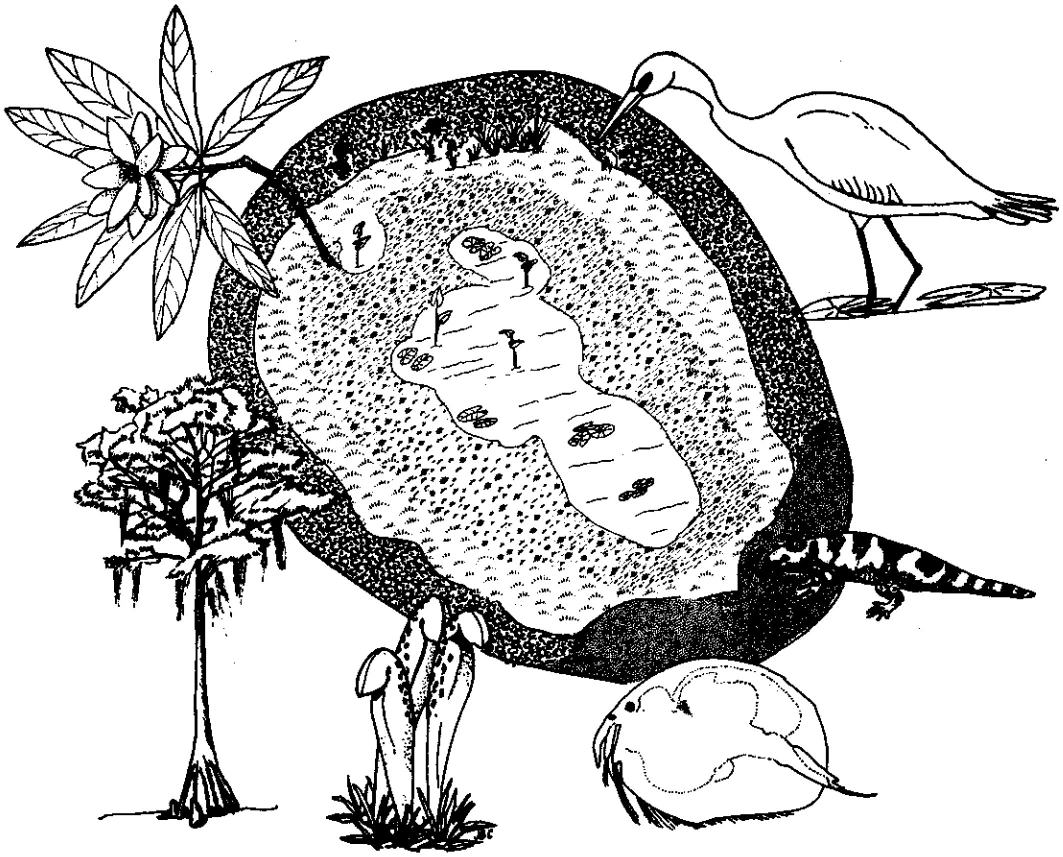
SRO-NERP-18

CAROLINA BAYS
OF THE SAVANNAH RIVER PLANT



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Carolina Bays of the Savannah River Plant,

Aiken, South Carolina

by

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INTRODUCTION

One hundred ninety-four confirmed or suspected Carolina bays have been identified on the Savannah River Plant (SRP) in South Carolina. These natural, shallow depressions occur on non-alluvial, interstream areas of the SRP (Figure 14). Carolina bays contain hydric or mesic communities and range from lakes to shallow marshes, herbaceous bogs, shrub bogs or swamp forests (Wharton 1978). A Carolina bay can generally be distinguished from other southeastern U.S. coastal plain wetlands on the basis of several unique features (Table 1). An elliptical contour with northwest to southeast alignment of the long axis and the frequent presence of a marginal sand rim are perhaps the most useful diagnostic features. Conspicuous environmental features include fluctuating water levels and concomitant changes in chemical and biological variables such as dissolved ion concentrations, peat accumulation, and vegetation composition.

Table 1. General features of Carolina bay depressions (all features may not apply to all bays).

- Naturally occurring shallow depressions of upland interstream areas of the southeastern Coastal Plain.
- 30,000-100,000 years old (or older).
- Elliptical or ovoid.
- Northwest/southeast orientation of the long axis.
- Complete or breached low, sandy marginal rims with greatest development on the southeastern margin.
- Depression partially filled with inorganic clays and silts and/or organic peats.
- Continually or seasonally inundated wetlands in the depression. Fires may periodically remove organic accumulations.

The geology and geomorphology of Carolina bay depressions were comprehensively described by Johnson (1942) and Prouty (1952) and were reviewed by Hutchinson (1957), Siple (1967), Price (1968), Schalles (1979), and Sharitz and Gibbons (1982). The ecological history and long-term succession of the bays and their surrounding terrestrial vegetation were addressed by Wells and Boyce (1953), Frey (1953, 1955), and Whitehead (1973) and were reviewed by Schalles (1979). Carolina bays are apparently pre-Holocene in age (Frey 1953, Whitehead 1973). Some contain lakes, although surface water levels have gradually decreased as the bays slowly fill with sediments and peat and as the surrounding groundwater levels decrease through local stream excision. Oxidative decomposition and fires during droughts have kept many bays from completely filling with peat.

Although much work has focused on the geology of Carolina bays, the composition and characteristics of their soils are described for relatively few sites. Many bays are reported to contain extensive organic deposits, whereas others are considered to be clay-based (hard-bottomed), with more poorly developed organic layers. Buell (1939, 1946) and Wells and Boyce (1953) described several Carolina bays in North Carolina which had peat deposits as thick as 4.5 m. Peat is a high quality, exploitable energy source with an average ash content of 4% and heating value of 23.3 MJ/kg (Ingram and Otte 1981). Gamble et al. (1977) used auger drilling to examine depositional features of surface sediments in North Carolina sites. They found evidence of two sand rim types: primary rims which edged the initial depressions and sometimes exhibited pedogenic soil development, and secondary rims which were formed by shoreline beach processes that reworked sand deposits of apparent aeolian origin. Bryant and McCracken (1964) and Bliley and Pettry (1979) analyzed soil texture and mineralogy for Carolina bay sites in North Carolina and the eastern shore of Virginia. Mineral soils were generally sandy loams; sands and silts were predominantly quartz. Based on limited sampling, clays of the depressions seemed to be largely kaolinite, vermiculite, and vermiculite-chlorite intergrades with lower and variable levels of montmorillonite, gibbsite, and mica (Ingram et al. 1959, Bliley and Pettry 1979).

Carolina bay water and soils display a moderately acidic ombrotrophic (i.e. precipitation-dominated) chemistry reflecting a dystrophic status (Schalles 1989). Primary productivity estimates are few, but a general pattern of low to moderate production is revealed (Frey 1949, Woodwell 1958, Tilly 1973, Schalles and Shure 1989). Topographic relief and site hydrology are the major determinants of vegetational composition. Average water level, water level amplitude, and the timing and duration of flood events may be good predictors of bay community types (Wharton 1978, Schalles 1979). The flora and fauna characteristic of Carolina bays appear well adapted to fluctuating water levels, dryouts, and fires.

Fires during severe droughts are an important factor in the community composition of Carolina bays (Buell 1946, Wells and Whitford 1976, Wharton 1978, Christensen et al. 1981, Hodge 1985). Succession proceeds in the absence of fire as peat buildup alters the topography and new species invade. However, growing peat deposits become increasingly vulnerable to fire during dry periods. Discrete fire paths may induce topographic discontinuities and can result in less predictable spatial patterns in vegetation. Fire directly affects wetland soils by increasing pH and releasing nutrients from accumulated plant debris. Plant species diversity often increases and flowering and productivity of herbaceous species are stimulated following a fire. If fires are intense or frequent, woody species are removed, creating herbaceous-dominated wetlands. Thus, alternating buildup and breakdown of the organic substrate may induce cyclic successional patterns.

The role of cultivation disturbance was discussed by Hodge (1985) in a study of eight herbaceous Carolina bays on and adjacent to the SRP (Aiken and Barnwell Counties). Ditching and draining, usually accompanied by cultivation, were frequent. One common effect of these practices within the bays was an increase in *Panicum hemitomon* or *Leersia hexandra* which resulted in almost pure stands. This is evident in both Ellenton Bay (Site 176) and Woodward Bay (Site 67). Although these bays have not been disturbed since 1951, both were intensively cultivated in the 1930s and 1940s.

Semi-aquatic fauna are characteristic of Carolina bay wetlands (Sharitz and Gibbons 1982). Carolina bays can be considered disconnected, mesic or hydric "islands" in the sandy, coastal plain interfluves which provide habitat for many species. The bays are biotically coupled to local terrestrial habitats by serving as sites of amphibian reproduction and larval development (Patterson 1978, Bennett et al. 1979, Sharitz and Gibbons 1982) and by providing forage and water for upland wildlife. The habitat diversity of bay depressions promotes distinct avian assemblages; wet depressions provide refugia for migratory waterfowl (Mayer et al. 1986).

The objectives of this National Environmental Research Park study were to inventory the Carolina bays on the SRP, summarize descriptive information collected to date on abiotic and biotic properties, and provide recommendations for future research and conservation.

CAROLINA BAYS ON THE SRP

An inventory of Carolina bays on the SRP was made by examining color infrared photography (scale 1:15,840). One hundred ninety-four confirmed or suspected bays were identified (Figure 14, Appendix I) and each bay was assigned a number and its position was located on a topographic map of the SRP (U.S.G.S. 1:48,000). Identification number, name (if known), location, wetland surface area (from Shields et al. 1982), and habitat type of each bay are presented in Appendix I.

Carolina bays are distributed in clusters or broad bands across the SRP (Figure 14). Lowest densities occur in the northeastern section. The bays occur at elevations ranging from 120 to 340 feet (36 to 104 m). The surface areas of bays on the SRP range from less than 0.3 acre (0.1 ha) to about 125 acres (50 ha). A number of small wetlands with circular outlines exist on the SRP. These areas, which may be small Carolina bays, are especially numerous near the floodplain of the Savannah River on the southwestern portion of the SRP. When included in Appendix I, such sites are generally listed as suspected bays. As many as several dozen small wetlands were not listed because they appear to lack elliptical shapes or a northwest to southeast orientation of the long axis (see criteria in Table 1). Aerial photography from the 1940s reveals that Sites 96, 97, and 98 (Figure 14) may be remnants of a very large bay covering about 550 acres (220 ha).

The median size of the SRP bays is about 2 acres (0.8 ha; Figure 1); only 15 sites exceed 10 acres (4 ha). Although some of the SRP bays occur in close proximity to one another (e.g. Sites 24 and 25, 91 and 92), no examples were found of the overlapping bay depressions reported by Johnson (1942) or Prouty (1952).

Carolina bays on the SRP have mineral soils with little or no peat accumulation. Most of the bays contain water, at least seasonally or in some years. Frey (1950) observed that such "hard-bottomed" bays in North Carolina occur primarily on the upper coastal plain terraces and that many of these higher-elevation sites have been cleared and drained for agriculture. About 80% of 168 bays (not including SRP sites) identified in Barnwell County, SC have farming activity on adjacent lands and at least 20% have been drained and farmed (Schalles, personal observation). Draining and clearing of southeastern coastal plain wetlands continues and many remaining nonagricultural bays are vulnerable to exploitation for agriculture and silviculture (Richardson et al. 1981, Sharitz and Gibbons 1982). Carolina bays on the SRP have remained largely undisturbed since 1950 and are valuable examples of these ecosystems.

HYDROLOGY

Carolina bays represent the only abundant natural lentic systems on the Georgia-Carolina Coastal Plain; their hydrology has been inadequately studied. Water chemistry of undisturbed Carolina bays on the SRP is typical of precipitation-dominated, ombrotrophic systems (Schalles, in press). Surface inflow channels are generally absent. Drainage channels occur with some frequency and many appear to have been man-made or modified. Today, through disuse, most of these channels are partially filled with sediments and discharge only during periods of extremely high water.

Water levels in three extensively studied SRP bays are compared in Figure 2. Although the water levels of these bays were grossly related to amount of precipitation, the amplitude and timing of changes differed. For example, Ellenton Bay (Site 176) and Thunder Bay (Site 83) had similar overall patterns, whereas Rainbow Bay (Site 189) had much greater fluctuation in water level (Figure 2). Schalles (1979) found that maximum water level fluctuations over an annual cycle in 1974-1975 were between 35 and 83 cm in six local bays. Hodge (1985) noted a similar range of 25-63 cm in the water level changes of eight SRP and Barnwell County bays during 1984-1985. Some differences in water level among bays are caused by differences in the amount of precipitation received, particularly during seasons of localized thunderstorms. Higher ratios of surface area to storage volume could result in proportionately higher losses to seepage in smaller bays. Strong seasonal differences in water loss rates were found in Ellenton and Thunder Bays (Figure 3) and appeared related to seasonality in evapotranspiration rates. Differences in water level and amplitude of bays may also be caused by local differences in groundwater behavior and by differences in the permeability of underlying strata. Wells and Boyce (1953) found strong evidence for much lower levels of lake-groundwater exchange in Black Lake (renamed Bay Tree Lake) versus White Lake in North Carolina.

Continuous or temporary connection to near-surface groundwater is probably a common feature of Carolina bays. Comparisons of surface water levels to the piezometric levels in four adjacent monitoring wells (Schalles and Cahill, unpublished; Figure 4) revealed conditions favorable to almost continuous subsurface seepage loss and periodic groundwater recharge at Thunder Bay. Schalles (1979) proposed that most groundwater-surface water interactions occur laterally, around the margins of the depressions, and that these connections are often lost during periods of low water levels. A similar hydrologic model was proposed by Heimberg (1976) for shallow cypress-dome depressions in central Florida. An impervious clay lens appears to underlie many of the SRP bays (see SOILS section). Soils in the center of the bays contain higher percentages of clays and silts than those closer to the rims. Consequently, soils in the center are less permeable and more poorly drained (Hodge 1985). Because site-specific hydrology is a controlling variable in Carolina bay ecosystems, detailed hydrological measurements and modelling should be a high priority for future research.

