

								Treatment Bays								
Bay	**5**	**124**	**126**	**131**	**171**	**5001**	**5011**	**5016**	**5071**	**5092**	**5128**	**5135**	**5184**	**5190**	**5204**	**5239**
2000	0.55	0.28	0	0.23	0.04	0	0.01	0.04	0	0	0.01	0.01	0	0	0.09	0.01
2001	0.78	0.81	0.29	0.97	0.24	0.51	0.50	0.44	0.01	0.26	0.95	0	0.29	0.47	0.97	0.51
2002	0.86	0.20	0	0.27	0.01	0.03	0	0.10	0.01	0	0.32	0	0.01	0.01	0.27	0.01
2003	1.0	0.94	1.0	1.0	1.0	0.86	1.0	1.0	0.76	1.0	1.0	0.96	1.0	1.0	1.0	0.92
2004	1.0	0.39	0.29	0.50	0.85	0.17	0.53	1.0	0.13	0.07	0.86	0.19	0.27	0.13	0.91	0.23
2005	1.0	0.62	0.58	0.80	0.55	0.41	0.72	1.0	0.05	0.43	0.85	0.29	0.70	0.49	0.93	0.39

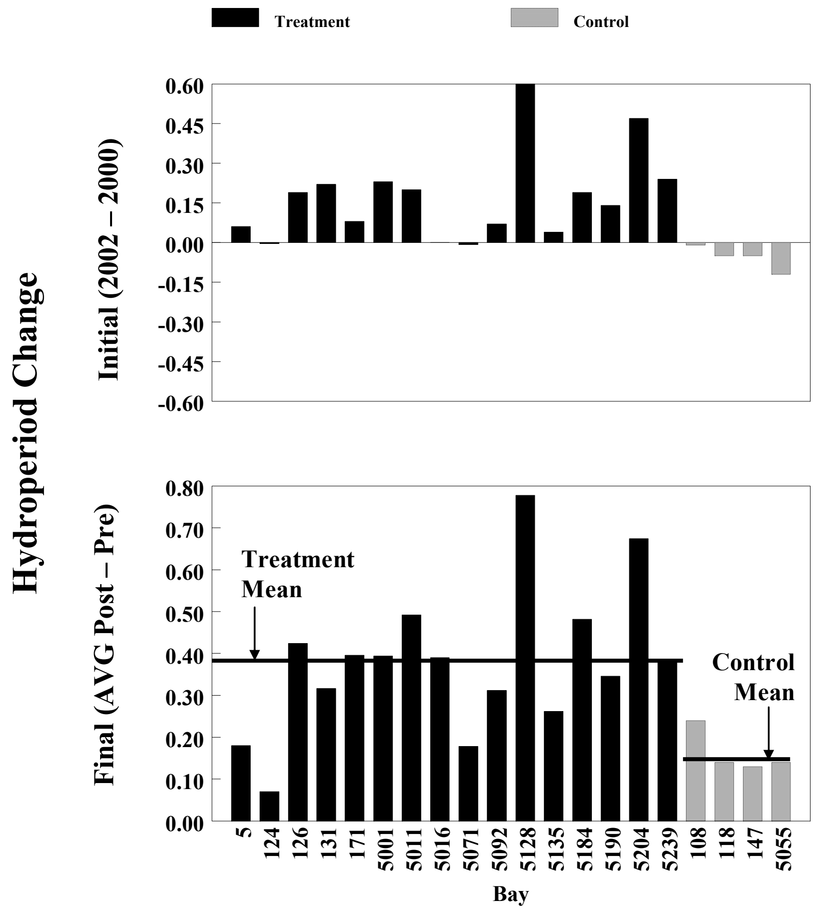

Figure 2.2. Initial (top) and final (bottom) hydroperiod change from treatment and control bays. Initial hydroperiod change was calculated by subtracting the mean 2001 and 2002 hydroperiod from the 2000 pre-restoration data. Final hydroperiod change was calculated by subtracting the mean post restoration hydroperiod (2001-2005) from the 2000 pre-restoration data.

Vegetation Response in Restorations of Small Carolina Bay Depressional Wetlands

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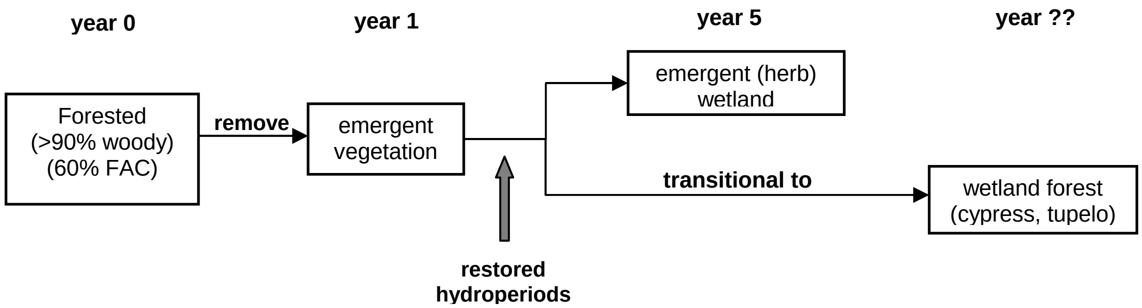
Introduction. As a sensitive indicator of hydrologic and substrate conditions, vegetation composition is a key component for assessing wetland restoration success. The Carolina bay restoration project was designed to use passive natural processes (plant recruitment from seed banks and seed dispersal) as the main revegetation method in all 16 experimental wetlands. In 8 wetlands, the passive method was supplemented by planting typical wetland tree species (baldcypress, swamp tupelo). Two typical wetland grasses (southern cutgrass, maidencane) were also planted into 56–150 m^2 test blocks in some wetlands. For this project design, the vegetation studies addressed two main questions: 1) were passive methods an adequate source of wetland plant species for revegetation? and 2) did vegetation composition, as influenced by restored hydroperiods, meet appropriate success criteria at the end of the 5-year assessment period? The first question was answered affirmatively, but with some caveats (De Steven et al. 2006). The seed banks were dominated by wetland herb species and were adequate to establish high emergent cover. However, seed bank species composition did not fully resemble that of natural reference wetlands, and unpredictable drought during the first two years favored woody resprouting that was difficult to control effectively. To address the second question, we present a model for vegetation assessment and summarize trends in the revegetation success criteria.

Methods. Detailed methods are described in De Steven et al. (2006). Briefly, percent covers of all plant species were recorded yearly from 2000 to 2005 in permanent 4-m^2 plots. Larger 100-m^2 plots were used to sample woody plant density and cover in 2000 (pre-restoration) and 2005 (final year). For planted trees, a sample of marked seedlings (up to 100 per species per site) was censused yearly in spring (April/May) for survival and height growth. Cover of planted grasses was monitored in 4-m^2 plots. Because forest harvest initiated large changes that were likely to be site-specific, our analysis approach used a repeated measures design (change over time from pre-restoration status) rather than comparison to unrestored "control" wetlands. For analysis, plant species were classed as wetland (OBL, FACW), facultative (FAC+, FAC), or "non-wetland" (FAC-, FACU, UPL).

***Model and Measures for Assessment*.** The project was designed such that the two desired vegetation "targets" were assigned randomly to the restored wetlands. A conceptual model (Figure 3.1) illustrates that: 1) the targets would develop at different rates, and 2) there are natural constraints on reaching the planned vegetation type. Within a 5-year period, success in establishing emergent (herbaceous) wetland should be evident, but the forest restorations would be only transitional to maturity. Ultimately, wetland vegetation will be regulated by the restored hydrology, which is a function of depression hydrogeomorphic properties and which cannot be engineered beyond any enhancements from ditch plugging. Long hydroperiods and deep ponding are needed to maintain emergent vegetation in the absence of fire (De Steven and Toner 2004). Thus, the potential to restore small shallow basins to emergent wetland could be limited by shorter restored hydroperiods. Given this constraint, it is appropriate to evaluate success in terms of improvement from pre-restoration composition, as well as in relation to reference wetlands.

FIGURE 3.1. Experimental Restoration Model



Relying on existing seed banks for revegetation limits the potential to closely match the species composition of reference wetlands, if some characteristic species are absent in a seed bank or disperse poorly. Therefore, when wetlands are not deliberately planted, functional measures of composition offer more appropriate success criteria than measures of species similarity. Useful measures are percentage and relative cover of wetland (OBL, FACW) species, and percentage and relative cover of herbaceous species. From reference wetland datasets for each target vegetation type (De Steven and Toner 2004), we determined the typical range of values for each measure, and used the minima of these ranges to define the threshold values for success by the 5th year (2005). For all restored wetlands, both percentage and relative cover of wetland species had to meet or exceed a reference threshold of 60%. Emergent wetlands had to meet or exceed reference thresholds of 60% herbaceous species and 60% relative herbaceous cover, whereas the forested restorations had a required minimum survival rate of 50% for planted trees. For improvement from pre-restoration composition (between 2000 and 2005), we used a net increase of at least 20% (generally equivalent to a percentage increase of at least 50%) for each measure as the required threshold for success.

Results and Discussion. Vegetation was influenced by the hydrology established after return of normal rains, but also by persistent effects of the early drought. By 2005, values for percent wetland species and relative cover of wetland species averaged 61% (range 34–76%) and 62% (range 11–96%) (Table 3.1). While average performance met the reference thresholds, some individual wetlands did not reach the threshold values (see Appendices for individual assessments). The constraints for these wetlands were: 1) resprouting of harvested trees and woody vines, most of which are facultative (FAC) species, and 2) restored hydroperiods that may be too short to support a predominance of wetland species. Similarly, herbaceous cover increased in all wetlands (Table 3.1), but some sites assigned to be “emergent” wetlands will not meet the reference threshold owing to woody resprouting or short hydroperiods that favor woody plant colonization. However, for all measures, nearly all wetlands showed net improvements within the limits allowed by restored hydroperiods, and thus may be considered successful in that context.

In the 8 planned “forested” wetlands, survival of planted tree seedlings averaged 79% for cypress (range 54–95%) and 23% for tupelo (typical range 2–32%) by 2005 (Table 3.2). Cypress survival exceeded the 50% success threshold in all 8 planted sites, but tupelo met the survival criterion in only one wetland. Possible reasons for high tupelo mortality in the first two years included drought sensitivity, planting into some unsuitable microsites (e.g., under water), or smaller initial seedling size (Sharitz et al. 2006). Attained tree heights typically ranged between 1.4–2.6 m for cypress (maximum 4.0) and between 0.6–1.8 m (maximum 3.1) for tupelo.

Management of upland forest buffers (thinned or not thinned in 2001) did not significantly influence any vegetation measures over the short term. A 2003 prescribed fire treatment applied to 6 pine-savanna margins spread into the interior of only one wetland, which was dry at the time of burning. Anecdotally, this wetland has had minimal woody resprouting. Without fire, a longer hydroperiod is important in favoring high coverage of herbaceous wetland species (see Figure 3.2)

In 12 restored wetlands, an experiment tested whether characteristic wetland grasses (cutgrass, *Leersia hexandra*; maidencane, *Panicum hemitomon*) could be established from transplants (rooted sprigs) as a means to accelerate revegetation. [*Panicum* plantings were later found to have included the similar wetland grass *Sacciolepis striata*]. By 2005, successful plantings achieved from 15% to 98% cover in the test plots. Ten of 12 *Panicum/Sacciolepis* plots and 6 of 12 *Leersia* plots achieved >60% cover. Compared to unplanted areas, planted plots had more rapid cover development and a vegetative structure more similar to herbaceous reference wetlands (De Steven and Sharitz 2007).