All Carolina bays on the SRP dry out periodically. Many of the smaller bays contain surface water only during wet seasons, whereas some of the larger depressions (e.g. Craig's Pond, Site 77, and Ellenton Bay) dry up only during prolonged drought. Ellenton Bay experienced severe

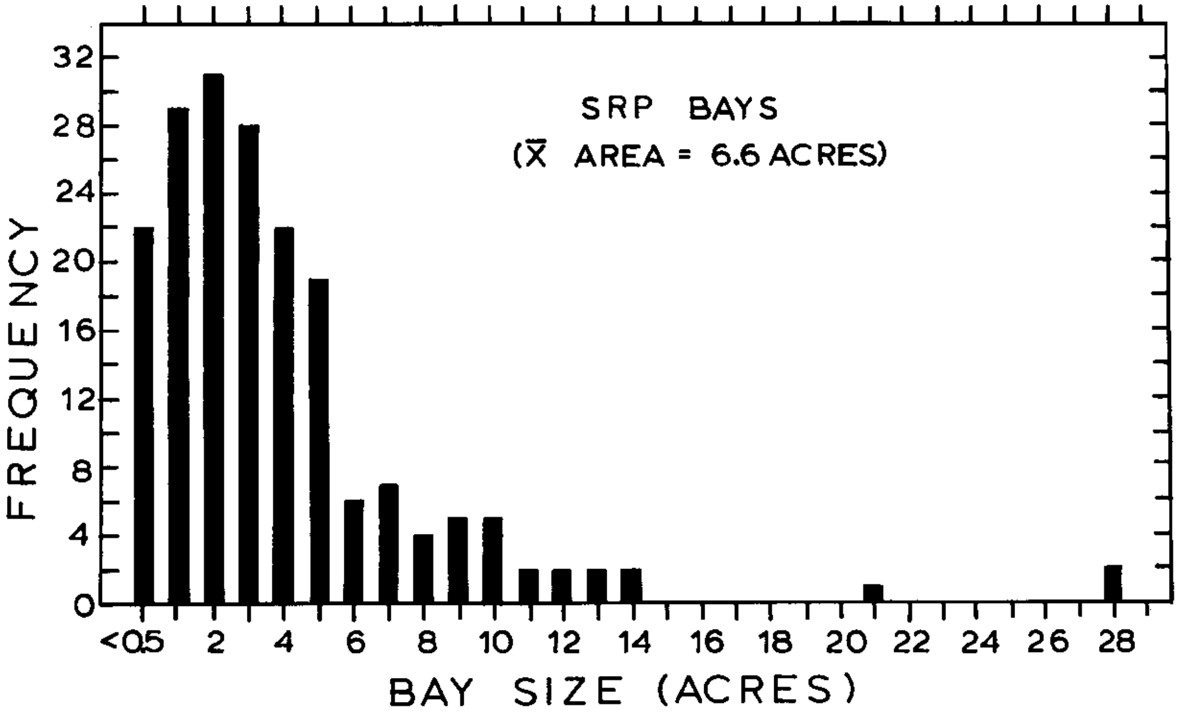

Figure 1. Size distribution of the Carolina bays of the SRP (acreage data from Shields et al. 1982).

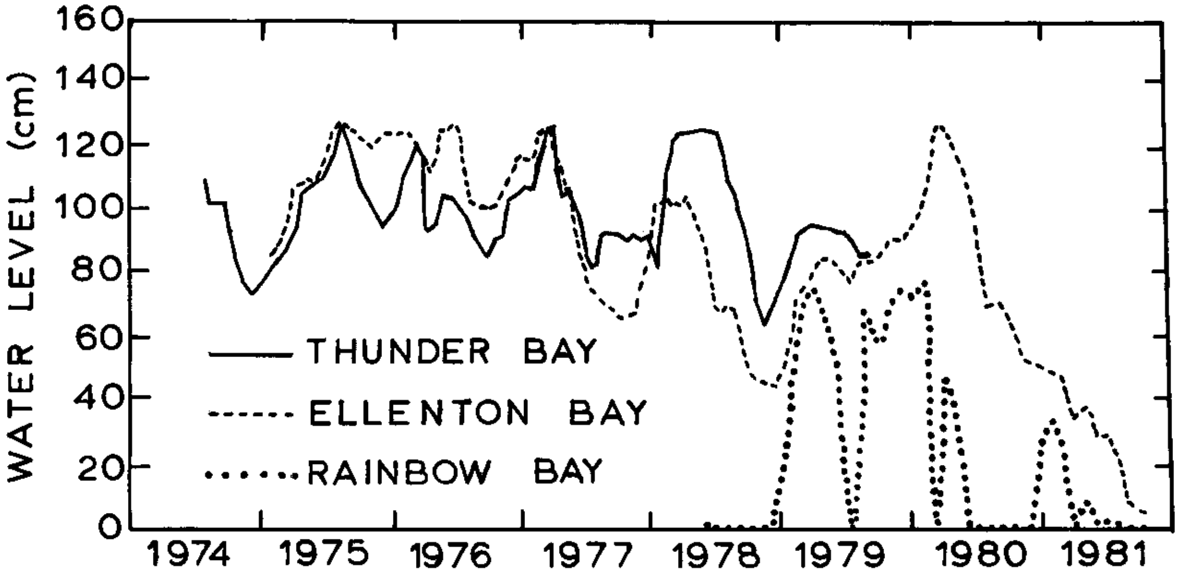

Figure 2. Surface water levels of three Carolina bays at the SRP (Thunder Bay, Site 83, data from Schalles and Shure 1989; Ellenton Bay, Site 176, and Rainbow Bay, Site 189, data from Sharitz and Gibbons 1982).

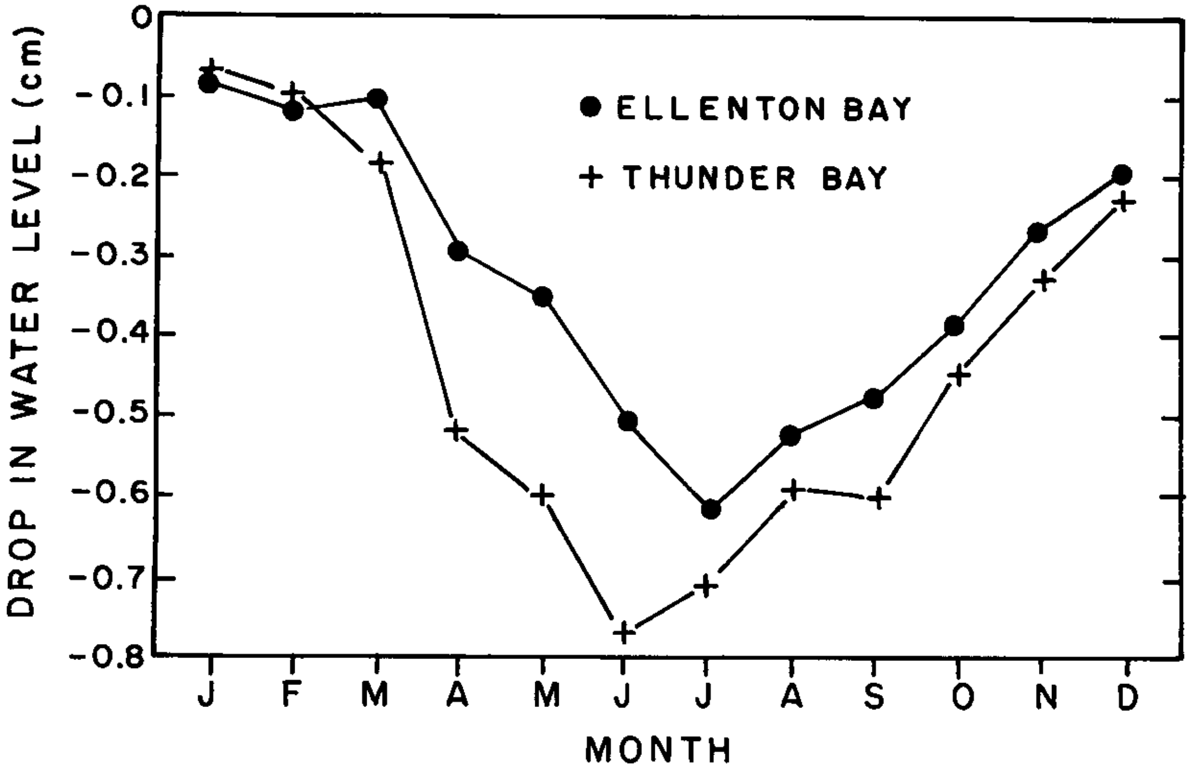

Figure 3. Daily water loss rates for Ellenton Bay (Site 176) and Thunder Bay (Site 83). Ellenton Bay data from Sharitz and Gibbons 1982, Thunder Bay data from Schalles and Cahill, unpublished.

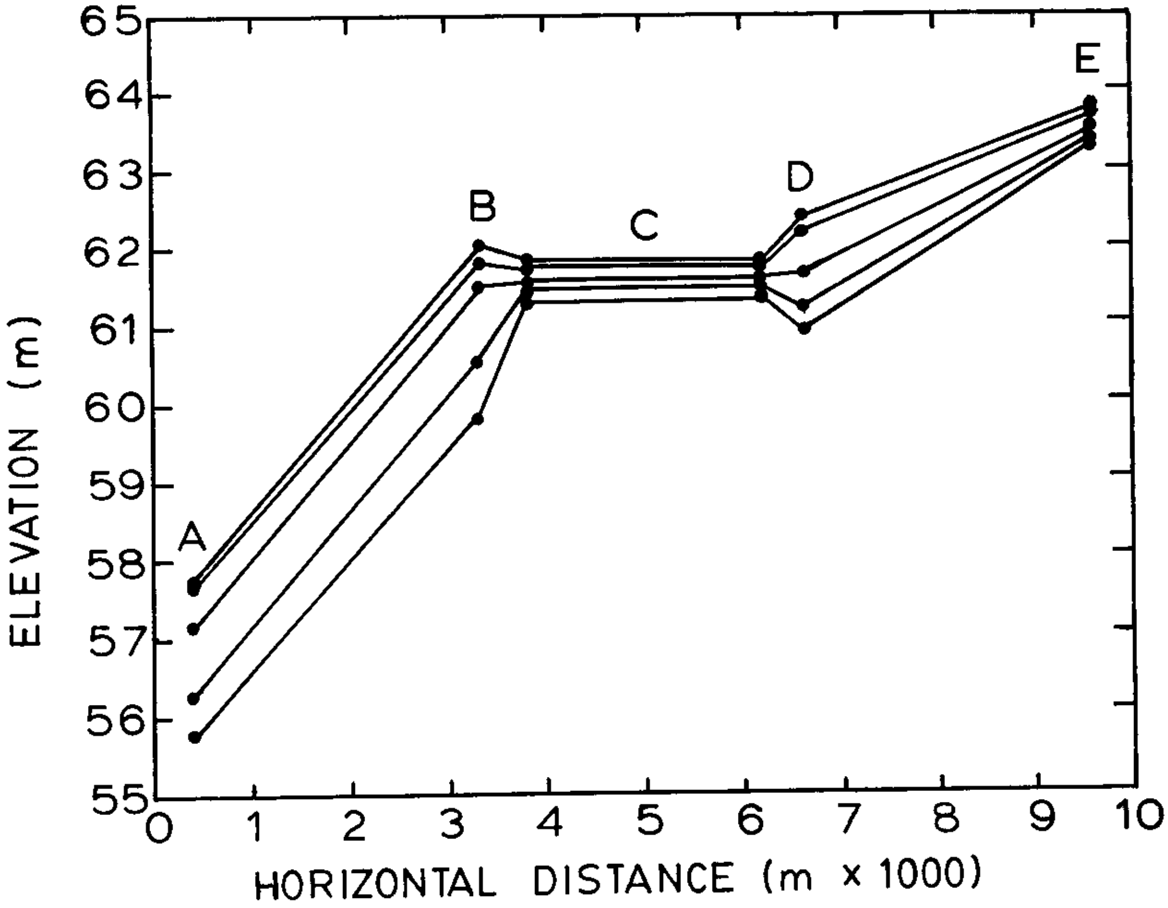

Figure 4. Comparison of surface water level in Thunder Bay (Site 83) versus water levels in four adjacent groundwater observation wells on five dates representing the range of water level stages encountered between 1976 and 1978. (Elevations in meters, National Geodetic Vertical Datum of 1929; C = bay surface; A, B, D, and E = observation wells. Well E is the farthest upslope and is located adjacent to Gate 19 on SRP road B-7. Unpublished data of Schalles and Cahill.)

drying (only a few deep holes held water) during droughts in 1968 and 1981 (Sharitz and Gibbons 1982) and in 1987 and 1988 (Pechmann, personal observation). Craig's Pond was dry to at least 20 cm below the surface in 1988 (Landaal, personal observation).

WATER CHEMISTRY

Several surveys of surface water chemistry in SRP Carolina bays have been made. For this report, two groups of analyses were performed: replicate samples from sixteen sites on single collection dates were obtained in the summer of 1979 and a more comprehensive survey of eighteen sites (including thirteen sites not visited the previous summer) was conducted between November 1979 and April 1980. Additionally, Schalles (1979) analyzed water samples between August 1974 and August 1975 from six bays on the SRP and the adjacent Barnwell County Industrial Park. Values for inorganic parameters were determined with standard atomic absorption spectrophotometry and titrametric procedures. A Beckman carbon analyzer was used for total carbon and inorganic carbon analyses. Redox (relative values), dissolved oxygen, temperature, conductivity, and pH measurements were made during the eighteen-site comparison with a Hydrolab in situ water quality analyzer. Schalles (1979) used a Yellow Springs Model 54 oxygen analyzer for more frequent measurements of oxygen and temperature vertical profiles and for diel studies.