Conclusions and Recommendations

- Where seed banks have predominantly wetland species, hydrologic restoration can promote successful passive revegetation. After ditch plugging (and harvest), all sites showed increases in wetland plant diversity and met jurisdictional criteria for hydrophytic vegetation. Several sites developed into high-quality emergent wetlands; others are on a trajectory to forested wetland with inclusions of planted cypress. Even in the drained state, many sites likely had some transient ponding, which possibly favored persistence of remnant seed banks or allowed new seed bank development over decades of abandonment in a reforesting landscape. Whether drained depressional wetlands on active agricultural lands could also be revegetated passively is less certain, but seed bank analyses could guide decisions about any need for supplemental planting.

- Restoring hydrology resulted in functional wetland plant communities. Achieving a specific target vegetation is more problematic, because individual depression hydroperiods are quite variable. Forest harvest allowed emergent vegetation to establish, but its persistence depends on controlling woody resprouting and also on longer restored hydroperiods that may be hard to predict. The experimental sites were assigned to the emergent wetland objective at random, not according to the potential to sustain herbaceous vegetation. Even after hydrologic restoration, small shallow depressions may have short natural hydroperiods and thus will develop forested wetland over the long term. If persistent emergent vegetation is desired, more effective means to control hardwood resprouting may be needed. Upland prescribed fires might retard woody regrowth, but only in drier years when fires can spread into wetland interiors.

- Matching the timing of restoration actions to wetland seasonal cycles may enhance success. For example, tree seedlings and grasses were planted in early spring, which allowed establishment during early wet conditions and a full season of first-year growth. The larger cypress seedlings survived well in all wetlands, whereas the smaller tupelo seedlings appeared more sensitive to inappropriate microsites (too dry or too deep). If restoration involves forest removal, harvesting just before the period of winter flooding might inundate stumps and reduce potential hardwood resprouting, although we could not test this hypothesis in this experimental project.

- When relying on passive revegetation to restore wetlands, functional measures of similarity to reference wetlands may be more appropriate for assessing restoration success.

TABLE 3.1. Change over time in species richness, total vegetative cover, and relative contributions of wetland (OBL, FACW) species and herbaceous species. Year 2000 is pre-restoration. Data are means (s.e.) averaged over *n* wetlands.

year	*n*	Number of species	Total percent cover	Percent wetland species	Relative cover of wetland species (%)	Percent herbaceous species	Relative herbaceous cover (%)
2000	*16*	23 (2)	148 (12)†	33 (3)	41 (5)	19 (4)	7 (3)
2001	*15**	44 (4)	78 (12)	51 (3)	48 (8)	69 (2)	76 (6)
2002	*16*	36 (2)	65 (5)	42 (2)	42 (6)	66 (2)	65 (5)
2003‡	*16*	17 (2)	37 (6)	53 (3)	48 (8)	41 (6)	30 (8)
2004	*16*	30 (3)	94 (5)	58 (4)	58 (8)	75 (2)	80 (5)
2005	*16*	35 (3)	101 (8)	61 (4)	62 (6)	66 (2)	63 (5)

* excludes one wetland that was not harvested until the end of year 2001

† includes pre-harvest forest canopy

‡ some 2003 values were temporarily reduced by deep and prolonged ponding from heavy rains

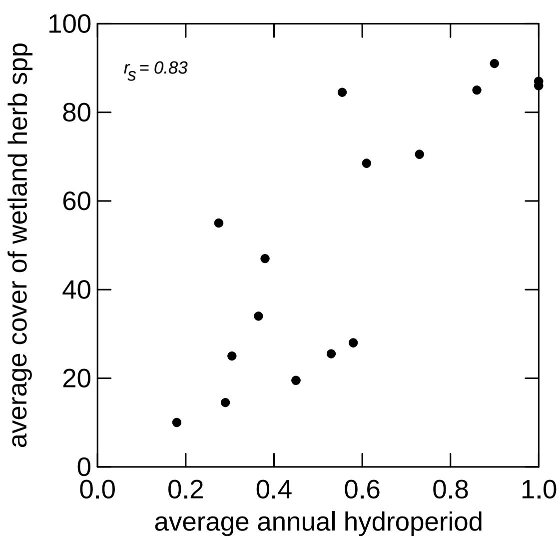
TABLE 3.2. Survival and attained shoot heights of baldcypress and tupelo seedlings planted into 8 wetlands in February 2001. Data are means (s.e.).

	seedling survival (%)		average seedling height (m)	
Year*	Cypress	Tupelo†	Cypress	Tupelo†
2001	100	100	1.03 (0.02)	0.56 (0.01)
2002	88 (4)	63 (5)	-	-
2003	82 (5)	26 (8)	1.26 (0.08)	0.62 (0.06)
2004	81 (5)	25 (8)	1.49 (0.10)	0.91 (0.09)
2005	79 (5)	23 (8)	1.93 (0.12)	1.20 (0.13)

*at time of planting in 2001; in April/May of subsequent years

† planted stock was found to include some water tupelo as well as swamp tupelo

FIGURE 3.2. Relative cover (%) of herbaceous wetland (OBL/FACW) species as a function of annual hydroperiod, averaged over 2004 and 2005 for each restored wetland. r_s is Spearman's rank correlation, where df = 14 and P < 0.01.



Aquatic Invertebrates in Carolina Bays and Other Wetland Ponds Before and After Restoration Treatments

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Introduction. Aquatic invertebrates are abundant and diverse in Carolina bays and other wetland ponds of the Savannah River Site (SRS), and they play important roles in the trophic structure of the communities (Taylor et al., 1999). We are studying 20 wetland ponds as part of the Carolina Bay Restoration Project conducted by the U.S.D.A. Forest Service with cooperation and collaboration of Savannah River Ecology Laboratory, the U.S. Fish and Wildlife Service, and several universities (Barton and Singer, 2001). All of these ponds had been ditched before 1951, when the land was acquired by the federal government. Most of the ditches were probably dug between the mid-19th and early 20th centuries to facilitate use of the land for crops or livestock. Since the creation of the SRS, all of sites had become forested, mainly with bottomland hardwoods or pine.

Methods. The pre-treatment information on the wetland ponds provides a baseline for detecting faunal changes after the ditches were plugged to restore natural hydrology in 2001-2002. Bimonthly sampling was conducted for three years during the pre-treatment phase (1998-2000, except August-October 1998). Sampling continued through 2001-2004 to characterize responses to treatment. Microcrustaceans were sampled qualitatively with a small, hand-held 100-Φm mesh net; macroinvertebrates were sampled semi-quantitatively with a standard 1-mm mesh D-frame sweep net. Because the set of ponds for the restoration study was changed after we began sampling, we have 3 years of pre-treatment data for 17 of the 20 ponds, 1 year for 2 ponds, and none for 1 pond.

<u>Predicted effects of treatments.</u> For the microcrustaceans, we predicted that species richness would increase with hydroperiod and with conversion from forested to herbaceous vegetation. We predicted that new species would colonize slowly. We also predicted that ephemeral habitat specialists, such as the clam shrimp *Lynceus gracilicornis*, would disappear in from ponds where hydroperiod was substantially increased. These predictions were based on extensive previous studies of local wetland ponds (for example: assemblages Mahoney, Mort, and Taylor, 1990, DeBiase and Taylor, in prep.; population dynamics and production Taylor and Mahoney, 1990, Leeper and Taylor, 1998; genetics Boileau and Taylor, 1994; life histories Taylor, Wyngaard, and Mahoney, 1990, Medland and Taylor, 2001).

For the insects, by analogy to microcrustaceans, we expected that species richness would increase with hydroperiod and with conversion from forested to herbaceous vegetation. We predicted that richness of large predatory insects, such as odonates, would increase with hydroperiod and that new species would colonize rapidly. These predictions were based on a few previous studies (assemblages McClure, 1994; population dynamics and production Schalles and Shure, 1989, Leeper and Taylor, 1998; life histories Cross, 1955, Kondratieff and Pyott, 1987).

Results.

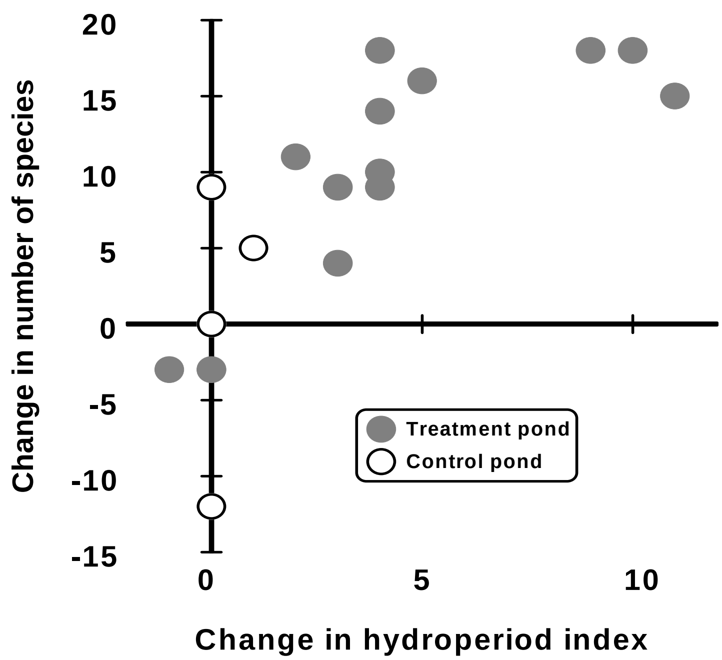
Responses to treatment. Restoration treatments were partially completed in 16 ponds in 2001, while 4 ponds were left untreated as controls. Because the designated set of study ponds changed after we began to sample, we have three years of pre-treatment data for 17 of the 20 ponds, 1 yr for 1 pond, and none for 2 ponds. Most of the treatments were completed in January 2002. The drought that began in late 1998 continued through 2002: one of the control ponds did not hold water on any post-treatment sampling dates in 2001-2002. All microcrustacean samples from February 2001 to December 2004 have been processed and analyzed. Processing of macroinvertebrate samples is underway.

Although the ditches affected the timing and duration of inundated periods, all of the basins supported functioning wetland ponds during the pre-treatment phase of the project (Dietz, 2001; Dietz et al., 2001).

Restoration extended the hydroperiods in all but two of the treatment ponds (Fig. 4.1). Species richness (3 to 35 species per pond before treatment; 12 to 37 species per pond after treatment) increased substantially in most of them. Responses were quicker than we predicted. Because all of the basins did support functioning wetland ponds before restoration, some species may have been present but dormant during the pre-treatment phase. Some may have been inadvertently imported during treatment activities. We have not yet detected loss of ephemeral hydroperiod specialists or responses to vegetation treatments.

The most serious limitation to the use of microcrustaceans in restoration studies has probably been the lack of baseline data for interpreting the results. Our protocols yielded many species (86 total) with modest effort. The taxonomy is manageable, we believe, especially among the wetland pond specialists. Because microcrustacean assemblages are dynamic, we do caution that sampling across seasons is critical. In further analyses, we will evaluate other metrics of response, such as indicator taxa or trajectories of assemblage composition (see Philippi, Dixon, and Taylor, 1998).

Figure 4.1. Response of microcrustacean species richness to restoration. Change in hydroperiod index is the difference between numbers of sampling dates when the pond held water during pre-treatment (1998-2000) and post-treatment (2001-2003) phases. Change in number of species is the difference between totals for the pre- and post-treatment phases. Three ponds are omitted because we lack complete pre-treatment data.



Demographic Responses of Amphibians to Wetland Restoration in Carolina Bays on the Savannah River Site

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Introduction. Commonly, guidelines for the assessment of success in recreated or mitigated wetlands require only the estimation of the survival of the planted trees and herbaceous wetland species. However, survivorship and growth of vegetation does not necessarily indicate functional success of the site. Therefore, more meaningful prescriptions are needed to define and evaluate success in restored or regenerated wetland areas. One recognized function of wetlands is in providing habitat for wildlife. Amphibians are sensitive within a narrow range of environmental conditions due to their permeable skin and biphasic life cycles, and many species are obligate wetland breeders. Therefore, amphibians are a logical choice to consider as a metric for restoration success due to their life history characteristics. Carolina bays serve as an important amphibian breeding sites. Many amphibians are philopatric and move less than two hundred meters from the breeding area. The temporal and spatial processes that affect colonization of restored sites have not been rigorously investigated.

This study examines the effects of hydrology and spatial context within a landscape of Carolina bays and neighboring wetlands on amphibian communities at the Savannah River Site. Variability in population and community parameters of amphibian species in healthy Carolina bay wetlands will be modeled for restoration and mitigation objectives.

Methods. The study included three 'reference' bays (functionally intact), three 'control' bays (with active drainage ditches), six 'treatment' bays (restored during 2001), and fours 'source' bays near two of the treatment bays (in effect creating two meta-populations). For purposes of this study, the 6 'treatment' bays were further classified into 2 groups of 3 bays as 'restored, un-thinned buffer' bays for sites which were not logged in the upland buffer and 'restored, thinned buffer' bays for those which were logged in the upland buffer as part of the restoration effort. Our reference bays were 79, 153, and 5038. Control bays were 118, 147, and 5055. The source bays were 168, 188 (located near treatment bay 5204) and 55 and 5170 (located near treatment bay 5135). The restored, un-thinned buffer bays were 5071, 5128, and 5204. The restored, thinned buffer bays were 126, 5135, and 5190.

Each bay was partially encircled with drift fences and pitfall traps such that approximately one-fourth of each bay was surrounded. Amphibians were given batch marks designating year and bay of capture using visible implanted elastomers. Amphibians were measured, marked, and released between January and July, 2000-2003. 2000 was a pre-restoration year, the bays were restored prior to the trapping season in 2001, and 2002 & 2003 were post-restoration years.

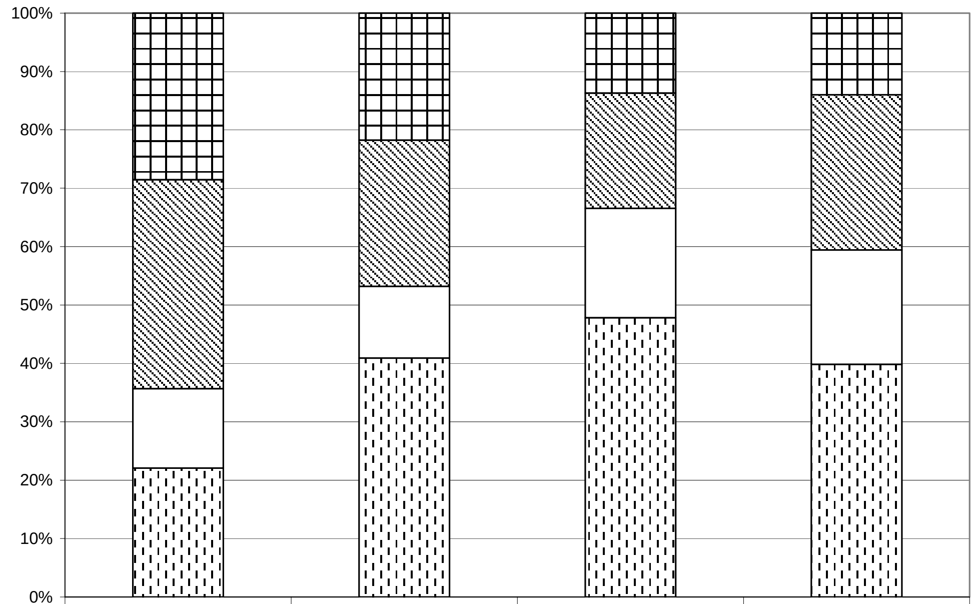
Results. A total of 43,342 amphibian captures representing 24 species occurred during the study (Table 5.1). Figure 1 illustrates the number of captured amphibians (excluding within-year recaptures) standardized by the number of available trap-nights for each year of the study. The number of traps varied between sites as the bays were of differing sizes. In addition, traps would occasionally flood, making them unavailable for short periods of time. The number of available trap-nights, then, is the sum of the number of traps available every night of the study. During year 2000, the 3 reference bays accounted for 36% of all captures, followed by the control bays with 28%, while all 6 treatment bays had only 36%. Post restoration, this began to change with the restored bays accounting for 54% of captures (with the un-thinned buffer bays having 41% and the thinned buffer bays having 13%) while the reference and control bays began to account for fewer captures. As evident from this figure, the restored, un-thinned buffer bays responded faster and more dramatically than the restored, thinned buffer bays.

Salamanders represent only 6,202 (or 14.3%) of total captures at all bays during the study. As evident in the table in Figure 5.2, salamander captures decreased at all bay classifications each year of the study (with the exception of the reference bays which increased between 2002 and 2003, but did not reach the numbers captured during 2000 and 2001. Most likely, the decrease can be attributed to the severe drought the region experienced during 2002 and a delay in the rainfall of 2003 resulting in drought-like conditions during the normal salamander breeding season. As the decrease in salamander captures was less dramatic in the control, reference, and even to a lesser extent the restored, un-thinned bays, it is possible that the additional timer harvest associated with the restored, thinned buffer bays may have also contributed to the decreased captures. The only statistically significant result determined by a repeated measure ANOVA was that the bays that underwent additional logging in the buffer experienced a significantly larger decrease in salamander populations than did the restored sites that were not logged in the buffer area. It is expected that these areas will recover in terms of salamander populations but a longer monitoring period would be recommended to support this assumption.

Anurans responded well to the restoration efforts. The restoration appears to have provided additional breeding habitat for several anuran species. Several species of anurans, including eastern spadefoot toads and southern toads, appear responded to the restoration efforts with respect to both increased adult breeding attempts and the number of metamorphic juveniles leaving the breeding bays. In Figure 5.3 the 2 restoration treatments combined account for only 39% of captures during the pre-treatment year, but for 73% of the captures by the second year post-restoration. While both restoration treatments created a favorable response for anuran species, the restored, un-thinned buffer bays had larger numbers of anuran captures than did the restored, thinned buffer bays.

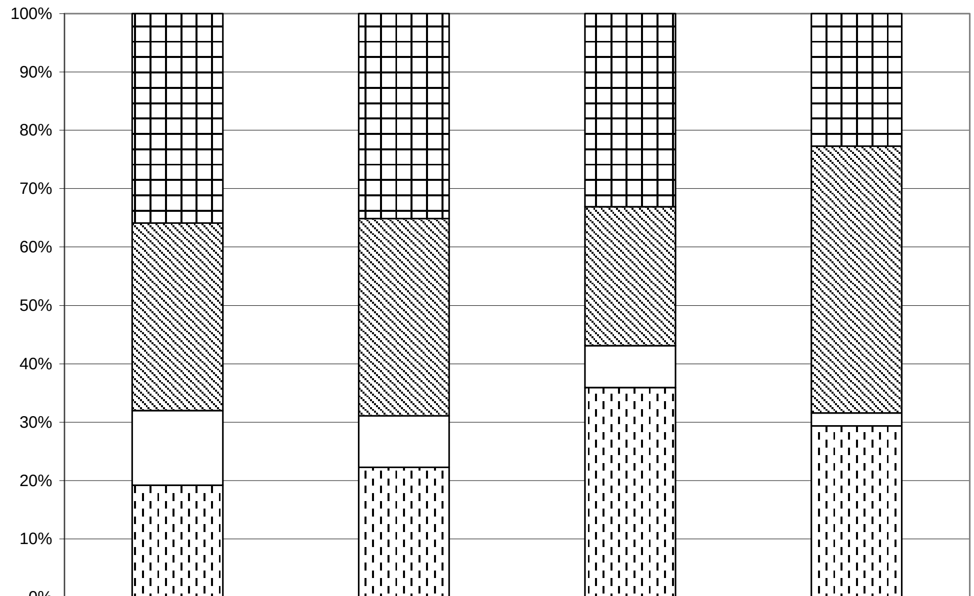
Table 5.1 Total number of amphibians captured alive or dead within each treatment classification during the entire study. Thinned bays underwent logging in the buffer zone around the bay and un-thinned bays had no harvesting within the buffer.

Species	Reference	Restored, thinned treatment	Restored, un-thinned Treatment	Control
Salamanders				
Ambystoma maculatum	21	0	403	32
Ambystoma opacum	401	220	99	492
Ambystoma talpoideum	1536	177	378	1694
Ambystoma tigrinum	9	2	1	55
Eurycea quadradigitata	2	2	1	8
Notophthalmus viridescens	30	61	44	125
Plethodon glutinosus	96	55	90	116
Pseudotriton ruber	21	0	3	27
Sub-total	**2116**	**518**	**1019**	**2549**
Anurans				
Acris gryllus	17	13	3	5
Bufo quercicus	57	4	4	0
Bufo terrestris	2453	1308	4072	1109
Gastrophryne carolinensis	1533	1036	1486	1060
Hyla cinerea	121	123	156	12
Hyla femoralis	63	2	201	173
Hyla squirella	0	2	26	0
Hyla versicolor/chrysoscelis	4	0	2	8
Pseudacris crepitans	18	15	4	6
Pseudacris nigrita	1	0	1	0
Pseudacris ornate	401	26	48	43
Rana capito	10	0	0	0
Rana catesbeiana	7	17	4	6
Rana clamitans	32	39	10	7
Rana utricularia	1586	188	346	1512
Scaphiopus holbrookii	2142	839	9686	1243
Sub-total	**8445**	**3612**	**16039**	**5184**
Count total	**10561**	**4130**	**17058**	**7733**



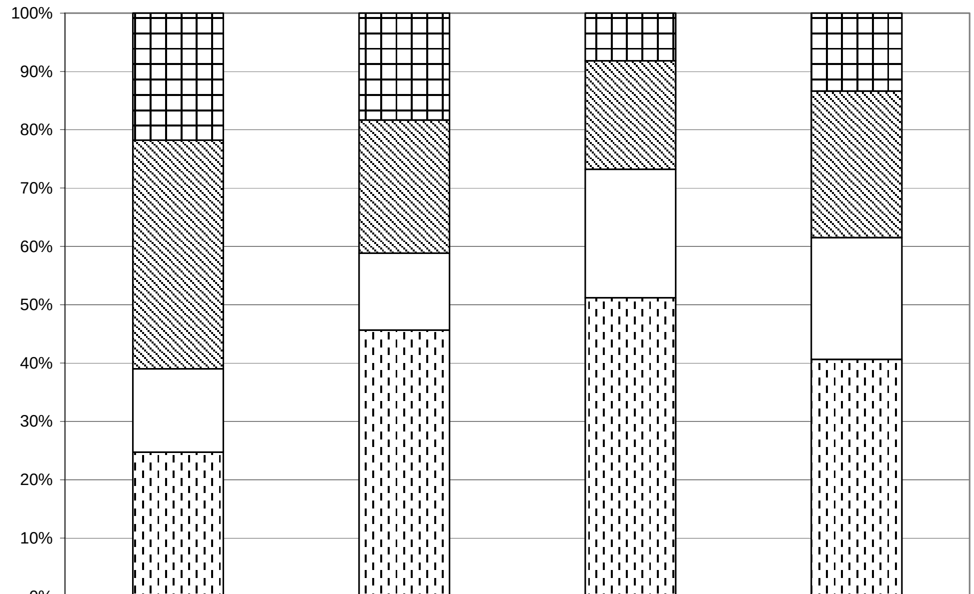
	2000	2001	2002	2003
Control	0.18469956	0.287598302	0.044005102	0.176062201
Reference	0.231849747	0.331346649	0.063456633	0.333935398
Restored, thinned	0.087955009	0.162524546	0.060131195	0.245770019
Restored, un-thinned	0.142958282	0.541318933	0.153658487	0.500759983

Figure 5.1. Total number of amphibian captures per trapnight by Carolina bay classification. Actual numbers per trapnight are presented in the data table under the graph. The graph shows the percentage of captures associated with each bay classification each year.