The surface waters of the surveyed bays were acidic (pH 3.8 - 5.5) with very low levels of calcium and total inorganic solutes (conductivities of 20-40 μmhos). Bay waters had low to moderate color and dissolved organic carbon (mean = 22 mg/l). These characteristics are similar to those reported for the Okefenokee Swamp (Auble 1984), North Carolina bay lakes (Frey 1949), lower coastal plain pocosins (Daniel 1981), a Florida cypress dome (Dierberg and Brezonik 1984), and lakes and ponds of the New Jersey Pine Barrens (Patrick et al. 1979). The moderate levels of color and dissolved organic carbon (DOC) in the bays can be attributed to the low calcium levels, abundance of living and decaying plant materials, and the shallow depths of the ponds.

No single element dominates cations in the bay ponds. Calcium was the most abundant cation (25% of total meq/l) in the 1980 survey of eighteen SRP bays. However, sodium, magnesium, and hydrogen ions were also significant (Table 2). The relatively high monovalent/divalent cation ratios, low total inorganic solutes, and occurrence of moderate acidity and dissolved organic carbon in SRP bays are likely the result of sea salt contributions to atmospheric chemistry in the region, very restricted watersheds with sandy, leached soils, periodic exchanges with low solute strength shallow groundwater, and high nutrient retention by vegetation (Schalles 1989). Cation balances in other southeastern wetlands were similar to those in SRP bays, but some differences existed. Sodium dominance was seen in the impounded waters of the SRP and other southeastern softwater wetlands (Table 2). Overall, the SRP bays had lower total cation levels than did these other coastal plain areas. Manganese concentrations in SRP bays were about one order of magnitude greater than the freshwater, global average (0.0013 meq/l) reported by Livingston (1963). A possible source of the manganese is conifer litter (Wetzel 1983) from marginal pine forests and concentrations in the ponds may attest to the importance of exchange pathways between these ponds and adjacent terrestrial habitats. However, local geologic features could also account for the manganese levels. A 1988 regional survey of bay surface water chemistry found that elevated manganese levels were mostly associated with upper coastal plain sites of the Aiken Plateau area (Newman and Schalles, unpublished).

Detailed chemical analyses of three SRP bays and three others in the vicinity of the plant (Table 3) were made as part of a 1988 regional survey of 53 sites. Overall, solute levels were higher than levels seen in previous SRP bay surveys. Potassium levels were notably higher and hydrogen ion levels lower. A very dry period during the early and mid-1980s and corresponding ecosystem responses may account for these differences (see section on bay chemistry dynamics below). Chloride was the dominant inorganic anion, with sulfate second in abundance (Table 3). Dissolved organic carbon averaged 14.1 mg/l and accounted for 39% of the total anionic charge. Dissolved silica values were moderate but quite variable. The dilute, acidic chemistry is a probable indicator of moderate to severe nutrient limitations in the bay ponds. Nutrient spiking experiments in nearby Risher Pond (an abandoned farm pond) revealed that sulfate introduction alone could stimulate C-14 fixation and that combinations

Table 2. Cation proportions for various southeastern coastal plain surface waters (softwater, lentic systems). Iron and manganese were probably present as colloids and thus do not contribute to total cation charge.

Cation (% meq/l)	This Report	SRP Farm Ponds[1]	North Carolina Pocosins[2]	Georgia Okefenokee Swamp[3]	Florida Cypress Dome[4]	Virginia Lake Drummond, Dismal Swamp[5]
Ca^{++}	24.4	18.6	34.9	7.6	25.4	38.2
Mg^{++}	17.4	21.0	16.6	9.4	20.1	16.9
Na^{+}	23.7	51.6	36.6	45.9	38.3	31.3
K^{+}	5.6	7.4	2.6	2.0	1.6	9.4
H^{+}	18.2		9.2	32.3	5.7	1.8
Fe^{++}	5.9			2.6	3.4	2.4
Mn^{++}	4.9		<0.1	1.4	1.4	
Σ(meq/l)	0.261		0.573	0.392	0.561	0.875

[1] Tilly (1975), [2] Daniel (1981), [3] Auble (1984), [4] Dierberg and Brezonik (1984), [5] Lichtler and Walker (1979).

of several ions (NO_3^-, $PO_4^{\equiv}$, Ca^{++}, and K^+) had variable but stimulatory results (Polisini et al. 1970). A more detailed analysis of major and trace nutrients and their significance to primary production is needed for Carolina bay ecosystems.

The acidic nature of the bay surface waters suggests a dystrophic condition. The acidity seems largely related to biological phenomena and low regional alkalinities. Interestingly, sphagnum moss, often implicated in bog acidity (Clymo 1964), is uncommon or absent from SRP bay communities. Organic acids and the metabolic products of sulfur bacteria (both chemosynthetic and photosynthetic) may be important sources of hydrogen ions in the bay ponds (Schalles 1979).

An increase in solute concentrations was noted in Bays 64 and 120 during a dry period in 1974; however, a much more pronounced increase was noted in early refilling stages. Conductivity values at these sites were about 600% greater in refilling stages than at similar water levels just prior to complete drying (Schalles 1979). This was attributed to an isolation of the ponds from groundwater exchanges, leaching of solutes from dead vegetation during refilling, and increased mineralization rates of soil detritus. Ponds that did not dry out had more modest solute response to changing water levels. Regression models of conductivity versus water level accounted for between 34 and 78% of the variance in conductivity for five sites with no surface exchanges, whereas no conductivity/water level relationship was found in a local bay pond at the Barnwell Industrial Park that received substantial storm runoff and surface flushing (Schalles 1989). Examination of individual solutes revealed that potassium, magnesium, and calcium had much higher negative correlations with water level than did sodium or DOC. In marsh

(1979) found that water level had stronger correlations with potassium and magnesium than with calcium, sodium, or pH. The lack of significant correlations between water level and sodium is puzzling. Sodium is a conservative ion (Wetzel

concentration effect with decreasing water level and surface volume. Although a lack of correlation between DOC and water level seems to exist in SRP sites, data obtained from four bays in 1979-80 (Figure 5) reveal seasonal behavior. DOC changes

Table 3. Detailed chemical analysis, including anion/cation charge balance, for surface waters in six Carolina bays sampled as part of a regional survey in January 1988.[1]

Variable	$\bar{x}$ (range, by sites) mg/l		$\bar{x}$ meq/l	$\bar{x}$ % meq
D.O.C.[2]	14.09	(8.08-21.71)	0.155	39.0
Cl^-	4.94	(3.44-7.99)	0.139	35.0
SO_4^{--}	3.32	(0.50-10.34)	0.069	17.4
HCO_3^-	2.07	(0.13-6.89)	0.034	8.6
Anions (Σ)	--		0.397	100.0
Na^+	3.08	(0.82-6.64)	0.134	32.8
Ca^{++}	2.12	(0.72-4.53)	0.106	26.0
K^+	3.83	(1.09-14.5)	0.098	24.0
Mg^{++}	0.78	(0.49-1.25)	0.064	15.7
H^+	0.006	(0.001-0.013)	0.006	1.5
Cations (Σ)	--		0.408	100.0
Sp. Conductance[3]	47.4	(28.6-98.2)		
pH	5.2	(4.9-6.1)		
SiO_2	2.82	(0.10-9.24)		
Fe (reactive)[4]	0.35	(0.28-0.63)		
Mn (reactive)[4]	0.18	(0.09-0.32)		

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[1] The sites were: Flamingo Bay (Site 3), Enchantment Bay (Site 40), Thunder Bay (Site 83), Mathis Lake in Aiken County, and Sister Lake and an unnamed site near Williston in Barnwell County. Four replicates were collected per site. Anions were determined with ion chromatography, metals with atomic absorption spectrophotometry, silica with molybdenum blue method (Newman and Schalles, unpublished)

[2] dissolved organic carbon, charge estimated from the analysis of Perdue et al. 1984

[3] in µmhos/cm

[4] from acid-pretreated samples, may be largely colloidal and values were not used in the charge balance analysis

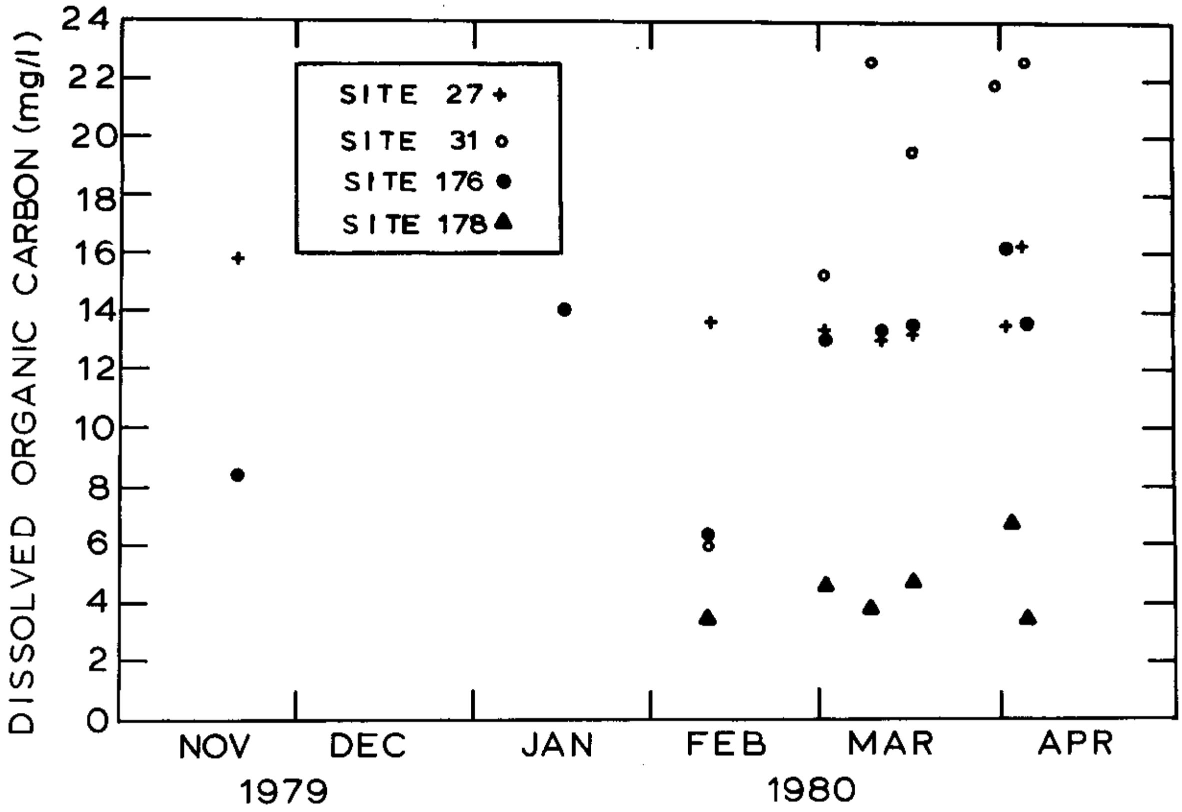

Figure 5. Dissolved organic carbon levels (average of two values per point) in four Carolina bays at the SRP (Site 27, Morse Code Bay; Site 31, Dry Bay; Site 176, Ellenton Bay; and Site 178, Asphalt Pond). See text for description of Asphalt Pond.

seasonal dynamics of biological processes than to evaporation. It should be noted that Site 178 (Asphalt Pond; Figure 5) is an anomaly, having been filled and paved with asphalt early in the history of the SRP, only to later have the pavement sink and the bay refill with water. This site, which has very low solute water, may function primarily as a precipitation collector with minimal groundwater exchanges and watershed contributions.

Relationships between variables measured in the 1979 and 1980 surveys were examined with product-moment correlation analysis (Table 4). Many of the significant correlations are related to similar behavior and cycling patterns (e.g. calcium and magnesium, iron and manganese) or dependency of some variables on others (e.g. conductivity on dominant ions, total carbon on organic carbon, pH on calcium, and iron on total organic carbon). Some variables such as potassium, oxygen, bay size, and bay elevation had few significant correlations (Appendix IIa and IIb). In general, many of the relationships are weak, even though statistically significant. Also, the correlations found in the surveys for this report are weaker than those found among the six sites studied in 1973-1974 (Schalles 1989).

In the three water chemistry analyses of SRP bays (1973-1974, 1979, and 1980), potassium exhibited the greatest overall variability (Table 5). The seasonal dynamics of potassium and its responsiveness to change in water levels may make this ion a useful variable to monitor the overall status of bay sites. Iron and manganese also exhibited high variability, while magnesium and conductivity had comparatively low variabilities. The higher coefficients of variation for the six sites in the 1973-74 study are largely attributable to the inclusion of two disturbed sites at the Barnwell County Industrial Park (Table 5). These two sites received considerable surface runoff and sedimentation from a large construction area. The disturbed ponds experienced high flushing rates, vegetation damage, and burial of organic sediments. These disturbances resulted in less acidity, lower DOC concentrations and monovalent to divalent cation ratios, and higher inorganic solute concentrations and conductivities than undisturbed sites (Schalles 1989). These changes were attributed to increased calcium bicarbonate loading, reduced biotic influence on the chemical environment, and open hydrology.

The more extensive comparison of eighteen sites in the 1980 survey revealed some patterns in cation concentrations (Figure 6A-H). Sites 61 and 92 had the highest calcium, magnesium, and total cation concentrations (Figures 6A, B, H). Both sites contain swamp forests and typically have very shallow water levels. A lack of correlation existed between the total cation concentration and H^+ rankings (Figures 6G, H). The highest pH was found in Sites 31, 92, and 176 and the lowest in 77. No physical or biological features were apparent to explain the pH ranking. Evidence from sodium/calcium ratios (Gibbs 1970) and from multivariate discriminant analysis of chemical survey data strongly implicated site-specific hydrology and differences in shallow groundwater chemistry as major factors in observed intersite variability (Schalles 1989). Much more intensive and comprehensive chemical sampling is required to further document and explain spatial and temporal chemistry patterns.