	2000	2001	2002	2003
Control	0.111094924	0.094163032	0.023498823	0.01997944
Reference	0.099431818	0.090689433	0.01690051	0.040176014
Restored, thinned	0.039638425	0.023656112	0.005091918	0.001975409
Restored, un-thinned	0.059372492	0.059697676	0.025520327	0.025797578

Figure 5.2. Number of salamander captures per trapnight by Caroline bay classification. Actual numbers per trapnight are presented in the data table under the graph. The graph shows the percentage of captures associated with each bay classification each year.



	2000	2001	2002	2003
Control	0.073604636	0.19343527	0.020506279	0.156082761
Reference	0.132417929	0.240657216	0.046556122	0.293759384
Restored, thinned	0.048316583	0.138868434	0.055039278	0.24379461
Restored, un-thinned	0.08358579	0.481621257	0.12813816	0.474962405

Figure 5.3. Number of anuran captures per trapnight by Caroline bay classification. Actual numbers per trapnight are presented in the data table under the graph. The graph shows the percentage of captures associated with each bay classification each year.

Conclusions. This study indicates that amphibians are a good metric with which to quantify wetland restoration success. More amphibians used the restored areas post-restoration. This study has shown that salamanders may be more susceptible to the restoration techniques (i.e. the use of heavy equipment) than anurans, suggesting that more than 3 years may be needed for salamander populations to recover from the process of habitat restoration. One potential drawback for using amphibians as a metric for success is the natural variation in amphibian breeding numbers. There is very high annual amphibian species composition and abundance among Carolina bays, making it difficult to distinguish a failed restoration from a drought year. Post-restoration monitoring needs to continue over a time frame long enough to allow average weather patterns, which heavily influence amphibian breeding, such that restoration assessment is not completely confounded with abnormal weather.

On a shorter timeframe, anuran species, toads in particular, may provide an immediate indicator of the potential success of a wetland restoration project. These species appear to require less time to recover from impacts associated with restoration and need shorter hydroperiods to complete breeding and juvenile metamorphosis. Combining information, from both anurans, as a short term indicator, and salamanders, as a long term indicator, should provide ample information as to the success of a wetland restoration project.

The Influence of Buffer Zone Management Techniques on Caroilina Bay Herpetofauna

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Introduction. Carolina bays are isolated wetlands that are unique to the southern portion of the Atlantic Coastal Plain. At least 34 species of amphibians are known to occur in Carolina bays on the Savannah River Site (SRS), near Aiken, South Carolina. Of these 34 amphibians, 31 species are terrestrial for at least a portion of their lives, and therefore also inhabit the thousands of acres of upland forests that border Carolina bays (Schalles et al,1989; Gibbons and Semlitsch, 1991). In addition, many reptile species use aquatic sites for food and cover and migrate to upland sites for nesting. Thus, the uplands adjacent to Carolina bays support high biodiversity of both reptiles and amphibians, and both the wetlands and their forested buffers provide important habitat for these and many other species, both vertebrates and invertebrates.

In the years 2000-2001, the Department of Energy initiated the restoration of 16 Carolina bays on the SRS as part of a wetland mitigation banking program. These bays had been ditched and drained before 1951, and all were forested at the time of restoration, which included harvest of trees from the bay interiors. Along with bay restoration, the program was designed to test two alternative treatments within the 100-meter upland buffers: closed-canopy mixed pine-hardwood versus open-canopy, prescribed-burned pine savanna.

Methods. In 2001, twelve bays were selected for upland herpetofauna monitoring. Six study bays were chosen with regard to the planned endpoint for the 100-meter buffer vegetation. Three would keep their mixed pine-hardwood buffers (pine-hardwood bays), and three would be thinned to become open canopy pine savanna (savanna bays). Three control bays that would not be restored until after 2005 and three reference bays that had never been drained were also monitored. During the same year, two herpetofaunal trapping arrays were installed 50 meters from the edge of each bay. One array was sited in the direction of the next-nearest neighboring wetland, and the other was placed on the opposite side of the bay. Drift fence arrays consisted of three 15 m fences, 1 m high and buried to a depth of at least 10 cm in a y-shaped configuration. Traps at each array included twelve pitfall traps, six funnel traps, three lengths of PVC tubing, and twelve 0.61 X 1.22 m coverboards, six plywood and six galvanized tin. The arrays were sampled every second day from January through July, beginning in 2002 and ending in 2005.

Vegetation surveys of the buffer sites centered on each array were conducted during August 2001 before harvest, and again during each of the following four summers until herpetofaunal monitoring was discontinued. Data collected included canopy coverage, diameter at breast height and species identification of overstory and mid-story trees, ground cover species coverage levels, coarse woody debris volume, and leaf litter depth.

This research was designed to test several hypotheses about the responses of reptile and amphibian assemblages to Carolina bay restoration and also to vegetation structure in the upland buffer. With regard to bay restoration, it was hypothesized that the buffers surrounding reference bays harbor the highest richness, diversity, and abundance of both reptiles and amphibians, that restored bays support less richness, diversity, and abundance than reference bays, but more than control bays. Assemblages in pine savanna buffers were expected to include a different suite of species than at those in mixed pine-hardwood buffers, both because of the more intensive recent disturbance, and because species adapted to higher levels of insolation under the open canopy could be expected to be more common in the savanna buffers. Once the data is analyzed, the vegetation data will allow other hypotheses to be investigated regarding the responses of herpetofaunal assemblages to the structure of vegetation in the uplands surrounding Carolina bays: whether herpetofaunal assemblage structure is more affected by wetland attributes like hydroperiod and bay size, or whether vegetation structure in the buffer plays a larger role in determining the herpetofaunal community structure in the buffer.

Results. From 1 January 2002 to 31 July 2005 a total of 47,334 individual amphibians and reptiles representing 67 species were captured. Amphibians comprised 97.0% of total captures. There were 19 species of frogs and toads (n=42,619, 90.0% of total captures) and 8 species of salamanders (n=3,304, 6.98% of total captures) (Table 6.1). The Eastern Spadefoot, *Scaphiopus holbrooki*, was the most commonly encountered anuran (n=20,677, 43.7% of total captures), while the Mole Salamander, *Ambystoma talpoideum*, was the salamander captured most often (n=2,442, 5.2% of total captures). Forty species of reptiles comprised only 3.0% of the total number of captures (n=1,411). Of these, seven species of lizards (n=998) represented 70.7% of reptile captures (2.1% of total captures).

In addition to these most-often captured species, we documented eleven South Carolina species of conservation concern at the twelve Carolina bays we sampled. On average, only 1.3 of these species of concern were found at each control bay, while restored bays averaged 2.3 species in mixed pine-hardwood buffers and 3 species in savanna buffers. An ANOVA comparison shows no significant differences between treatments, however.

Three explosive breeding frog species were the most commonly encountered species, and they were captured in greater numbers at restored bays than control bays, regardless of buffer treatment. This indicates that these more opportunistic species are taking early advantage of the restored habitat. Other upland-adapted frog species, those which migrate relatively long distances from water after breeding, were captured in the greatest numbers at reference bays, but were also captured more often in savanna buffers than pine-hardwood buffers or at control bays. Two of these species are South Carolina species of concern, including the state-endangered Carolina Gopher Frog.

The Carolina Gopher Frog is a longleaf pine savanna specialist (Means, 2006), and is listed as an endangered species in South Carolina. It breeds in fish-free wetlands and has been documented only sporadically on the SRS, despite extensive monitoring of many of its wetlands (Semlitsch et al, 1995). In 2003, we captured adult Carolina Gopher Frogs entering two of the bays with savanna buffers during the short, rainfall-dependent breeding season. In June of the same year, we captured emigrating juveniles at the third savanna bay and also at a single reference bay. In 2005, we captured adults and juveniles at the same reference bay and a single adult at a fifth bay, a restored bay with a mixed pine-hardwood buffer. It is likely that bay restoration enhanced available breeding habitat for this species.

Table 6.1. Mean captures per year per bay of herpetofaunal guilds. Treatments with different letters were significantly different (α=0.05). Too few turtles and aquatic snakes were captured for analysis.

Taxon Guild	Control *(Mean ± S.E.)*		Pine-Hardwood *(Mean ± S.E.)*		Savanna *(Mean ± S.E.)*		Reference *(Mean ± S.E.)*		P
Amphibians									
Frogs									
Explosive Breeders	155.8 ± 32.9	**A**	267.5 ± 46.9	**B**	302.4 ± 67.8	**B**	257.9 ± 52.7	**AB**	0.0232
Upland Frogs	1.6 ± 0.8	**A**	2.1 ± 0.6	**AB**	5.4 ± 1.9	**B**	18.3 ± 8.6	**C**	0.0028
Aquatic Frogs	5.8 ± 2.4	**B**	11.8 ± 4.2	**B**	2.6 ± 0.9	**A**	21.3 ± 6.5	**C**	0.0002
Arboreal Frogs	2.8 ± 1.1	**A**	18.1 ± 7.7	**B**	4.3 ± 1.9	**A**	5.6 ± 1.3	**AB**	<0.0001
Salamanders									
Aquatic Breeders	43.1 ± 22.6	**A**	48.7 ± 19.6	**A**	33 ± 9.4	**A**	99.1 ± 29.8	**B**	0.0081
Terrestrial Breeders	4.2 ± 1.7	**AB**	7.3 ± 2.3	**B**	2.4 ± 0.8	**A**	4.5 ± 0.8	**AB**	0.0449
Reptiles									
Lizards									
Mesic Lizards	12.8 ± 4.3	**A**	13.8 ± 2.2	**A**	10.7 ± 1.7	**A**	17.2 ± 2.6	**B**	0.0343
Xeric Lizards	6.3 ± 1.5	**B**	2.7 ± 0.9	**A**	10.7 ± 3	**B**	8.8 ± 2.1	**B**	0.0017
Snakes									
Fossorial Snakes	3.8 ± 1.5	**A**	5.3 ± 1	**A**	3.3 ± 1.1	**A**	6.1 ± 2.3	**A**	0.2166
Large Snakes	2 ± 0.7	**A**	2.7 ± 0.7	**A**	2.8 ± 0.7	**A**	2 ± 0.7	**A**	0.3806
Aquatic Snakes	0.58 ± 0.42	-	0.25 ± 0.18	-	0.42 ± 0.23	-	0.75 ± 0.37	**-**	-
Turtles	0.2 ± 0.1	**-**	1 ± 0.4	**-**	0.6 ± 0.3	**-**	1.7 ± 0.4	**-**	-

Arboreal frogs appear to be early colonizers of the restored bays with pine-hardwood buffers, taking advantage of the mesic conditions under the intact buffer canopy and the emergent vegetation in bay interiors for calling sites. Several species of frogs that are rarely found far from water were captured most often at reference bays and least often in savanna margins, where they may be more prone to desiccation. Aquatic-breeding salamanders, mostly the Mole Salamander and other *Ambystoma* species, were captured in the greatest numbers at reference bays. The terrestrial-breeding members of the Slimy Salamander complex were captured less often in savanna buffers than pine-hardwood buffers, an indication that thinning may have had a negative impact, perhaps both directly due to the disturbance of forestry operations and also due to the decreased canopy coverage.

The seven lizard species were remarkably ubiquitous - only three bays supported less than all seven species. More individuals of mesic species of lizards were captured at reference bays, but less of the xeric-adapted and sun-loving species were captured in pine-hardwood buffers. Though snakes comprised almost 40% of the study-wide species richness, they only made up 1% of the captures. No treatment effects were detected for captures of all snakes or for the smaller fossorial and semi-fossorial species. Other snake groups were captured too infrequently to analyze, as were turtles.

Using a repeated measures ANOVA on adult individuals (non-recaptures), we found similar diversity (Shannon-Weiner's H'), species richness (S_{obs}), and evenness (Pielou's J') of both reptiles and amphibians at all treatments, with the single exception of Shannon's diversity index for reptiles. Reptile diversity was higher at reference bays and restored bays with pine-hardwood buffers than it was at control bays or restored bays with thinned buffers. However, after slicing the results to search for differences between treatments within specific years, the only year in which the difference was significant was 2003, the extremely wet year with by far the fewest reptile captures and lowest richness.