Spatial and temporal variability in oxygen and temperature were noted in the bay ponds. Strong oxygen and temperature stratification often existed when emergent or floating-leaf vegetation was present, even in shallow waters (Figure 7). Bottom strata exhibited very low oxygen levels (less than 0.5 mg/l) during most of the year Stratification and destratification can occur almost daily. Horizontal patterns were demonstrated with in situ Hydrolab measurements made in December 1979 in Dry Bay (Site 31). Highest oxygen values were found in shallow water with abundant filamentous algae while the lowest value was found in a macrophyte-shaded area with abundant detritus (Table 6). In general, bay pond margins had the greatest overall physical-chemical variability. Thunder Bay pond (Site 83) displayed marked seasonal patterns (Schalles 1989). Average water column oxygen values ranged from about 7 to 8 mg/l in midwinter to about 1.5 to 2 mg/l in late summer. Average water column temperatures varied from approximately 27°C in midsummer to 7°C in midwinter. The high spatial (both vertical and horizontal) and temporal (both daily and seasonally) variability in oxygen and temperature necessitate detailed measurements of these parameters before correlations with biotic and other abiotic variables can be established.

Table 4. Correlation coefficients (r) for 1979 and 1980 water chemistry analyses (extracted from correlation matrices in Appendix IIa and b).

Parameter Pair and r		Parameter Pair and r	
(1979 Data, $\underline{n}$ = 32)*(1980 Data, cont.)			
Ca/Mg	.763	Mg/Mn	.647
Ca/TOC	.652	Na/CAT	.628
Mg/RATIO	-.644	Ca/RATIO	-.562
Na/COND	.621	Mn/CAT	.550
Ca/RATIO	-.613	Mg/COND	.519
TOC/COND	.587	COND/CAT	.467
TOC/FE	.580	TIC/TEMP	.461
TOC/MG	.577	Fe/CAT	.457
Ca/COND	.542	Ca/Mn	.455
		Na/COND	.437
(1980 Data, $\underline{n}$ = 54)+		Na/RATIO	.429
TOC/TC	.998	Na/Mg	.418
Mg/CAT	.884	H/REDOX	.415
Mg/TC	.819	H/K	.415
Mg/Ca	.796	TC/RATIO	-.387
CAT/TC	.769	Ca/H	-.371
Ca/CAT	.738	Mg/RATIO	-.371
Mn/TC	.701	TC/OXY	-.363
COND/TEMP	.700		
Ca/TC	.654		

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* 1979 variables: calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), iron (Fe), manganese (Mn), total dissolved organic carbon (TOC), conductivity (COND), RATIO = Na + K/Ca + Mg. Significant r (p = 0 .01) = 0.514.

\+ 1980 variables: all of above and total cations (CAT), temperature (TEMP), hydrogen ion (H), redox potential (REDOX), dissolved oxygen (OXY), total inorganic carbon (TIC), and total carbon (TC). Because of the high TOC/TC correlation, only TC r values are given. Significant r (p = 0 .01) = 0.348.

SOILS

Soils of Carolina bays are poorly studied. Bay soils generally grade from well-drained sands on the xeric rims to consolidated sandy loams in the wetland centers. Hodge (1985) observed two conditions in sandy surface soils of the bay rims and adjacent interbay areas on or near the SRP. In one condition, the surface sand was 75-150 cm thick and was underlain by a sandy clay loam (Blanton series). In the second condition, the surface layer was excessively drained sand with depths exceeding 2 meters (Lakeland series). Interior to the bay rims, Hodge found a narrow zone with loamy surface sands 15-35 cm thick overlying a sandy clay loam horizon about 45 cm thick and a third horizon of about 75 cm composed of sandy loams or loamy sands. The central floors of most bays on or near the SRP have shallow, consolidated loamy soils which vary from 15-75 cm in thickness. A consolidated, gray clay hardpan is consistently found below the loamy stratum. Hodge (1985) determined that these hardpans averaged about 70 cm thick and that soils immediately below the hardpans were sandy clay loams. Organic horizons are generally thin, but often increase with increasing water depths and hydroperiods. The surficial mineral soils of the bay interiors are typically dark and contain numerous fine charcoal fragments indicating earlier fires (Schalles 1979).

Most soils occurring in the interiors of bays at the SRP and vicinity fit an Ochraquult classification (Hodge 1985). Ochraquult soils have thin, dark epipedons, thin to moderately thick argillic horizons, and base saturations of less than 50%. Such soils are inundated for at least three months of the year and have poor drainage. Soils of the SRP bays are largely Rembert and Ogeechee series loams, but also include Williman and Lumbee loamy sands (Hodge 1985). Interior to the sandy bay rims, soils of the following series are less frequently encountered: Duplin, Plummer, Faceville, Orangeburg, and Johnston (Hodge 1985).

Texture analysis (method of Boyoucous 1927) was performed on samples from the upper 20 cm of soil in the wetland communities of the six bays used in the 1973-74 comparative survey (Schalles 1979).

Table 5. Coefficients of variation (S.D./x̄) for three surveys of Carolina bays at the SRP and vicinity.

Parameter	1973-74 6 Sites n=216	1979 16 Sites n=32	1980 18 Sites n=54
Ca++	1.14	0.44	0.51
Mg++	0.44	0.36	0.33
Na+	0.81	0.38	0.40
K+	1.66	0.84	0.76
Conductivity	0.89	0.32	0.27
D.O.C.	0.53	0.29	0.93
Fe++	-	0.67	0.61
Mn++	-	0.73	0.77
H+	-	-	0.77

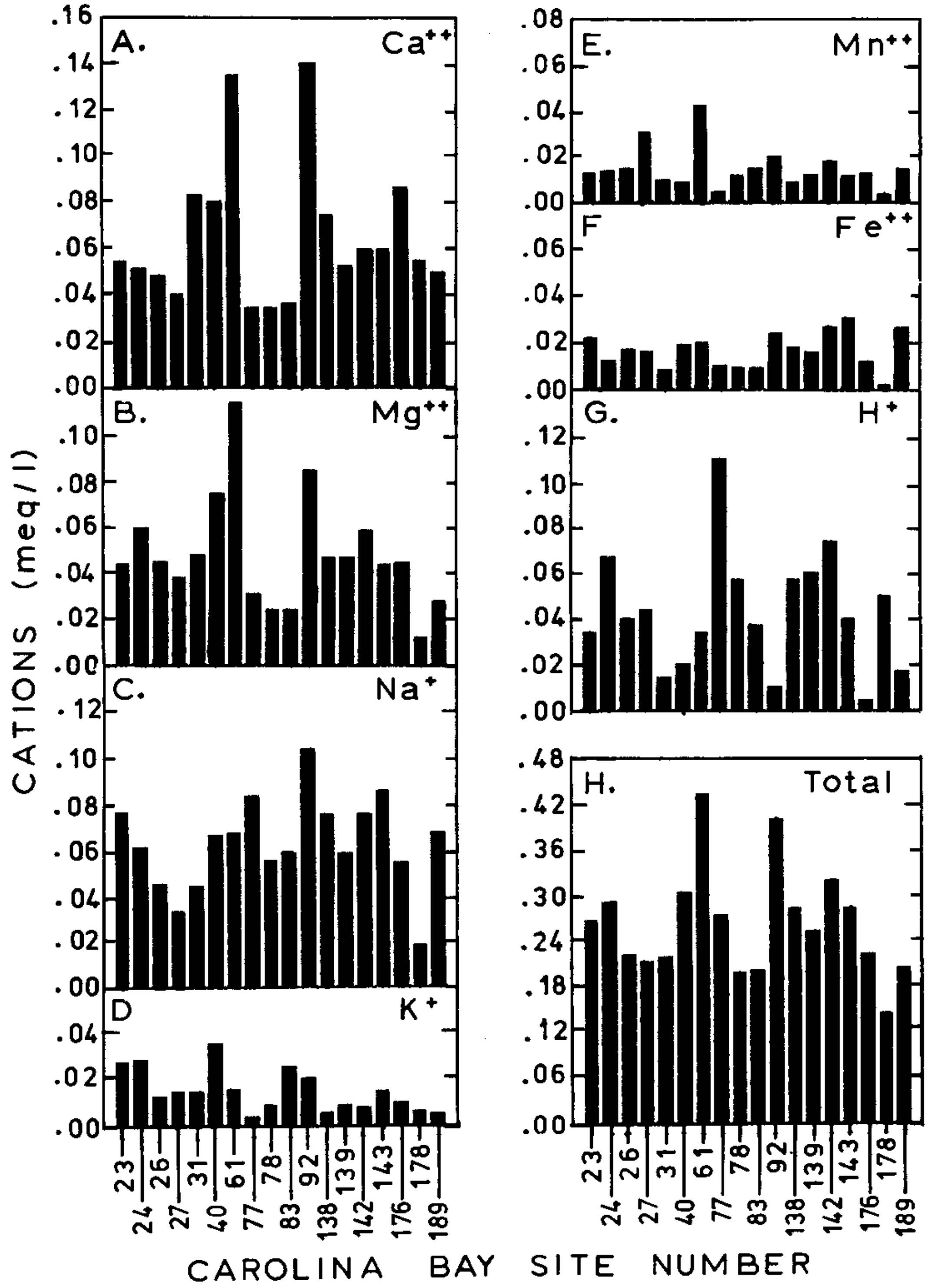


Figure 6A-H. Average ($\underline{n}=3$) surface water concentrations (meq/l) of seven cations and total cations measured between January and March 1980 in 18 Carolina bays at the SRP (see Appendix I for locations of the numbered bay sites).

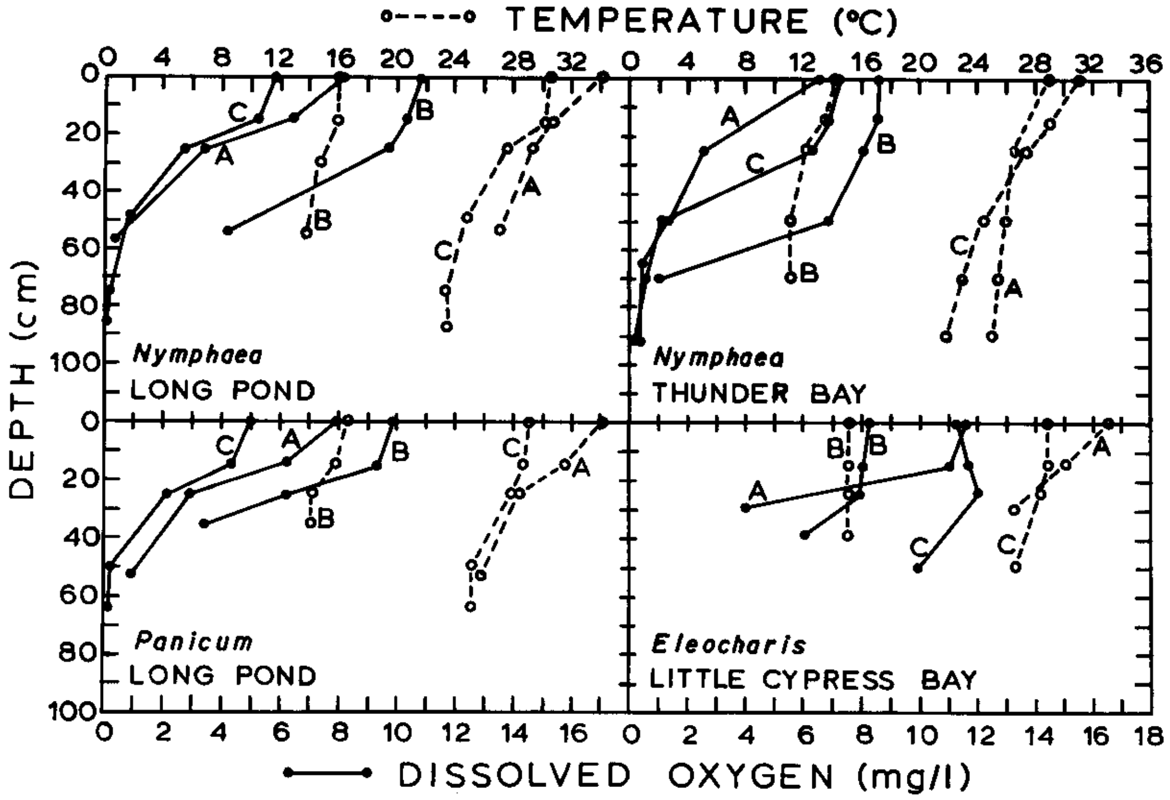


Figure 7. Vertical profiles of dissolved oxygen and temperature at four sampling stations in three of the Carolina bays used in the 1974-75 intersite comparisons (Schalles 1979). The data presented are typical of those found in emergent (see *Panicum* and *Eleocharis*) and floating leaf (see *Nymphaea*) vegetation zones. Lowest data points in profiles represent depth at which bottom was encountered. All data were obtained in afternoon periods (A--September 1974, B--February 1975, C--June 1975).

Sand, silt, and clay averaged 45.5%, 20.1%, and 34.4%, respectively. However, the proportions varied considerably, with percent sand values ranging from 27.0-62.2% in the six bays (Table 7). Although the two sites at the Barnwell Nuclear Fuel Plant experienced significant siltation and runoff from a construction area, their textures were near average. Bulk samples (upper 20 cm) from the wetland interiors of eight other bays on the east side of the SRP and adjacent Barnwell County had the following sand, silt, and clay proportions [$\underline{n} = 16$; $\bar{x}$(S.D.)]: 61.8% (16.9%), 23.6% (10.3%), and 14.6% (9.1%). The reason for the higher sand and lower clay values in this second group of sites is unclear. However, average sand and clay percentages in this latter group of eight bays were similar to the averages reported for two Carolina bays with mineral soil in northeastern South Carolina (Jones 1981) and for 12 low elevation bays of Virginia's Eastern Shore (Bliley and Pettry 1979).

Loss on ignition (LOI) data were obtained (combustion at 550°C for 24 hours) for three depth strata in thirty-one soil cores from the wetland communities of fifteen sites surveyed for this report. LOI values were generally low at all depths (Figure 8). These low values confirm the relatively oxidized, mineral nature of surface soils in upper coastal plain bays as reported by Frey (1951) for higher elevation North Carolina sites. Frequency analyses revealed a bimodal distribution for organic content in the 0-7.5 cm layer and tighter clustering for the two deeper layers (Figure 8). Correlation coefficients (r) for the upper/middle, upper/lower, and middle/lower strata LOI pairings were 0.77, 0.70, and 0.83, respectively. Many SRP bays have surface organic layers of less than 15 cm. However, the maximum thickness of peat in site 142 exceeds 1 m. Three peat samples from this bay had an average LOI of 87.3%. The occurrence of significant peat in site 142 could reflect a more stable hydrology with almost

Table 6. Water chemistry of eight stations at Dry Bay (Site 31) measured with a Hydrolab on December 7, 1979.

Station	Description	°C	pH	Redox (E_h)	O_2 (mg/l)	Cond. (µmhos/cm)
1	near shore, open pool	10.4	5.2	+230	7.6	30
2	open pool	10.4	5.2	+242	7.1	27
3	open pool surrounded by water lillies	10.2	5.4	+251	5.6	25
4	abundant macrophytes and detritus	10.2	5.4	+242	3.8	24
5	open pool near center, abundant detritus	9.6	5.4	+258	3.3	25
6	open pool	9.3	5.5	+211	4.2	26
7	shallow, abundant filamentous algae	10.9	5.9	+206	11.0	24
8	near shore, abundant macrophytes	10.9	5.5	+249	6.1	23

continual groundwater recharge that reduces exposure to the atmosphere and enhances peat development. This bay is located between the 130 and 140 ft (42.7-45.9 m) isocontours and is relatively close to Steel Creek and the Savannah River floodplain. However, other SRP bays with similar locations near streams or the floodplain lack significant peat buildup. Hodge (1985) found several Carolina bays at the SRP and adjacent Barnwell and Aiken Counties with peat layers of 50-100 cm.

Soil pH values were determined for several sites using soil/distilled water slurries (1:1 volume ratio, soil samples were air dried). The pH [x̄/(S.D., derived by taking averages of the hydrogen ion concentrations), n = 10] of 0-7.5, 7.5-15, and 15-22.5 cm strata in five sites in our 1979 survey averaged

Table 7. Soil data for six Carolina bays on the SRP and adjacent Barnwell Nuclear Fuel Plant (BNFP). Data are averages for six stations at each site. Standard deviations are shown in parentheses.

Site	pH	Sand (%)	Silt (%)	Clay (%)	LOI[1] (%)	Cs-137[2] (pCi/gm)
Little Cypress	4.1	39.5	26.9	33.7	13.7	1.70
(Site 64)	(0.1)	(9.8)	(3.4)	(7.5)	(3.4)	(0.36)
Thunder Bay	4.0	51.2	16.1	32.7	9.3	1.36
(Site 83)	(0.1)	(8.9)	(2.6)	(8.0)	(2.6)	(0.33)
Route 9 Bay	4.2	27.0	30.9	42.2	12.4	2.32
(Site 120)	(0.1)	(12.9)	(6.1)	(8.0)	(2.7)	(0.83)
Ponding Area 1	4.0	37.2	17.3	45.5	7.8	2.23
(BNFP)	(0.2)	(16.8)	(5.3)	(12.1)	(2.5)	(0.52)
Ponding Area 2	3.9	56.3	16.2	27.5	3.3	1.14
(BNFP)	(0.2)	(13.4)	(6.2)	(8.3)	(0.8)	(0.36)
Long Pond	4.1	62.2	12.9	25.0	3.5	0.95
(BNFP)	(0.1)	(10.9)	(3.9)	(8.0)	(1.4)	(0.20)

[1] percentage loss on ignition at 450°C.

[2] picocuries per gram dry weight.

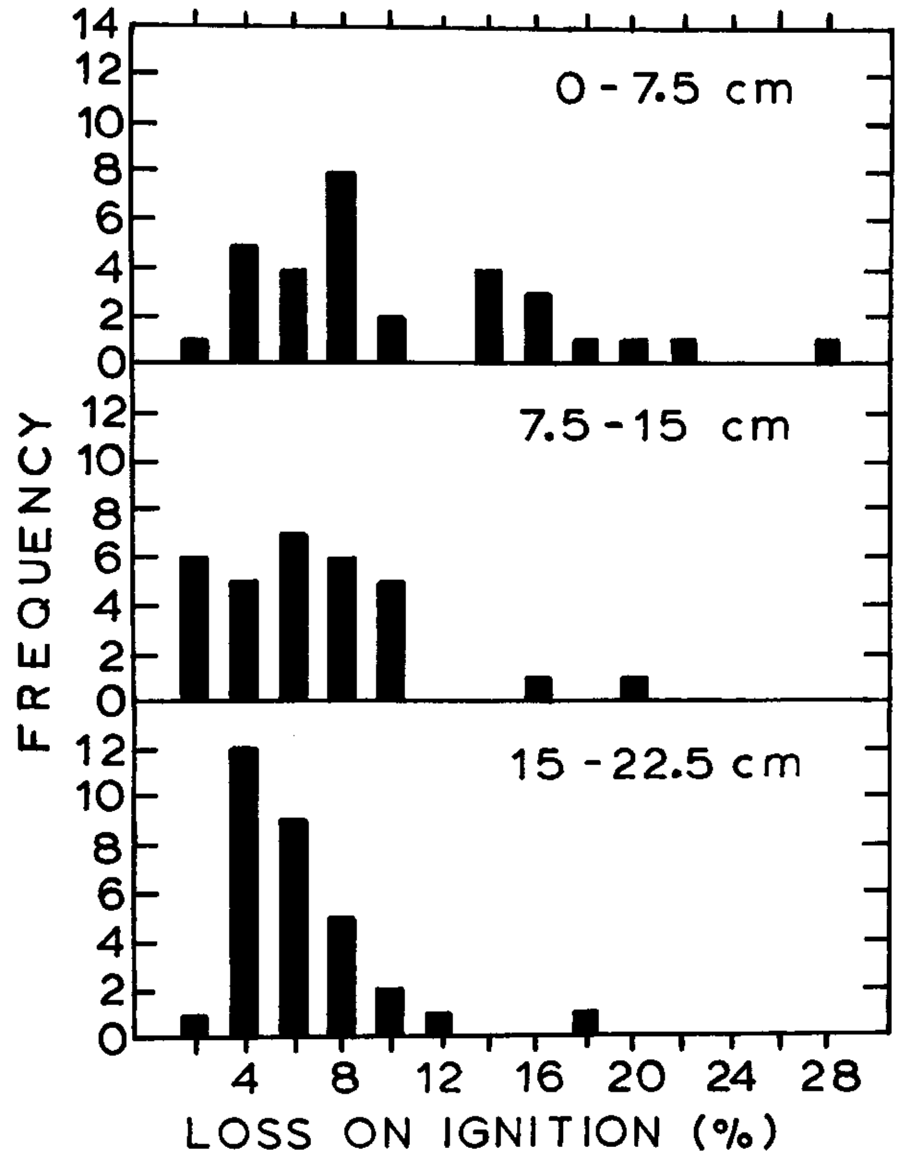


Figure 8. Frequency distribution of percentage loss on ignition (LOI) values for three depth strata in 31 soil/sediment cores from 15 Carolina bays at the SRP.

3.84 (0.35), 3.83 (0.41), and 3.81 (0.47). Soil pH values (upper 20 cm) of the six bays in the 1973-74 comparative study ranged from 3.9-4.1 (Table 7). The acidic, reduced conditions of saturated bay soils must be a dominant chemical factor. However, no significant correlations were found between pH and soil texture, % LOI, or soil Cs^{137} (Table 8).

Values of Cs^{137} from global atmospheric fallout were determined for sampling station soils in the six sites used in the 1973-74 comparison (Table 7). Activity levels were measured in oven-dried soil samples placed in counting vials and analyzed for Cs^{137} using a Nuclear-Chicago autogamma counting system with a 7.7 cm NaI(TI) well-type scintillation crystal. Samples were run until 4000 counts were accumulated (20 cpm background) and counting rates were corrected for background, counting efficiency, sample geometry, and sample weight. A substantial range (0.95-2.32 pCi/g) was found in the site averages. As expected, Cs^{137} levels had positive correlations with percentages of clay and organic matter and a negative correlation with sand percentages (Table 8). Soil retention capacity, rather than differences in loading rates and hydrologic turnover, appears to be the dominant factor affecting intersite fallout cesium differences.

Hodge (1985) conducted soil chemistry analyses for Carolina bays on or near the SRP. Data for seven variables from twenty-four locations in six bays are summarized in Tables 9 and 10. The range of LOI values was similar to those reported above, whereas pH values were higher (Table 9). A remarkable consistency was found in the cation exchange capacity values of the six sites. Low levels of extractable cations and phosphorus were found. However, Sister Lake (near the SRP) had noticeably higher extractable P, Ca, and Mg than the other sites (Table 9). Extractable nitrate was consistently nondetectable in Hodge's samples. Phosphorus had very strong positive correlations with calcium and LOI (Table 10). Other significant positive correlations included Ca/LOI, CEC/pH, Ca/Mg, and CEC/K. Relatively strong negative correlations were found for pH/P and pH/LOI (Table 10). The low levels of exchangeable soil nutrients are consistent with the dilute, nutrient poor water of Carolina bay wetlands. Woodwell (1958) found that growth of pine seedlings in bay soils was strongly limited by

Table 8. Pearson product-moment correlation coefficient (r) matrix for parameters of surface (upper 20 cm) soils for six stations in each of six Carolina bays at the SRP and adjacent Barnwell Nuclear Fuel Plant.

	pH	Sand	Silt	Clay	% LOI
Sand	0.289				
Silt	0.375	-0.838			
Clay	0.082	-0.920	0.556		
% LOI	0.344	-0.752	0.774	0.587	
Cs-137	0.289	-0.728	0.627	0.656	0.555

both P and N. The comparatively low organic matter, which may include a significant fraction of inert charcoal fragments, and the low to moderate clay levels presumably limit nutrient binding and exchange capacities of bay soils. Nutrients such as N and P normally are found in less available organic forms in such soils (Barnes 1981).

VEGETATION

Several wetland community types typical of undrained coastal plain sites are found within SRP bav depressions. A list of vascular plants for eight bays studied by Hodge (1985) on and adjacent to the SRP is given in Appendix III. Topographical relief and hydrology are the principal determinants of vegetation composition in the bays, although edaphic conditions play a role. The duration and magnitude of inundation creates a range of conditions favoring different vegetation associations.

A xeric to hydric gradient occurs from the peripheral sand rim to the center of bay depressions. Kelley and Batson (1955) described several concentric vegetational zones in Craig's Pond (Site 77). The outermost zone lies along the sandy rim of the bay and is dominated by trees such as loblolly (*Pinus taeda*) and longleaf pines (*P. palustris*), black gum (*Nyssa sylvatica*), blackjack oak (*Quercus marilandica*), turkey oak (*Q. laevis*), and sweet gum (*Liquidambar styraciflua*). Several shrubs, such as sumac (*Rhus copallina*), gallberry (*Ilex glabra* and *I. coriacea*), and red bay (*Persea borbonia*) also occur

Table 9. Summary of soil chemistry analyses for six Carolina bays on the SRP and Barnwell County, SC (from Hodge 1985). Elemental analyses are given as parts per million of extractable ions. Extractable nitrate (values not given) was less than 1 ppm in all samples.

Site	(n)	P	K	Ca	Mg	CEC[1]	% LOI[2]	pH
Woodward Bay (Site 67)	3	3	24	68	7	28.6	9.2	4.6
Craig's Pond (Site 77)	4	2	8	49	4	28.3	9.6	4.5
Sarracenia Bay (Site 78)	4	7	14	67	9	28.8	6.4	4.6
Ellenton Bay (Site 176)	4	4	15	110	8	29.7	3.9	5.0
Sister Lake (Barnwell Co.)	6	15	19	230	16	29.2	8.5	4.6
Youngblood Bay (Barnwell Co.)	3	1	20	68	6	28.7	11.3	4.6

[1] Cation exchange capacity (meq/100 g dry weight).

[2] Percentage loss on ignition at 450°C.

here. Inside this zone of woody species are several bands of herbaceous vegetation, each of which is dominated by grass species. The first is characterized by broomsedge (*Andropogon virginicus*), but also contains numerous herbs including pitcher plants (*Sarracenia* spp.). Inside this zone is a band of vegetation dominated by three-awn grass (*Aristida affinis*) and in deeper water areas, surrounding the central pool of water, species of maidencane (*Panicum* spp.) are abundant. The pond in the middle of the bay contains typical floating-leaved aquatic plants such as the water lilies *Nymphaea odorata* and *Nymphoides aquaticum*. In a subsequent floristic study of Craig's Pond, Hodge (1985) found similar patterns, with the exception of the area between the *Andropogon* and *Panicum* zones (Figure 9).

Seventeen natural herbaceous community types were found in the eight Carolina bays studied by Hodge (1985). As many as six types were found in one bay (Craig's Pond). For Craig's Pond and Ellenton Bay (Site 176), the composition and distribution of herbaceous species in community types along the hydrologic gradient from the rim to the hydric center are illustrated in Figures 9 and 10.