While diversity indices and other metrics like richness and evenness are often useful, they can also oversimplify the complex interactions of species presence and absence. Dissimilar communities with similar species richness and relative abundances can appear to be equivalent, even when different species are thriving. In this case, the lack of differences in overall diversity measures obscures the fact that species with differing habitat requirements are more abundant at different treatments. Nevertheless, the diversity index, richness, and evenness metrics followed a consistent pattern, with reference bays exhibiting the highest diversity and control bays the lowest, though the differences were not significant. Four years of sampling may not be sufficient to see these patterns, with some authors recommending a minimum of five years (Petranka et al, 2003; Pechmann et al, 1991), due to the highly variable, weather-dependent activity patterns of these animals. During the extremely dry year of 2002, for example, very few amphibians were captured, yet during the following extremely wet year, amphibian captures increased by an order of magnitude, while richness and abundance of captured reptiles were low. Since sampling was begun immediately after restoration, much of the differences we have seen can be considered a response to disturbance, especially since the desired vegetation structures will likely take several more years to develop. Additionally, the vast majority of reptiles and amphibians that may colonize these sites are relatively philopatric and are not strong dispersers, so it may take several years before the communities reach a relatively stable species composition, especially at the more isolated bays. Sampling after more time has passed since restoration could cause some of the patterns indicated by our data to be more clearly discerned.

Bird Response to Carolina Bay Restoration

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Introduction/Methodology. We assessed bird response to bay restoration and to two alternative goals within the 100-m upland margin surrounding each bay (pine savanna versus mixed pine-hardwood forest). We compared bird use of restored bays to that of control (drained, un-restored) and reference (undisturbed) bays. We compared the following among restoration treatments: density of breeding forest birds and frequency of use by foraging wetland birds (waterfowl and wading birds).

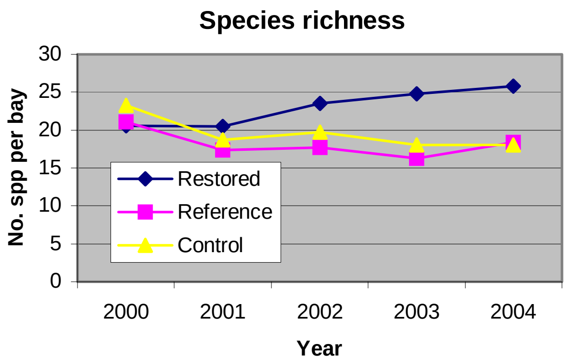
Results. Drainage of bays does not seem to affect birds using the uplands surrounding bays but it eliminates wetland birds, as this group was less abundant in drained bays (pre-restoration) than in herbaceous and forested reference bays.

Table 7.1. Mean pre-restoration bird observations.

Birds	*Drained (mean ± SE)*	*Reference (mean ± SE)*	*P*
Total no. species	21.0 ± 1.0	23.5 ± 1.8	0.220
Total no. individuals	98.7 ± 8.0	116.3 ± 11.3	0.202
Wetland Species			
No. species	0	8	N/A
No. individuals	0	26	0.004
Upland Species			
Brown-headed Nuthatch (*Sitta pusilla*)	0.69 ± 0.51	0.54 ± 0.75	0.631
Indigo Bunting (*Passerina cyanea*)	2.23 ± 0.79	3.68 ± 1.23	0.309
Summer Tanager (*Piranga rubra*)	3.03 ± 0.61	3.22 ± 0.72	0.840

Bird response to restoration was monitored during the breeding seasons for one year pre-restoration (2000) and four years post-restoration (2001-2004) using strip transects through the bays and upland buffers.

Species richness and abundance were lowest in restored bays prior to their restoration, but by the first breeding season post restoration, both community indices were higher in restored bays than in either reference bays or control bays. This was likely due to a response by upland birds, which dominate the avian communities of the treatment areas, to the buffer treatments (see below).



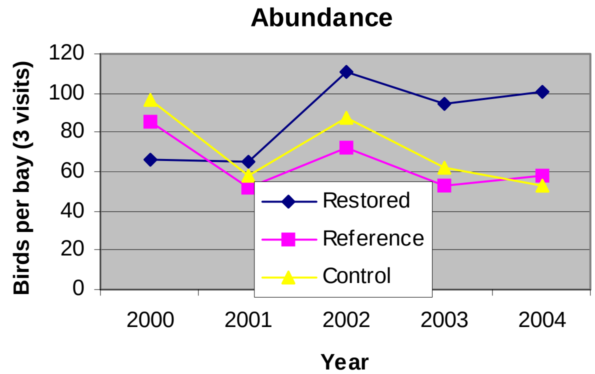


Figure 7.1. Species richness and abundance of restored, reference and control bays.

Prior to restoration (2000), no wetland birds were observed in any bay under study, including reference bays, presumably due to drought conditions. During the first year post-restoration, restored bays supported approximately half as many wetland birds as reference bays, while unrestored bays (controls) had none. In 2002, water levels were again low and no wetland birds were observed in the bays. However, in both 2003 and 2004 when the drought had ended, restored bays supported as many or more wetland birds than reference bays, both of which supported more than control bays.

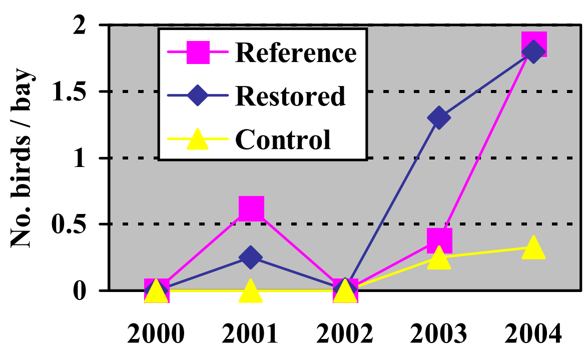


Figure 7.2. Number of wetland birds observed in restored, reference and control bays.

Species richness and the abundance of most bird species (primarily upland species) responded to the margin treatments also, with abundance differing over time. Although species richness in pine savanna buffers declined initially due to the understory disturbance from treatment harvesting, most species were more abundant in pine savanna buffers by the second year post-treatment. Three general responses were observed, as typified by Brown-headed Nuthatch, Indigo Bunting, and Red-eyed Vireo. Species that nest and forage in the pine canopy (e.g., Brown-headed Nuthatch), responded positively to the removal of hardwoods in the first year post-treatment and their abundance remained high in the savanna treatment. Species that nest in the understory of the pine forest (e.g., Indigo Bunting), responded positively in the second year post-treatment, as understory structure increased with the canopy thinning, and their abundance remained high. Species that use hardwoods and tend to avoid open savanna and edge habitat (e.g., Red-eyed Vireo) declined overall, but more dramatically where hardwoods were removed (i.e., in pine savanna buffers).

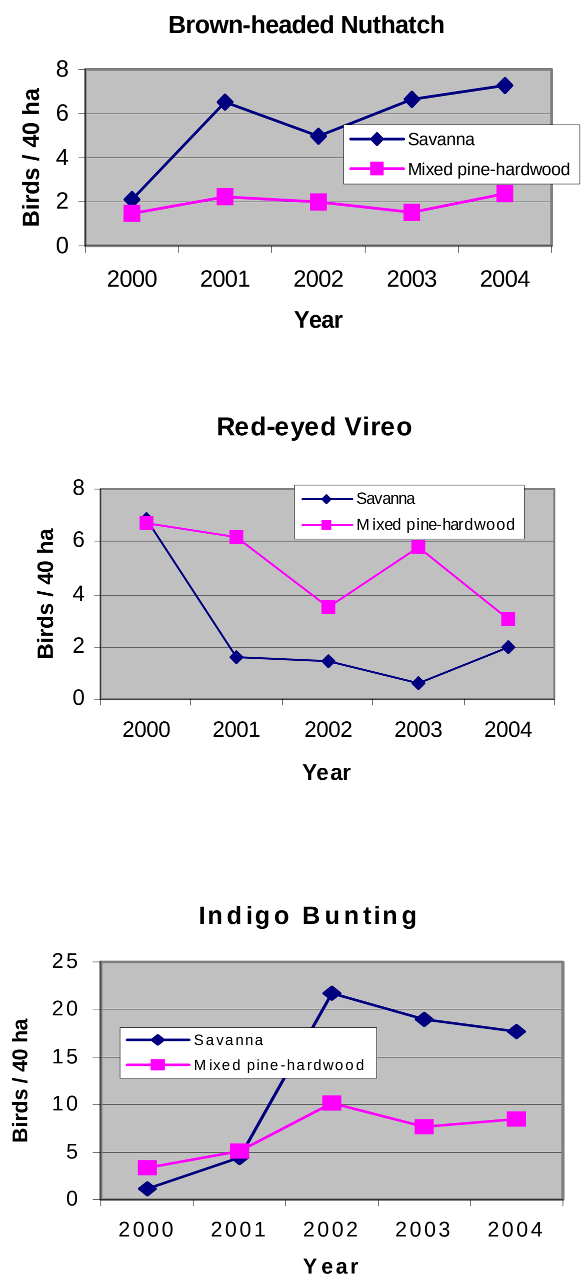


Figure 7.3. Influence of margin treatment on bird usage.

Despite severe drought that limited restoration of the hydrology of Carolina bay wetlands, several species of birds responded positively to bay restoration activities. Wetland birds, which had not used the bays prior to restoration, were recorded whenever water was ponded at numbers at least as great as in undisturbed bays. Additionally, upland birds of the shrub-scrub community, a group of considerable conservation concern, responded positively to management of the upland pine savanna buffers surrounding bays.

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Awards

United States Forest Service, Regional Forester's Award for Natural Resource Stewardship; Carolina Bay Restoration Project; 2006. (Research and Management Team awarded for the Carolina bay restoration project)

Society of Wetland Scientists: Honorable Poster Presentation; Award to Danielle Andrews, 2005. (Danielle received the award for her poster on Carolina bay soils and hydrology)

Outstanding Student Award to S. E. Dietz-Brantley, The Entomological Society of Pennsylvania, 2002. (Susan received this award for her M.S. thesis work on the restoration bays.)

Appendix I

Carolina Bay Success Criteria Summary Sheets

Appendix I. Individual bay summaries of post-restoration hydrology and vegetation, and assessments of restoration success.

Each restored wetland was evaluated for success in three categories:

1. By year 5, did hydrology and vegetation meet COE *jurisdictional* criteria?
2. By year 5, did hydrology and vegetation measures *increase* from pre-restoration (year 0) values?
3. By year 5, did hydrology and vegetation measures achieve *reference* wetland values, or show a positive trajectory toward those values?

Hydrology Assessment: Mean post-restoration annual and growing-season hydroperiods (averaged over years 1–5) were scored as follows:

1. "yes" for jurisdictional hydrology if continuously inundated for >5% of the growing season (11 days)
2. "yes" for any increase in mean post-restoration hydroperiod over the pre-restoration value
3. "yes" for meeting reference criteria if mean hydroperiod was:
    a. >30% for forested bays and >50% for herbaceous bays on an annual basis
    b. >30% for forested bays and >40% for herbaceous bays during the growing season
    [minimum threshold values based on a 1995–2003 hydrology dataset for 6 forested SRS bays and 14 herbaceous SRS bays that were relatively undisturbed (R. F. Lide, unpublished data)]

Also presented are the maximum observed water depth and ponded surface area.