Ordination results of vegetation cover data for samples from Craig's Pond support a preliminary designation of six community types (Hodge 1985; Figure 11). There is a general trend from hydric to mesic conditions (left to right) along the detrended correspondence analysis (DCA) Axis 1. The distribution or arrangement of community type samples along this axis reflects a gradient from permanently inundated wetland to seasonally wet/dry wetland. The arrangement of samples along Axis 1 is the same as the natural arrangement of community types in Craig's Pond. The distribution of samples along DCA Axis 2 appears to follow the gradient of peat observed in Craig's Pond soils. The *Nymphaea odorata-Brasenia schreberi* community type occurs in the deepest water and on 0.2-0.5 m thick peat deposits, while *Panicum hemitomon-Pontederia cordata* occur on peat deposits over 1 m thick.

Ordinations by Hodge (1985) of vegetation samples from Ellenton Bay (Figure 12) do not reveal a major gradient. Ellenton Bay was disturbed before the early 1950s when the Atomic Energy Commission acquired the area. Aerial photographs of Ellenton Bay taken in 1943 show that part of the

Table 10. Pearson product-moment correlation coefficient matrix for soil chemistry parameters in six Carolina bays on the SRP and in Barnwell County, SC (n = 24, data from Hodge 1985).

	pH	P	K	Ca	Mg	CEC
P	-0.537					
K	0.327	-0.155				
Ca	-0.401	0.940	0.077			
Mg	-0.179	0.691	0.471	0.858		
CEC	0.769	0.022	0.522	0.227	0.435	
% LOI	-0.564	0.963	-0.049	0.973	0.760	0.022

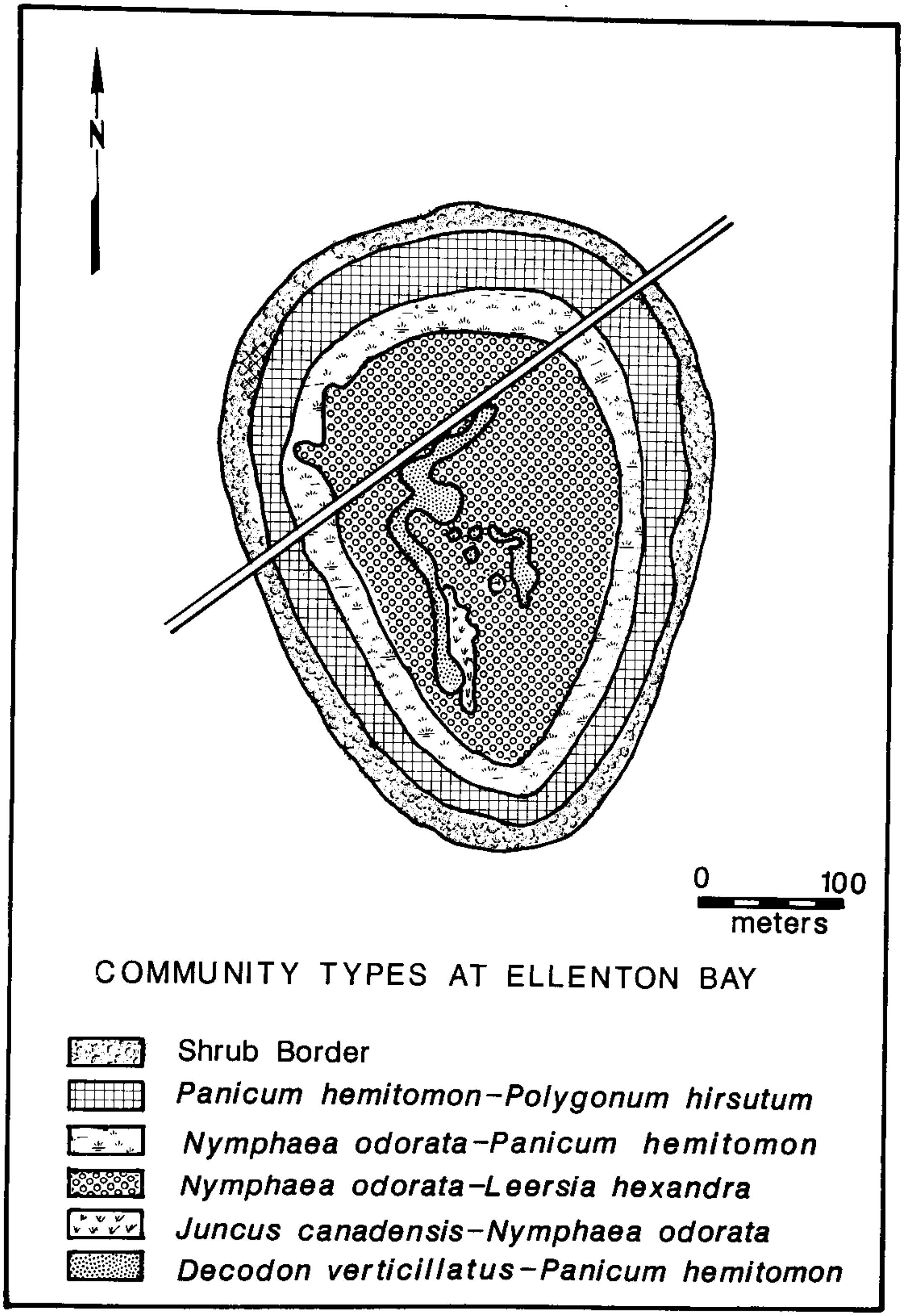


Figure 9. Community types at Craig's Pond (Site 77; Hodge 1985).

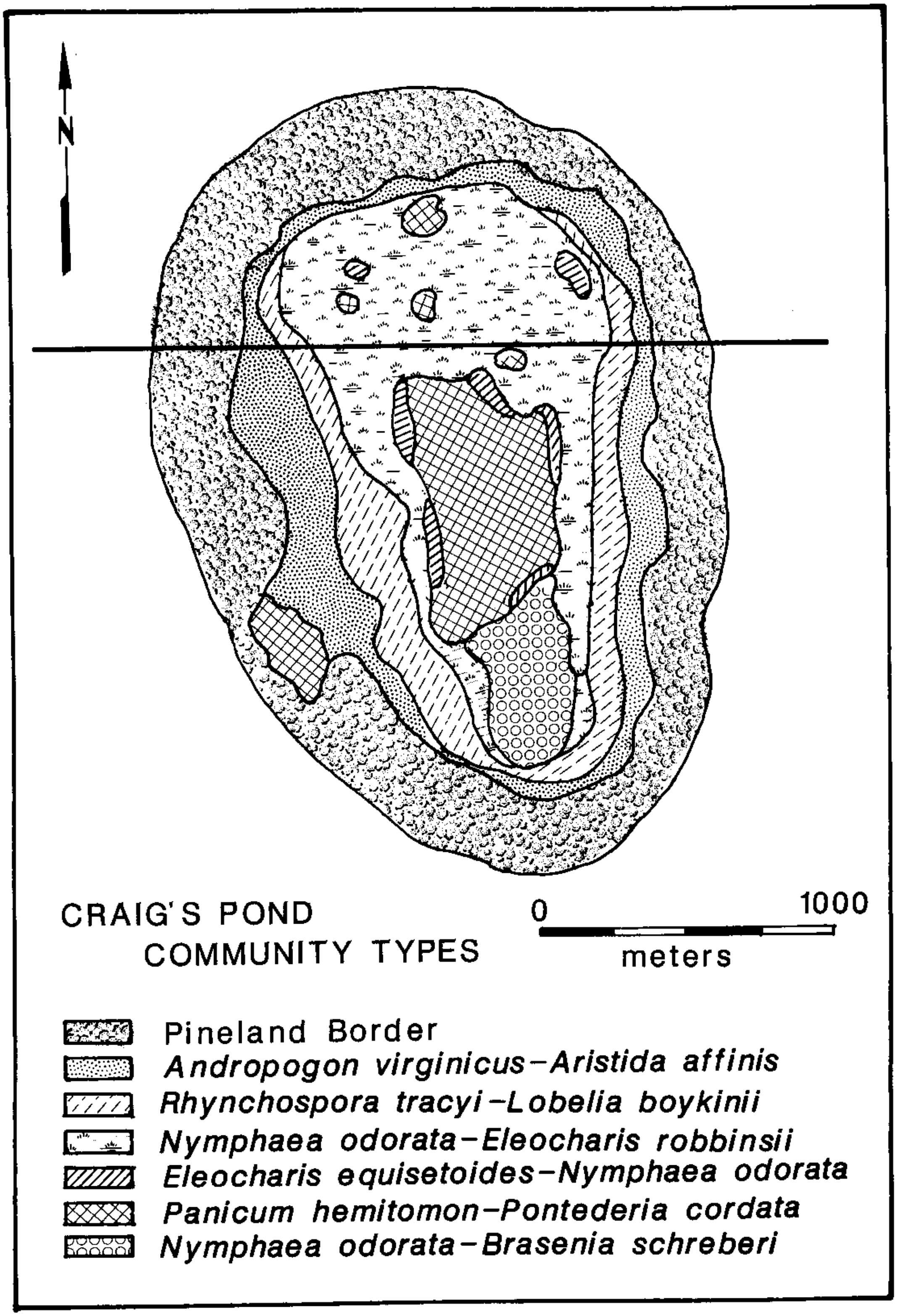


Figure 10. Community types at Ellenton Bay (Site 176; Hodge 1985).

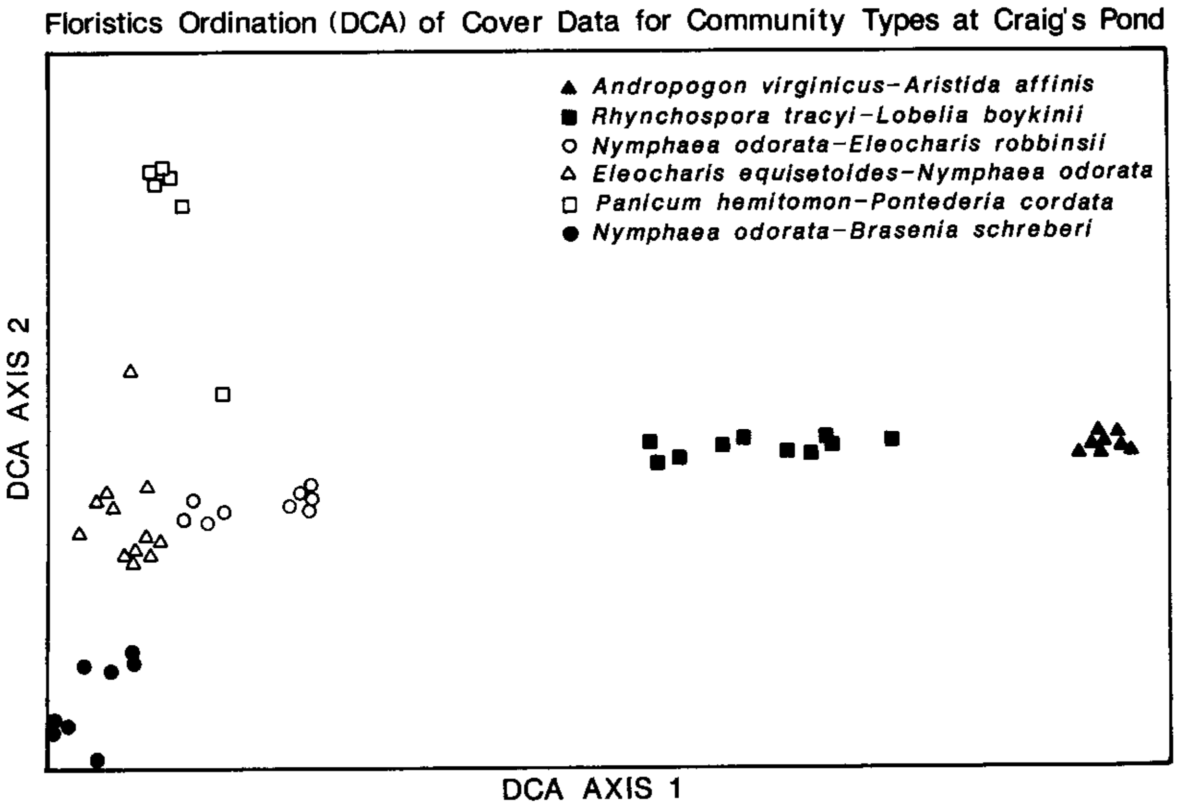


Figure 11. Detrended correspondence analysis ordination of vegetation cover data from Craig's Pond (Site 77; Hodge 1985).