Vegetation Assessment: Five measures (species richness, % herbaceous species, relative herbaceous cover, % wetland species, and relative cover of wetland species) were each scored as follows:

1. "yes" for jurisdictional vegetation if ≥50% of species and cover in year 5 have an indicator category of FAC or wetter
2. "yes" for increase from pre-restoration if the net difference between year 0 and year 5 was at least 11 species for richness or at least 20% for all percentage variables. [These values represent at least a 50% increase over pre-restoration means.]
3. "yes" for meeting reference criteria if the year 5 value met or exceeded the minimum of the typical range for reference wetlands (De Steven & Toner 2004), with threshold values of:
    a. 10 species for species richness (all wetlands)
    b. 60% for relative number and cover of herbaceous species (emergent wetlands only; forested wetlands are immature and have no required threshold for herb or woody cover)
    c. 60% for relative number and cover of wetland (OBL/FACW) species (all wetlands)

    Percentage variables were scored as "marginal" if within 5% of the reference value.

4. In addition, for bays experimentally targeted as "forested" wetland, survival of planted trees was required to be ≥50% by year 5.

Also presented are the dominant plant species by year 5, generally based on the 50/20 rule.

Success Evaluation: The experimental design assigned a target vegetation type (herbaceous or forested) randomly to each bay. However, a restored hydroperiod is constrained by basin geomorphic properties, and may be inadequate to support the assigned target. In particular, emergent herbaceous vegetation is difficult to maintain without a long hydroperiod or recurring fire. Therefore, if assessments in categories 1 and 2 were positive, we considered restorations successful even if they did not fully match the originally targeted reference type (category 3).

Bay 5 Summary Measures (*Target*: emergent herbaceous wetland; hardwood-pine forest buffer)

Measure	Value by year 5	Wetland meets jurisdictional criteria?	Value increased from pre-restoration?	Value meets or on trajectory to reference standard?
Hydrology				
Mean annual hydroperiod (% of year)	92	–	yes	yes
Mean growing-season hydroperiod (% of year)	93	yes	yes	yes
Maximum water depth (cm)	76	–	–	–
Maximum surface area (ha)	1.20	–	–	–
Vegetation				
Species richness (no.)	22	–	no	yes
% herbaceous species	64	–	yes	yes
Rel. herbaceous cover (%)	81	–	yes	yes
% OBL/FACW species	86	yes	yes	yes
Rel. OBL/FACW cover (%)	94	yes	yes	yes

Dominant species in year 5 (% cover): *Carex striata* (54), *Acer rubum* (8)

Summary: Before restoration (year 0), this was a wet site that ponded for 74% of the year and 55% of the growing season. Vegetative cover was 71% wetland (OBL/FACW) species, but 65% woody. After restoration (year 5), the wetland has a semipermanent hydroperiod (mean >90%) and vegetation dominated by OBL/FACW herbaceous (emergent) species. Nearly all measures increased from pre-restoration values, and cover of a typical dominant emergent (peatland sedge, *C. striata*) nearly doubled from its pre-restoration extent. Only minor resprouting of red maple and sweetgum has occurred.

Assessment: Successful hydrology enhancement and conversion to emergent wetland. The wetland meets both jurisdictional and reference criteria for hydroperiod and vegetation.

Remedial actions: None needed.

Bay 124 Summary Measures (*Target*: forest/savanna wetland; pine savanna buffer)

Measure	**Value by year 5**	**Wetland meets jurisdictional criteria?**	**Value increased from pre-restoration?**	**Value meets or on trajectory to reference standard?**
Hydrology				
Mean annual hydroperiod (% of year)	63†	–	yes	yes†
Mean growing-season hydroperiod (% of year)	59†	yes	yes	yes†
Maximum water depth (cm)	57†	–	–	–
Maximum surface area (ha)	0.86	–	–	–
Vegetation				
Species richness (no.)	58	–	yes	yes
% herbaceous species	63	–	yes	yes
Rel. herbaceous cover (%)	32	–	yes	yes
% OBL/FACW species	56	yes	yes	marginal
Rel. OBL/FACW cover (%)	35	yes	no	no
		–	–	–
Planted cypress survival (%)	83	–	–	yes
Planted tupelo survival (%)	22	–	–	no
Mean cypress height (m)	1.74	–	–	–
Mean tupelo height (m)	1.61	–	–	–

†ponded area confined primarily to a 0.15 ha portion of the total area

Dominant species in year 5 (% cover): *Liquidambar styraciflua* (22), *Acer rubrum* (11), *Dichanthelium* spp. (9), *Quercus nigra* (6), *Pinus taeda* (6)

Summary: Before restoration (year 0), 124 was ponded for 56% of the year and 28% of the growing season, but mainly in a deeper sub-basin. Vegetative cover was 99% woody and 75% FAC species. After restoration (year 5), growing-season hydroperiod averaged 59% in the deeper sub-basin, but the remaining area was drier. Owing partly to vigorous resprouting of sweetgum (FAC+), relative cover of wetland (OBL/FACW) species did not increase substantially and does not meet reference standards. Herbaceous cover increased, but will decline after canopy closure. Swamp tupelo survived poorly, but cypress survival was high. The site will be mostly a short-hydroperiod forested system dominated by facultative species, with inclusions of cypress.

Assessment: Success determination (restored or enhanced) is at regulatory discretion. Hydroperiod in most of the basin is too short to favor dominance by wetland species, but at minimum the deeper sub-basin has jurisdictional hydrology and vegetation. Cypress survival exceeded the required 50% threshold. Planted wetland grasses (*Leersia, Panicum/Sacciolepis*) were introduced successfully.

Remedial actions: None. Planned burning of the upland buffer may influence woody plant cover in the future.

Bay 126 Summary Measures (*Target*: emergent herbaceous wetland; pine savanna buffer)

Measure	Value by year 5	Wetland meets jurisdictional criteria?	Value increased from pre-restoration?	Value meets or on trajectory to reference standard?
Hydrology				
Mean annual hydroperiod (% of year)	42	–	yes	no
Mean growing-season hydroperiod (% of year)	43	yes	yes	yes
Maximum water depth (cm)	61	–	–	–
Maximum surface area (ha)	0.90	–	–	–
Vegetation				
Species richness (no.)	43	–	yes	yes
% herbaceous species	71	–	yes	yes
Rel. herbaceous cover (%)	53	–	yes	no
% OBL/FACW species	51	yes	yes	no
Rel. OBL/FACW cover (%)	33	yes	no	no

Dominant species in year 5 (% cover): *Campsis radicans* (21), *Eupatorium capillifolium* (19), *Polygonum hydropiperoides* (12), *Smilax rotundifolia* (12)

Summary: Before restoration (year 0), 126 had no ponded water. Vegetative cover was 99% woody, but 53% wetland (OBL/FACW) species, owing to abundant willow oak (FACW) in the canopy. After restoration (year 5), the hydroperiod is seasonal (mean >40%) and partially comparable to the herbaceous reference standard. Although herbaceous (emergent) cover increased substantially, cover of wetland species did not because of removal of FACW trees and spread of FAC woody vines (trumpet creeper, catbrier). The restored seasonal hydroperiod may be too short to suppress these vines in the long term. There has been only limited tree resprouting; thus, the site may persist for some time as an emergent-shrubby wetland with a mix of wetland and facultative species.

Assessment: Successful. Nearly all measures increased from pre-restoration levels (failure of wetland species cover to show an increase is an artifact of pre-restoration forest composition). The wetland meets jurisdictional and some reference criteria for hydroperiod and vegetation. Planted wetland grasses (*Leersia, Panicum/Sacciolepis*) were introduced successfully.

Remedial actions: None needed. Planned burning of the upland buffer may influence woody plant cover in the future.

Bay 131 Summary Measures (*Target*: forest/savanna wetland; pine savanna buffer)

Measure	Value by year 5	Wetland meets jurisdictional criteria?	Value increased from pre-restoration?	Value meets or on trajectory to reference standard?
Hydrology				
Mean annual hydroperiod (% of year)	76	–	yes	yes
Mean growing-season hydroperiod (% of year)	71	yes	yes	yes
Maximum water depth (cm)	77	–	–	–
Maximum surface area (ha)	1.05	–	–	–
Vegetation				
Species richness (no.)	20	–	yes	yes
% herbaceous species	60	–	yes	yes
Rel. herbaceous cover (%)	62	–	yes	yes
% OBL/FACW species	80	yes	yes	yes
Rel. OBL/FACW cover (%)	78	yes	yes	yes
Planted cypress survival (%)	74	–	–	yes
Planted tupelo survival (%)	13	–	–	no
Mean cypress height (m)	1.68	–	–	–
Mean tupelo height (m)	1.51	–	–	–

Dominant species in year 5 (% cover): *Polygonum hydropiperoides* (19), *Campsis radicans* (9), *Ludwigia palustris* (8), *Taxodium distichum* (6)

Summary: Before restoration (year 0), 131 was ponded 44% of the year and 23% of the growing season. Vegetative cover was 98% woody, 49% FAC, and 51% OBL/FACW owing to presence of some OBL wetland trees (red maple) in the canopy. After restoration (year 5), the wetland has a long hydroperiod (mean >70%), and the vegetation is dominated by wetland (OBL/FACW) species. Cypress survival was high, but swamp tupelo survived poorly, either from drought stress or over-inundation.

Assessment: Successful. All measures increased from pre-restoration levels, and the wetland meets both jurisdictional and reference criteria for hydroperiod and vegetation. Cypress survival exceeded the required 50% threshold.

Remedial actions: None needed.

Bay 171 Summary Measures (*Target*: emergent herbaceous wetland; hardwood-pine forest buffer)

Measure	Value by year 5	Wetland meets jurisdictional criteria?	Value increased from pre-restoration?	Value meets or on trajectory to reference standard?
Hydrology				
Mean annual hydroperiod (% of year)	50	–	yes	yes (marginal)
Mean growing-season hydroperiod (% of year)	53	yes	yes	yes
Maximum water depth (cm)	121	–	–	–
Maximum surface area (ha)	1.35	–	–	–
Vegetation				
Species richness (no.)	35	–	no	yes
% herbaceous species	77	–	yes	yes
Rel. herbaceous cover (%)	82	–	yes	yes
% OBL/FACW species	74	yes	yes	yes
Rel. OBL/FACW cover (%)	87	yes	yes	yes

Dominant species in year 5 (% cover): *Hydrochloa caroliniensis* (18), *Ludwigia palustris* (12), *Leersia hexandra* (10), *Eleocharis acicularis* (8)

Summary: Before restoration (year 0), 171 was ponded 10% of the year and 4% of the growing season. Vegetative cover was 90% woody and 74% FAC species. After restoration (year 5), the wetland has a seasonal hydroperiod (mean ~50%) and vegetation dominated by herbaceous (emergent) and wetland (OBL/FACW) species. A shrub zone of buttonbush (OBL) recovered successfully after site harvest.

Assessment: Successful. All important measures increased from pre-restoration levels, and the wetland meets both jurisdictional and reference criteria for hydroperiod and vegetation. Planted wetland grasses (*Leersia, Panicum/Sacciolepis*) were introduced successfully.

Remedial actions: None needed.

Bay 5001 Summary Measures (*Target*: emergent herbaceous wetland; hardwood-pine forest buffer)

Measure	**Value by year 5**	**Wetland meets jurisdictional criteria?**	**Value increased from pre-restoration?**	**Value meets or on trajectory to reference standard?**
Hydrology				
Mean annual hydroperiod (% of year)	39	–	yes	no
Mean growing-season hydroperiod (% of year)	40	yes	yes	yes (marginal)
Maximum water depth (cm)	58	–	–	–
Maximum surface area (ha)	0.51	–	–	–
Vegetation				
Species richness (no.)	44	–	yes	yes
% herbaceous species	79	–	yes	yes
Rel. herbaceous cover (%)	80	–	yes	yes
% OBL/FACW species	62	yes	yes	yes
Rel. OBL/FACW cover (%)	44	yes	yes	no

Dominant species in year 5 (% cover): *Eupatorium capillifolium* (21), *Panicum verrucosum* (16), *Quercus nigra* (11), *Dichanthelium* spp. (8)

Summary: Before restoration (year 0), 5001 did not pond water. Vegetative cover was 100% woody and 89% FAC. After restoration (year 5), the hydroperiod is seasonal (mean ~40%) but only marginally comparable to the herbaceous reference standard. The site is dominated by herbaceous (emergent) vegetation, but wetland (OBL/FACW) species cover did not fully meet reference thresholds. Some limited resprouting of water oak and sweetgum (FAC species) has occurred. The restored seasonal hydroperiod will likely favor a mix of wetland and facultative species, and could allow some woody plant colonization in the future.