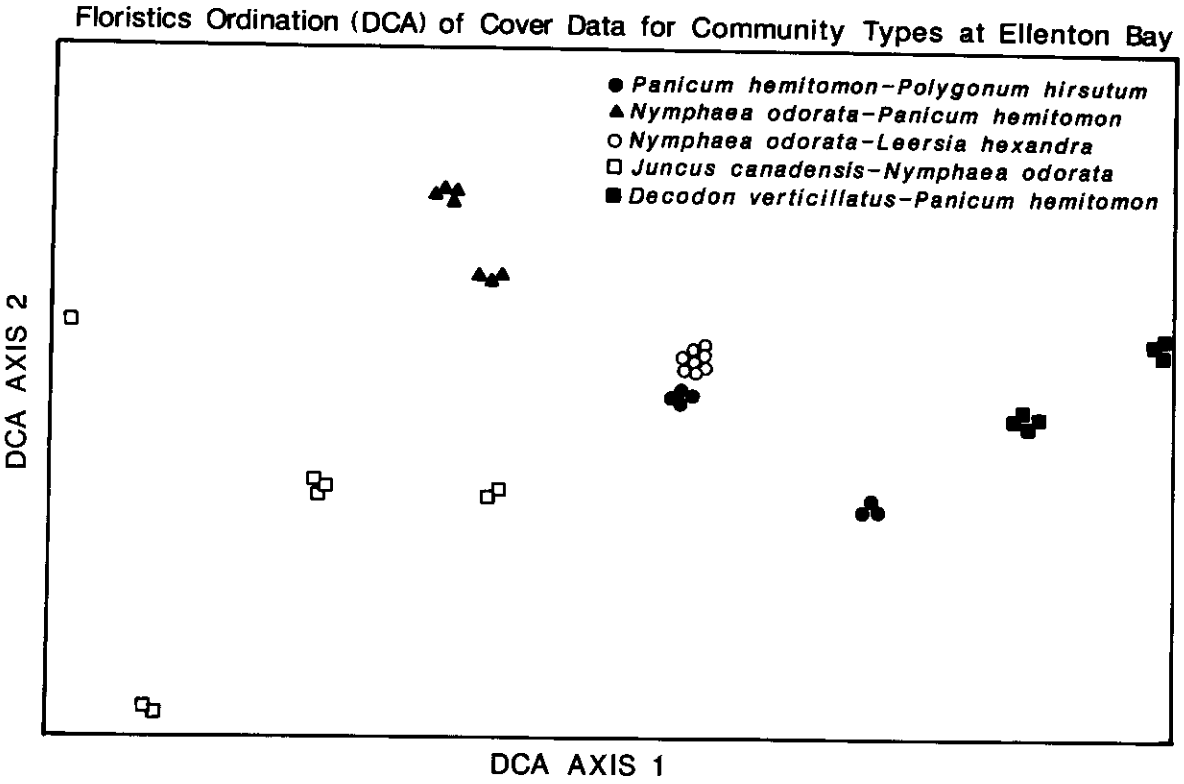


Figure 12. Detrended correspondence analysis ordination of vegetation cover data from Ellenton Bay (Site 176; Hodge 1985).

bay and surrounding area was intensively cultivated and pastured prior to acquisition. This previous cultivation may explain the almost perfectly concentric pattern of low diversity community types found in Ellenton Bay today (Figure 10).

Field observations and the results of Hodge's study (1985) suggest that short-term succession from herbaceous to woody dominated communities in bays of the Upper Coastal Plain occurs when water levels are low. After a bay has been ditched and drained, *Cephalanthus occidentalis*, *Diospyros virginiana*, or *Liquidambar styraciflua* commonly germinate on the exposed soil. A woody-dominated community soon becomes established. In undisturbed bays, organic material accumulates faster in the semipermanently to permanently inundated areas where conditions are at or approach anoxia throughout the year. In these deeper areas of the bays, peat may accumulate until it is exposed during periods of low water levels. During these periods, seeds of woody species may become established and initiate the development of a woody-dominated community. Thus, long-term succession may proceed by the process of paludification.

Another interpretation of long-term community succession is based on the abundant charcoal fragments in bay soils and the rates of inorganic filling which appear to be extremely low in undisturbed sites. A cyclical succession pattern may have maintained relatively stable community structures throughout the Holocene. Under this scenario, periodic drying and fires, coupled with negligible inorganic filling, have prevented the classic linear succession pattern of basin filling. Present vegetation patterns may simply reflect the current moisture gradients and recent fire histories within these sites. It seems probable that short-term population distribution patterns shift with prevailing moisture conditions. Short-term cycles may, in turn, be superimposed on a relatively longer-term geological trend (perhaps thousands of years) of a reduction in average water level and an increase in hydroperiod amplitude as a result of eroding regional streams, lowering of water tables by valley excision, and a very gradual inorganic filling of the depressions from aeolian transport.

Few studies have measured the primary productivity of these diverse wetlands. Schalles and Shure (1989) described the vegetation of Thunder Bay (Site 83) as dominated by a shallow zone of maidencane (*Panicum hemitomon*) and cutgrass (*Leersia hexandra*), and a deeper central area of water lily (*Nymphaea odorata*) and water shield (*Brasenia schreberi*). Standing root crop averaged 780 g dry wt/m^2 in the aquatic zone. Root/shoot ratios were high and averaged about 8. Total net primary production of macrophytes (harvest method) averaged about 260 g dry wt/m^2/yr. Algal composition in Thunder Bay was dominated by desmids, diatoms, and filamentous chlorophytes. Algal chlorophyll *a* averaged 25 mg/m^2. Significant levels of photosynthetic bacteria pigments were found in samples from Thunder Bay and several other SRP bay sites. Bacteriochlorophyll *a* averaged 17 mg/m^2 in Thunder Bay (Schalles and Shure 1989).

The distribution and temporal dynamics of detritus in the bays with mineral soil is of particular interest. Detritus rarely achieves steady state levels because of water level dynamics. Decomposition of saturated detritus may proceed relatively slowly in these acidic, reduced environments until drying occurs. Kormondy (1968) studied decomposition rates in the *Nymphaea odorata* and *Brasenia schreberi* zones of Ellenton Bay. He believed that the decomposition rates in the pond, as measured by *Nymphaea* and *Brasenia* leaf decomposition and cellulose strip disappearance, were insufficient to accommodate the annual detritus input. Detritus was measured in situ in Thunder Bay (Schalles 1979). Coarse particulates ($\geq$ 6 mm) and fine particulates (< 6 mm) in the detrital mat averaged 290 and 790 g dry wt/m^2, respectively. Fine particulates had a rather even distribution whereas levels of coarse particulates were notably higher in emergent vegetation zones.

INVERTEBRATE FAUNA

Invertebrates have been described from only a few Carolina bays of the SRP. Cross (1955) surveyed odonate distributions in Carolina bays and other aquatic habitats of the SRP. Invertebrates were intensively surveyed in 1979 at Rainbow Bay (Site 189) and Sun Bay (Site 45), with detailed listings of taxa and their relative abundances provided in tabular form (Savannah River Ecology Laboratory 1980). Intensive work at Sun Bay disclosed a diverse insect assemblage with 119 families from fourteen orders identified. Artificial substrate collectors were placed in several aquatic nicrohabitats in and around the two bays.)ipterans were the most abundant taxa at both Sun ind Rainbow Bays. Oligochaetes and isopods were elatively common in the Rainbow Bay collectors, ut were not collected in Sun Bay (Table 11).

Macroinvertebrates were quantified from 1975-77 at Thunder Bay (Site 83) using a cylinder nclosure technique (Schalles and Shure 1989). Total macroinvertebrate biomass was low with an nnual average of about 800 mg dry wt/m^2. Four nsect orders dominated the invertebrates.)donates, dipterans, hemipterans, and coleopterans veraged 396, 210, 87, and 83 mg/m^2, respectively. Macroinvertebrates in Thunder Bay were similar in omposition, but contributed only about 20% of the enthic biomass measured by Benke (1976) in an bandoned farm pond on the SRP. The dystrophic bog chemistry and periodic drying apparently prevent or severely restrict the occurrence of several freshwater invertebrate groups in the Thunder Bay wetland community. Ephemeropterans, megalopterans, and trichopterans were infrequent and plecopterans, amphipods, isopods, decapod crustaceans, gastropods (except the limpet *Ferrisia*), bivalves, and oligochaetes were absent during this study. The very low calcium levels in undisturbed upper coastal plain bays may be the primary limiting factor for molluscs, decapods and other malacostracans, and perhaps annelids Snails were frequently observed in two nearby Carolina bays at the Barnwell County Industrial Park. The bays had received runoff and sediments from a construction area and had significantly higher calcium levels (averages of 9.5 and 14 mg/l for the two sites).

Table 11. Density of certain insect orders, oligochaetes, and isopods (number of individuals/20 cm^2) determined by artificial substrate sampling at Rainbow (Site 189) and Sun (Site 45) Bays. Data from Savannah River Ecology Laboratory (1980).

	TAXA							
Microhabitat	Ephemeroptera	Coleoptera	Diptera	Hemiptera	Odonata	Tricoptera	Oligochaeta	Isopoda
Rainbow Bay								
Deep open water	2.5	0	44.5	0.5	3	0	16.5	10.5
Shallow water in button bush	4.5	1.3	9.6	3.3	1.6	0	5	15.3
Sun Bay								
Open disturbed pond	0	1.5	30.5	1	0	0	0	0
Open weed-filled pond	0	2	59	1	0.5	0	0	0
Pond in button bush	0	6.5	41	0	0	0	0	0
Drainage ditch	3	1	38.5	0.5	0.5	0	0	0
Drainage ditch, flowing	0	5	101	0	0	0	0	0

The zooplankton of Carolina bays on the SRP are diverse, abundant, and at least moderately productive (Taylor et al. 1989, Mahoney, Mort, and Taylor, unpublished). Calanoid and cyclopoid copepods, cladocerans, and rotifers are ubiquitous. Anostracans and conchostracans are sporadically distributed, but may be very abundant where they occur. The median biomass of zooplankton in Rainbow Bay was 100 mg dry wt/m^2 in 1984 and production was 6.2 g dry wt/m^2 or 62 kg for the entire bay. The community in Rainbow Bay showed marked changes in species composition during the wet season (Figure 13). In such bays, which function as temporary ponds, all of the zooplankton have resting stages that lie dormant in the sediments during the dry season. Varied times of emergence from these resting stages contribute to the succession of species in Rainbow Bay. Zooplankton comprise an important part of the diets of larval salamanders (Taylor et al. 1988). Insect larvae may also prey heavily on the zooplankton.

VERTEBRATE FAUNA

Vertebrates are conspicuous and relatively abundant members of the Carolina bay fauna. Perhaps because of the water level oscillations and dry periods, no vertebrates found in SRP bays are considered strictly endemic to such habitats of the Sandhills coastal plain region. All aquatic and semi-aquatic vertebrates, except fish, apparently use migration or aestivation strategies during dry periods. For example, sirens (*Siren intermedia* and *Siren lacertina*) form cocoons and aestivate during dry-outs (Conant 1975). The mole salamander (*Ambystoma talpoideum*) is commonly terrestrial as an adult but is paedogenic in situations where water is usually permanent. It may have evolved this pattern of metamorphosis in response to unpredictable water levels that may result in potentially ephemeral aquatic habitats becoming permanent ponds with no fish predators (Patterson 1978, Semlitsch 1985).

Although large Carolina bay lakes in North Carolina have resident fish populations composed of several species (Frey 1951, Bailey and Frey 1958), it is likely that most bays do not have permanent fish inhabitants because of periodic drying. Fishes have been observed in several Carolina bays on the SRP (Bennett and McFarlane 1983). The following fish were observed in four Carolina bays on the SRP during 1978-1983: redfin pickerel (*Esox americanus*), mud sunfish (*Acantharchus pomotis*), sunfish (*Lepomis* spp.), lake chubsucker (*Erimyzon sucetta*), and mosquitofish (*Gambusia affinis*; Thorp and Caldwell, personal observation). Fewer than 10% of the Carolina bays on the SRP are known to have permanent fish populations, although overwash from neighboring swamps or streams may reestablish the ichthyofauna of formerly dry basins.

Although fishes are not a dominant feature in most bays, other vertebrates are diverse and their productivity may be high. Several species of reptiles and amphibians are associated with Carolina bays on the SRP (Gibbons and Patterson 1978, Gibbons and Semlitsch 1990). Gibbons (1970) noted over thirty species of amphibians and reptiles in and around Ellenton Bay (Site 176). The use of bays by vertebrates is sometimes astonishing, as revealed by the high number of semi-aquatic animals migrating to and from the water (Table 12). Rainbow Bay (Site 189), which has an aquatic perimeter of less than 450 m (1476 ft), had approximately 10,000 individuals of the southern leopard frog (*Rana utricularia*) moving in or out in one year (Pechmann, personal observation). This is an average of one frog for every 2 cm of pond margin. A similar calculation for Ellenton Bay, which is much larger, indicates that one adult mole salamander (*Ambystoma talpoideum*) enters to breed each winter per 20 cm of perimeter (Patterson 1978) and as many as 11,000 recently metamorphosed individuals may exit during one week (Semlitsch, personal observation). These 11,000 salamanders are equivalent to one per 11 cm of perimeter and contribute a total biomass of 70 kg. Schalles and Shure (1989) obtained in situ estimates of salamander density and biomass in the aquatic area of Thunder Bay (Site 83). No fish were present in the community. Over an annual cycle in a 1 ha sampling grid *Siren intermedia*, *Notophthalmus viridescens*, and *Ambystoma talpoideum* populations averaged 0.15, 1.18 and 1.46 individuals/m^2 and 8.03, 3.12, and 1.23 kg dry wt/ha, respectively. During the same period, anuran larvae (primarily Ranidae) averaged 1.03 kg dry wt/ha.