Assessment: Successful. All measures increased from pre-restoration levels, and the wetland meets jurisdictional and most reference criteria for hydroperiod and vegetation. Planted wetland grasses (*Leersia, Panicum/Sacciolepis*) were introduced successfully.

Remedial actions: None feasible. Prescribed burning (as a potential woody control measure) is not planned for this site.

Bay 5011 Summary Measures (*Target*: emergent herbaceous wetland; pine savanna buffer)

Measure	**Value by year 5**	**Wetland meets jurisdictional criteria?**	**Value increased from pre-restoration?**	**Value meets or on trajectory to reference standard?**
Hydrology				
Mean annual hydroperiod (% of year)	50	–	yes	yes (marginal)
Mean growing-season hydroperiod (% of year)	55	yes	yes	yes
Maximum water depth (cm)	63	–	–	–
Maximum surface area (ha)	0.95	–	–	–
Vegetation				
Species richness (no.)	38	–	yes	yes
% herbaceous species	68	–	yes	yes
Rel. herbaceous cover (%)	61	–	yes	yes
% OBL/FACW species	59	yes	marginal	marginal
Rel. OBL/FACW cover (%)	81	yes	no	yes

Dominant species in year 5 (% cover): *Panicum hemitomon* (20), *Acer rubrum* (14), *Hydrochloa caroliniensis* (11), *Liquidambar styraciflua* (10)

Summary: Before restoration, 5011 was ponded for 1% of the year and growing season during the drought year of 2000 (year 0), but may have been somewhat wetter in previous years. Vegetative cover was 70% woody, but 80% OBL/FACW owing to the presence of some OBL wetland trees (red maple, swamp tupelo) in the canopy. After restoration (year 5), the hydroperiod is seasonal (mean >50%). Cover of herbaceous (emergent) species increased and met reference thresholds. Cover of wetland (OBL/FACW) species exceeded reference thresholds, but did not show an increase owing to abundant red maple in the pre-restoration canopy. Cover of woody species may increase in the long term, because both wetland (red maple, swamp tupelo) and facultative (sweetgum) trees have resprouted to some extent.

Assessment: Successful. Most measures increased from pre-restoration levels, and the wetland meets jurisdictional and most reference criteria for hydroperiod and vegetation. A planted wetland grass (*Panicum/Sacciolepis*) was introduced successfully.

Remedial actions: None feasible. Prescribed burning of the upland buffer could potentially influence woody resprouting in the future; however, implementation of burning at this site has proved difficult owing to Site operational constraints.

Bay 5016 Summary Measures (*Target*: forest/savanna wetland; hardwood-pine forest buffer)

Measure	Value by year 5	Wetland meets jurisdictional criteria?	Value increased from pre-restoration?	Value meets or on trajectory to reference standard?
Hydrology				
Mean annual hydroperiod (% of year)	74	–	yes	yes
Mean growing-season hydroperiod (% of year)	71	yes	yes	yes
Maximum water depth (cm)	59	–	–	–
Maximum surface area (ha)	0.80†	–	–	–
Vegetation				
Species richness (no.)	14	–	yes	yes
% herbaceous species	57	–	yes	yes
Rel. herbaceous cover (%)	76	–	yes	yes*
% OBL/FACW species	79	yes	yes	yes
Rel. OBL/FACW cover (%)	83	yes	yes	yes
Planted cypress survival (%)	94	–	–	yes
Planted tupelo survival (%)	32	–	–	no
Mean cypress height (m)	2.30	–	–	–
Mean tupelo height (m)	1.66	–	–	–

†area exceeds surveyed area for bay interior, which may indicate a flooded condition
*high (comparable to emergent wetland)

Dominant species in year 5 (% cover): *Panicum hemitomon* (68), *Rhynchospora corniculata* (16)

Summary: Before restoration (year 0), 5016 was ponded for 35% of the year but only 4% of the growing season. Vegetative cover was 92% woody, 52% FAC, and 48% OBL/FACW owing to presence of some OBL wetland trees (red maple, swamp tupelo) in the canopy. After restoration (year 5), the wetland has a long hydroperiod (mean >70%) and high cover of herbaceous and wetland (OBL/FACW) species. Survival of planted cypress was very high, but swamp tupelo survival was moderately low.

Assessment: Successful. All measures increased from pre-restoration levels, and the wetland meets both jurisdictional and reference criteria for hydroperiod and vegetation. Cypress survival exceeded the required 50% threshold.

Remedial actions: None needed.

Bay 5071 Summary Measures (*Target*: forest/savanna wetland; hardwood-pine forest buffer)

Measure	Value by year 5	Wetland meets jurisdictional criteria?	Value increased from pre-restoration?	Value meets or on trajectory to reference standard?
Hydrology				
Mean annual hydroperiod (% of year)	20	–	yes	no
Mean growing-season hydroperiod (% of year)	19	yes	yes	no
Maximum water depth (cm)	50	–	–	–
Maximum surface area (ha)	0.85	–	–	–
Vegetation				
Species richness (no.)	32	–	no	yes
% herbaceous species	50	–	yes	yes
Rel. herbaceous cover (%)	30	–	yes	yes
% OBL/FACW species	35	yes	marginal	no
Rel. OBL/FACW cover (%)	14	yes	no	no
Planted cypress survival (%)	83	–	–	yes
Planted tupelo survival (%)	15	–	–	no
Mean cypress height (m)	1.87	–	–	–
Mean tupelo height (m)	0.87	–	–	–

Dominant species in year 5 (% cover): *Campsis radicans* (43), *Dichanthelium* spp. (31), *Ampelopsis arborea* (20), *Liquidambar styraciflua* (18)

Summary: Before restoration (year 0), 5071 was ponded 2% of the year and none of the growing season. Vegetative cover was 99% woody and 70% FAC. After restoration (year 5), mean hydroperiod has increased to ~20% but does not approach that of the forested reference standard. Owing to vigorous resprouting of woody FAC species, relative cover of wetland (OBL/FACW) species has not increased and does not meet reference standards. Herbaceous cover increased, but will decline after canopy closure. Swamp tupelo survived poorly, but cypress survival was high. This site's watershed characteristics do not support a hydroperiod comparable to wetter forest depressions. 5071 will persist as a short-hydroperiod forested wetland dominated by facultative species, with inclusions of cypress.

Assessment: Success determination (restored or enhanced) is at regulatory discretion. The wetland now has jurisdictional hydroperiod and vegetation, and cypress survival exceeded the required 50% threshold. A planted wetland grass (*Panicum/Sacciolepis*) was introduced successfully.

Remedial actions: None. Prescribed burning (as a potential woody control measure) is not planned for this site.

Bay 5092 Summary Measures (*Target*: forest/savanna wetland; pine savanna buffer)

Measure	Value by year 5	Wetland meets jurisdictional criteria?	Value increased from pre-restoration?	Value meets or on trajectory to reference standard?
Hydrology				
Mean annual hydroperiod (% of year)	31	–	yes	yes (marginal)
Mean growing-season hydroperiod (% of year)	35	yes	yes	yes
Maximum water depth (cm)	51	–	–	–
Maximum surface area (ha)	1.36†	–	–	–
Vegetation				
Species richness (no.)	38	–	yes	yes
% herbaceous species	58	–	yes	yes
Rel. herbaceous cover (%)	31	–	yes	yes
% OBL/FACW species	49	yes	yes	no
Rel. OBL/FACW cover (%)	56	yes	no	marginal
Planted cypress survival (%)	64	–	–	yes
Planted tupelo survival (%)	2	–	–	no
Mean cypress height (m)	1.99	–	–	–
Mean tupelo height (m)	0.98	–	–	–

†area exceeds surveyed area for bay interior, which may indicate a flooded condition

Dominant species in year 5 (% cover): *Quercus phellos* (24), *Polygonum hydropiperoides* (12), *Ampelopsis arborea* (11)

Summary: Before restoration (year 0), 5092 did not pond water. Vegetative cover was 99% woody, 55% FAC and 45% OBL/FACW owing to the presence of laurel/willow oak (FACW species) in the canopy. After restoration (year 5), the wetland has a seasonal hydroperiod (mean>30%). Emergent cover increased, but will decline with canopy closure. Owing to resprouting of willow oak (FACW) and colonization by black willow (OBL), cover of wetland (OBL/FACW) species approached the reference standard. Survival of cypress was adequate, but swamp tupelo survived very poorly. The restored short-seasonal hydroperiod will likely favor a forested wetland dominated by a mix of wetland and facultative species, with inclusions of planted cypress.

Assessment: Successful. Most measures increased from pre-restoration values, and the wetlands meets jurisdictional and some reference criteria for hydroperiod and vegetation (failure of wetland species cover to show an increase is partly an artifact of pre-restoration forest composition). A planted wetland grass (*Panicum/Sacciolepis*) was introduced successfully.

Remedial actions: None feasible. Planned burning of the upland buffer may influence woody plant cover in the future.

Bay 5128 Summary Measures (*Target*: forest/savanna wetland; hardwood-pine forest buffer)

Measure	Value by year 5	Wetland meets jurisdictional criteria?	Value increased from pre-restoration?	Value meets or on trajectory to reference standard?
Hydrology				
Mean annual hydroperiod (% of year)	79	–	yes	yes
Mean growing-season hydroperiod (% of year)	80	yes	yes	yes
Maximum water depth (cm)	72	–	–	–
Maximum surface area (ha)	0.77	–	–	–
Vegetation				
Species richness (no.)	40	–	yes	yes
% herbaceous species	78	–	yes	yes*
Rel. herbaceous cover (%)	80	–	yes	yes*
% OBL/FACW species	68	yes	yes	yes
Rel. OBL/FACW cover (%)	87	yes	yes	yes
Planted cypress survival (%)	95	–	–	yes
Planted tupelo survival (%)	75	–	–	yes
Mean cypress height (m)	1.91	–	–	–
Mean tupelo height (m)	1.05	–	–	–

*high (comparable to emergent wetland)

Dominant species in year 5 (% cover): *Proserpinaca pectinata* (16), *Panicum verrucosum* (13), *Leersia hexandra* (8), *Eleocharis acicularis* (8)

Summary: Before restoration (year 0), 5128 was ponded 1% of the year and growing season. Vegetative cover was 99% woody, and 54% OBL/FACW owing to presence of planted slash pines (FACW) in the canopy. After restoration (year 5), 5128 has been restored to a high-quality wetland with a long hydroperiod (mean ~80%), a diverse vegetation of herbaceous and wetland (OBL/FACW) species, and high survival of planted trees. This was the only planted site (of eight) in which swamp tupelo achieved adequate survival.

Assessment: Successful. All measures increased from pre-restoration levels, and the wetland meets both jurisdictional and reference criteria for hydroperiod and vegetation. Survival of planted trees exceeded the required 50% threshold. Planted wetland grasses (*Leersia, Panicum/Sacciolepis*) were introduced successfully.

Remedial actions: None needed. Control of minor sweetgum and water oak resprouting could further enhance vegetation quality.

Bay 5135 Summary Measures (*Target*: emergent herbaceous wetland; pine savanna buffer)

Measure	Value by year 5	Wetland meets jurisdictional criteria?	Value increased from pre-restoration?	Value meets or on trajectory to reference standard?
Hydrology				
Mean annual hydroperiod (% of year)	27	–	yes	no
Mean growing-season hydroperiod (% of year)	29	yes	yes	no
Maximum water depth (cm)	30	–	–	–
Maximum surface area (ha)	0.26	–	–	–
Vegetation				
Species richness (no.)	26	–	no	yes
% herbaceous species	50	–	yes	no
Rel. herbaceous cover (%)	48	–	yes	no
% OBL/FACW species	48	yes	marginal	no
Rel. OBL/FACW cover (%)	62	yes	marginal	yes

Dominant species in year 5 (% cover): *Eleocharis melanocarpa* (16), *Panicum verrucosum* (14), *Acer rubrum* (14), *Pinus taeda* (14)

Summary: Before restoration (year 0), 5135 was ponded 1% of the year and growing season. Vegetative cover was 86% woody, 49% FAC, and 45% OBL/FACW owing to the presence of red maple (OBL species) in the canopy. After restoration (year 5), the hydroperiod is temporary to short-seasonal (mean <30%) but shorter than the herbaceous reference standard. There has been considerable woody resprouting and woody encroachment from the wetland margin. Wetland (OBL/FACW) species cover met the reference standard owing to increased cover of herbaceous wetland species and resprouting of red maple (OBL). However, in the long term, this site's small size, short hydroperiod, and shallow ponding depth are unlikely to support the originally planned emergent vegetation without frequent fire. Instead, conditions favor a small forested wetland with a mix of wetland and facultative species.

Assessment: Success determination (restored or enhanced) is at management discretion. Most measures increased from pre-restoration values, and the wetland meets jurisdictional criteria for hydroperiod and vegetation. Planted wetland grasses (*Leersia, Panicum/Sacciolepis*) were introduced successfully.

Remedial actions: None feasible. Planned burning of the upland buffer may influence woody plant cover in the future.

Bay 5184 Summary Measures (*Target*: forest/savanna wetland; pine savanna buffer)

Measure	**Value by year 5**	**Wetland meets jurisdictional criteria?**	**Value increased from pre-restoration?**	**Value meets or on trajectory to reference standard?**
Hydrology				
Mean annual hydroperiod (% of year)	48	–	yes	yes
Mean growing-season hydroperiod (% of year)	45	yes	yes	yes
Maximum water depth (cm)	74	–	–	–
Maximum surface area (ha)	0.84	–	–	–
Vegetation				
Species richness (no.)	41	–	yes	yes
% herbaceous species	61	–	yes	yes
Rel. herbaceous cover (%)	57	–	yes	yes
% OBL/FACW species	45	yes	yes	no
Rel. OBL/FACW cover (%)	47	yes	yes	no
Planted cypress survival (%)	54	–	–	yes†
Planted tupelo survival (%)	9	–	–	no
Mean cypress height (m)	1.41	–	–	–
Mean tupelo height (m)	0.67	–	–	–

†cypress underplanted (insufficient density)

Dominant species in year 5 (% cover): *Dichanthelium* spp. (31), Quercus phellos (18), *Liquidambar styraciflua* (18), *Polygonum hydropiperoides* (15), *Scirpus cyperinus* (15)

Summary: Before restoration (year 0), 5184 did not pond water. Vegetative cover was 99% woody and 72% FAC species. After restoration (year 5), the hydroperiod is seasonal (mean >40%). Cover of herbaceous and wetland (OBL/FACW) species increased, but wetland species cover did not reach the reference threshold because the hydroperiod also supports FAC species. Survival of swamp tupelo was low. Cypress was underplanted owing to contractor error, but survival was adequate. The restored seasonal hydroperiod will likely favor a forested wetland dominated by a mix of wetland and facultative species, with inclusions of planted cypress.

Assessment: Successful. All measures increased from pre-restoration levels, and the wetland meets jurisdictional and some reference criteria for hydroperiod and vegetation. Cypress survival exceed the required 50% threshold, although density is lower than planned. .

Remedial actions: None needed. Planned burning of the upland buffer may influence woody plant cover in the future; however, implementation of burning at this site has proved difficult owing to Site operational constraints.

Bay 5190 Summary Measures (*Target*: emergent herbaceous wetland; pine savanna buffer)

Measure	Value by year 5	Wetland meets jurisdictional criteria?	Value increased from pre-restoration?	Value meets or on trajectory to reference standard?
Hydrology				
Mean annual hydroperiod (% of year)	35	–	yes	no
Mean growing-season hydroperiod (% of year)	42	yes	yes	yes
Maximum water depth (cm)	51	–	–	–
Maximum surface area (ha)	0.65	–	–	–
Vegetation				
Species richness (no.)	30	–	no	yes
% herbaceous species	77	–	yes	yes
Rel. herbaceous cover (%)	96	–	yes	yes
% OBL/FACW species	55	yes	yes	marginal
Rel. OBL/FACW cover (%)	42	yes	yes	no

Dominant species in year 5 (% cover): *Carex albolutescens* (16), *Dichanthelium* spp. (13), *Eupatorium capillifolium* (12), *Rhexia mariana* (9)

Summary: Before restoration (year 0), 5190 did not pond water. Vegetative cover was 92% woody and 73% FAC. After restoration (year 5), the site has developed a seasonal hydroperiod (mean ~40%) that is partially comparable to the herbaceous reference standard. The site is dominated by herbaceous vegetation; prescribed burning of the upland buffer in year 3 carried into the wetland and may have reduced woody resprouting. Cover of wetland (OBL/FACW) species increased substantially, but did not meet reference criteria because the hydroperiod also supports FAC species. The restored seasonal hydroperiod will likely favor a mix of wetland and facultative species, and could allow some woody plant colonization in the long term.

Assessment: Successful. All important measures increased from pre-restoration levels, and the wetland meets jurisdictional and most reference criteria for hydroperiod and vegetation. Planted wetland grasses (*Leersia*, *Panicum/Sacciolepis*) were introduced successfully.

Remedial actions: None needed. Planned burning of the upland buffer may influence woody plant cover in the future.

Bay 5204 Summary Measures (*Target*: forest/savanna wetland; hardwood-pine forest buffer)

Measure	Value by year 5	Wetland meets jurisdictional criteria?	Value increased from pre-restoration?	Value meets or on trajectory to reference standard?
Hydrology				
Mean annual hydroperiod (% of year)	79	–	yes	yes
Mean growing-season hydroperiod (% of year)	82	yes	yes	yes
Maximum water depth (cm)	90	–	–	–
Maximum surface area (ha)	0.89†	–	–	–
Vegetation				
Species richness (no.)	31	–	yes	yes
% herbaceous species	71	–	yes	yes*
Rel. herbaceous cover (%)	96	–	yes	yes*
% OBL/FACW species	71	yes	yes	yes
Rel. OBL/FACW cover (%)	96	yes	yes	yes
Planted cypress survival (%)	87	–	–	yes‡
Planted tupelo survival (%)	19	–	–	no
Mean cypress height (m)	2.52	–	–	–
Mean tupelo height (m)	1.27	–	–	–

†area exceeds surveyed area for bay interior, which may indicate a flooded condition
*high (comparable to emergent wetland)
‡cypress was underplanted (insufficient density)

Dominant species in year 5 (% cover): *Spirodela* spp. (34), *Erianthus* spp. (23), *Typha* sp. (13)

Summary: Before restoration (year 0), 5204 was ponded 12% of the year and 9% of the growing season. Vegetative cover was 100% woody but 72% OBL/FACW owing to presence of some wetland trees (red maple, laurel oak) in the canopy. After restoration (year 5), the site has a long hydroperiod (mean ~80%) and vegetation dominated by herbaceous and wetland (OBL/FACW) species. Swamp tupelo survival was low. Cypress was underplanted owing to contractor error, but survival was high.

Assessment: Successful. All measures increased from pre-restoration levels, and the wetland meets both jurisdictional and reference criteria for hydroperiod and vegetation. Cypress survival exceeded the required 50% threshold, although density is lower than planned. Planted wetland grasses (*Leersia, Panicum/Sacciolepis*) were introduced successfully.

Remedial actions: None needed.

Bay 5239 Summary Measures (*Target*: emergent herbaceous wetland; hardwood-pine forest buffer)

Measure	Value by year 5	Wetland meets jurisdictional criteria?	Value increased from pre-restoration?	Value meets or on trajectory to reference standard?
Hydrology				
Mean annual hydroperiod (% of year)	39	–	yes	no
Mean growing-season hydroperiod (% of year)	41	yes	yes	yes (marginal)
Maximum water depth (cm)	102	–	–	–
Maximum surface area (ha)	1.68†	–	–	–
Vegetation				
Species richness (no.)	41	–	yes	yes
% herbaceous species	65	–	yes	yes
Rel. herbaceous cover (%)	48	–	yes	no
% OBL/FACW species	60	yes	yes	yes
Rel. OBL/FACW cover (%)	57	yes	yes	marginal

†area exceeds surveyed area for bay interior, which may indicate a flooded condition

Dominant species in year 5 (% cover): *Salix nigra* (18), *Ludwigia palustris* (18), *Campsis radicans* (14), *Eupatorium capillifolium* (11), *Ampelopsis arborea* (11)

Summary: Before restoration (year 0), 5239 was ponded for 1% of the year and growing season. Vegetative cover was 99% woody, 55% FAC, and 33% OBL/FACW owing to presence of some wetland trees (red maple, elm, willow oak) in the canopy. After restoration (year 5), the hydroperiod is seasonal (mean ~40%) and only marginally comparable to the herbaceous reference standard. Covers of herbaceous and wetland (OBL/FACW) species increased substantially, but neither fully achieved reference standards. There has been limited resprouting of red maple and sweetgum, but black willow (OBL) colonized naturally. The restored seasonal hydroperiod is likely too short to favor the planned emergent wetland in the long term; rather, the site will likely develop as a forested wetland with a mix of wetland and facultative species.

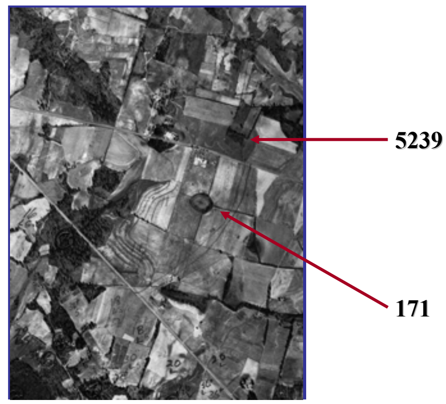
Assessment: Successful. All measures increased from pre-restoration levels, and the wetland meets jurisdictional and some reference criteria for hydroperiod and vegetation. A planted wetland grass (*Panicum/Sacciolepis*) was introduced successfully.

Remedial actions: None. Prescribed burning (as a potential woody control measure) is not planned for this site.

Appendix II

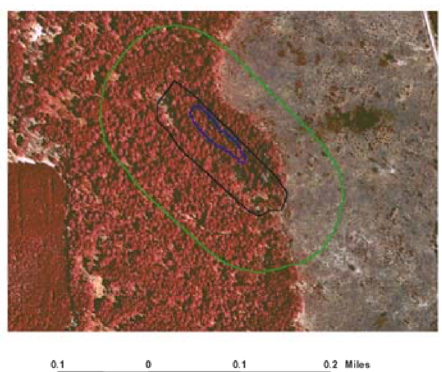
Photographs Outlining Project Progress

SRS Carolina Bays
1951 Condition



Pre-Restoration Condition

Bay 5128



Carolina Bay Restoration – Timber Harvest

Pre-Harvest

During Harvest

During Harvest

After Harvest

Carolina Bay Harvest, 2000-2001

Mixed Pine/Hardwood, Bay 5071

Open Canopy Pine Savanna, Bay 126

Forest Planting

Herbaceous Planting

Hydrologic Disturbance


Drainage Ditch


Active Drain

Ditch Repair

Before and After Harvest


Bay 5190


Bay 5128

Herbaceous Plots

5204

126

Bay Burning

131

Data Logger and Piezometer Nest (5184)

Hydrology Monitoring Equipment

Sample Well (5135)

Throughfall Collector (5011)

Seedling Growth

4 yr Tupelo

4 yr Cypress

Status Summer 2005

Bay 124

Bay 5128