The abundance of amphibians in Carolina bays altered by agricultural, forest management, or construction activities (e.g., Sun Bay, Site 45, Table 12; Lost Lake, Site 28; Bennett et al. 1979), may be higher than expected. In 1979, more than 500 ornate chorus frogs (*Pseudacris ornata*), 5,000

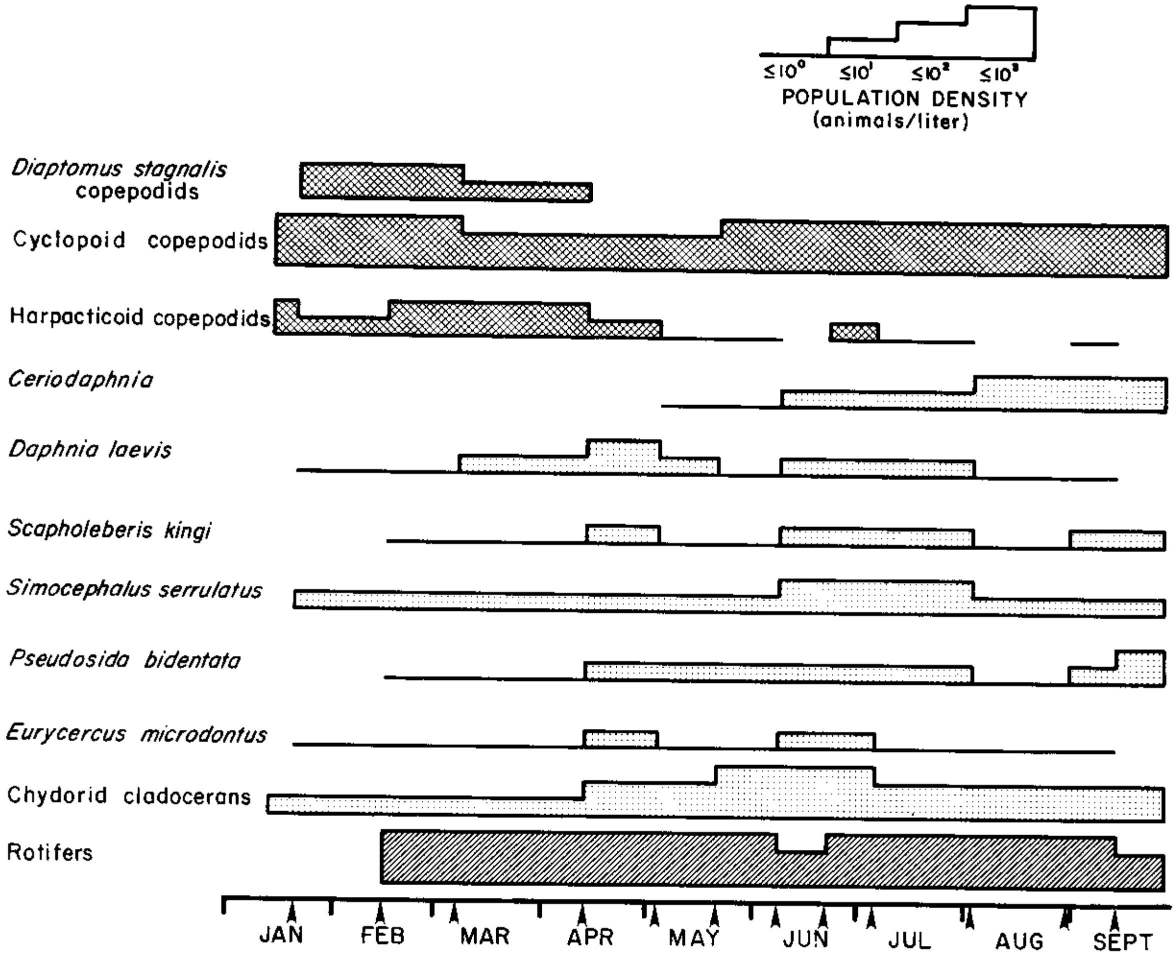
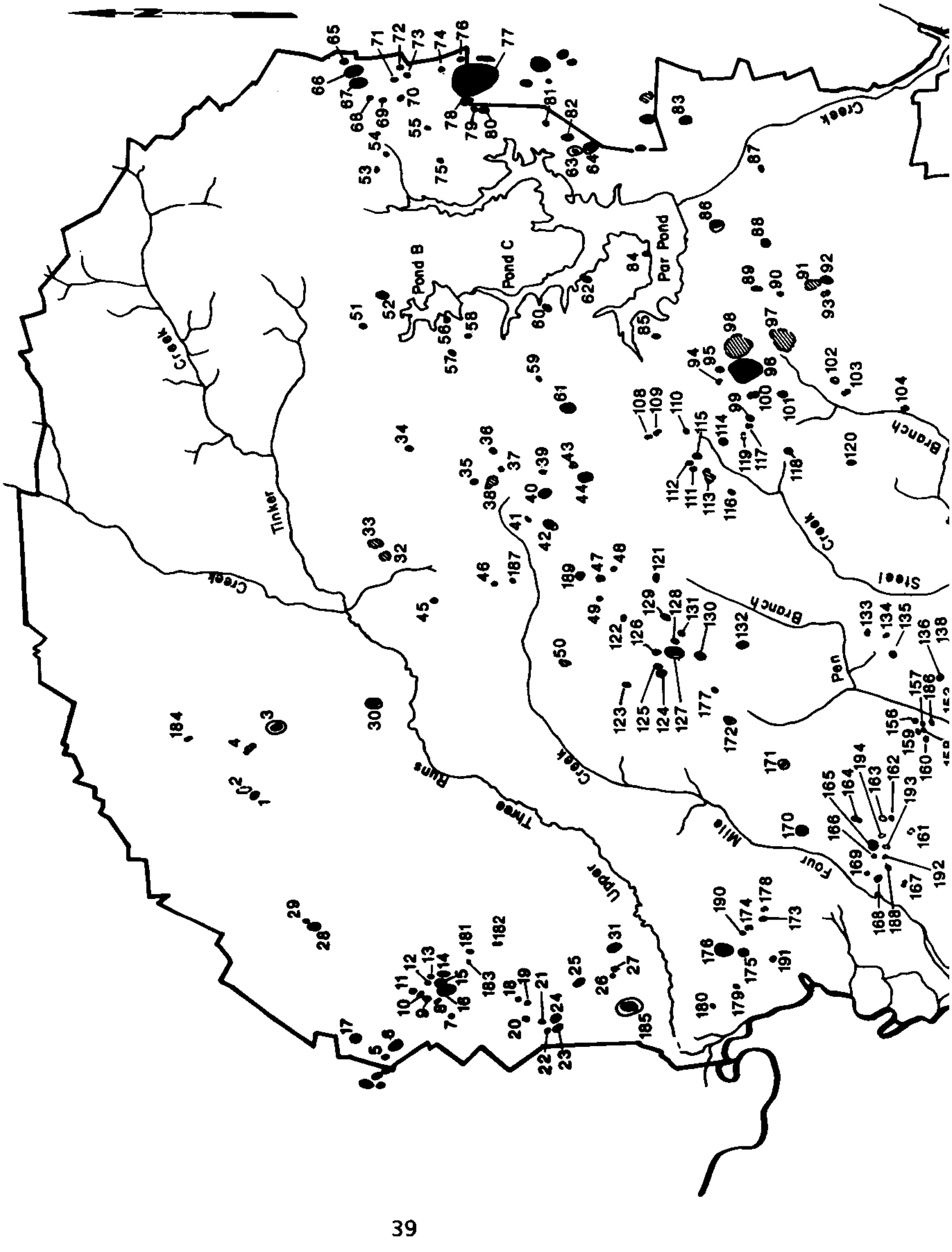


Figure 13. Changes in zooplankton species composition from January to September 1984 at Rainbow Bay, Site 189 (from Taylor, unpublished data).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Pond C
Par Pond
Creek
Tinker
Creek
Branch
Steel
Creek
Branch
Pen
Four Mile
Creek
Upper Three Runs
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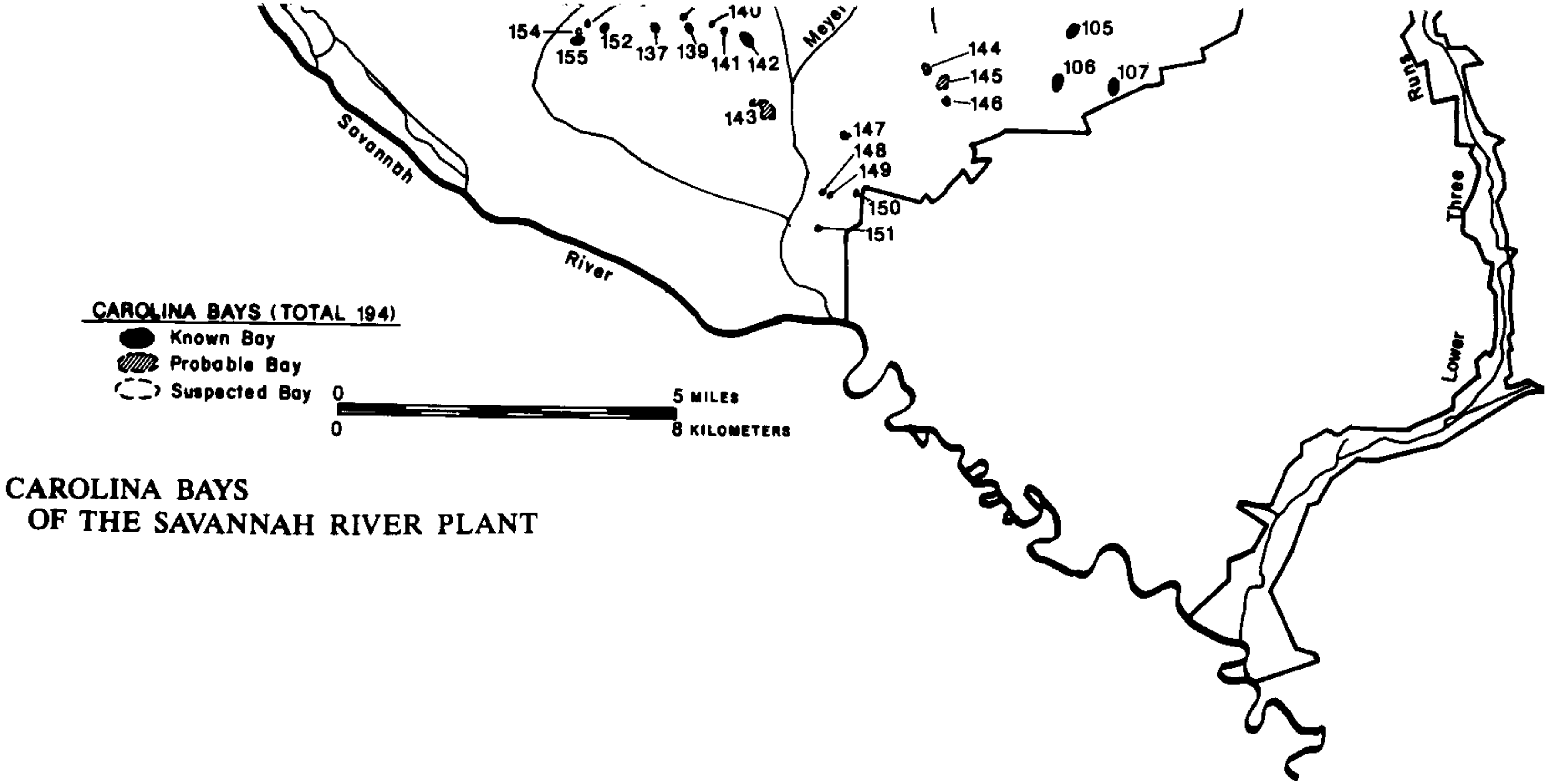

Figure 14. Known and suspected Carolina bays of the SRP, South Carolina. Numbers correspond to bay identities in Appendix I.

Table 12. Utilization of Carolina bay habitats by small vertebrates. Numbers indicate selected vertebrate species captured (original an recaptured) in drift fences with pitfalls at Rainbow Bay and Sun Bay, SRP, SC, for one year, March 1979-March 1980 (adapte from Gibbons and Semlitsch 1982).

	Rainbow Bay				Sun Bay			
	Entering		Exiting		Entering		Exiting	
Species	Adult	Juv.	Adult	Juv.	Adult	Juv.	Adult	Juv.
Class Amphibia								
Order Caudata								
Ambystoma talpoideum	1,750	154	499	3,856	6,028	0	938	0
Ambystoma tigrinum	129	46	42	992	57	1	4	1
Notophthalmus viridescens	1,625	968	609	15,013	3,452	5	2,100	23
Total of all salamanders (9 species)	3,953	1,201	1,212	19,874	9,595	6	3,087	24
Order Anura								
Scaphiopus holbrooki	69	33	39	34	1,803	134	483	58
Bufo terrestris	424	644	79	689	580	375	98	622
Hyla crucifer	346	212	205	1,329	594	12	239	50
Pseudacris ornata	235	28	89	1,158	392	9	79	18
Gastrophryne carolinensis	1,122	18	418	15	887	1	420	0
Rana clamitans	27	30	19	1,136	27	35	1	7
Rana utricularia	699	2,024	610	52,287	154	29	24	7
Total of all frogs (16 species)	3,197	3,053	1,569	57,106	4,486	680	1,355	767

Table 12. Continued

Species	Rainbow Bay				Sun Bay			
	Entering		Exiting		Entering		Exiting	
	Adult	Juv.	Adult	Juv.	Adult	Juv.	Adult	Juv.
Class Reptilia								
Order Chelonia								
Kinosternon subrubrum	29	6	25	6	49	59	14	11
Deirochelys reticularia	8	9	10	2	14	14	4	1
Total of all turtles (6 species)	43	16	39	9	70	74	19	14
Order Squamata								
Suborder Sauria								
Anolis carolinensis	26	2	19	2	5	0	12	0
Sceloporus undulatus	18	1	8	3	9	3	5	6
Cnemidophorus sexlineatus	2	2	1	0	19	7	19	2
Total of all lizards (9 species)	53	7	43	5	36	11	40	9
Suborder Ophidia								
Storeria occipitomaculata	26	1	37	0	4	0	2	0
Diadophis punctatus	7	2	10	0	7	1	15	3
Tantilla coronata	17	0	11	0	42	0	46	0
Total of all snakes (19 species)	92	7	88	2	68	5	85	5
Class Mammalia								
Blarina breyicauda	68	1	40	0	26	0	20	0
Reithrodontomys humulis	16	0	146	8	1	0	0	0
Sigmodon hispidus	7	0	14	0	5	0	18	0
Total of all mammals (13 species)	168	3	251	9	76	1	63	1
Total of all species	7,506	4,287	3,202	77,005	14,331	777	4,649	820

southern leopard frogs, and 500 mole salamanders entered or left Sun Bay, an area on the SRP of less than 1 ha completely drained by construction activity in the previous year. Similarly, Lost Lake on the SRP had been altered by agricultural practices prior to the 1950s and, later, by the release of industrial by-products into the lake (Bennett et al. 1979). Half of this bay is now bordered by managed pine plantations. Nonetheless, extrapolation of captures by intermittent fencing and pitfall traps to the shoreline length bordered by the pine forest yielded estimates of 5,000 southern toads (*Bufo terrestris*), 2,000 mole salamanders, and 1,000 spadefoot toads (*Scaphiopus holbrooki*) that entered or left the lake in one summer.

Although amphibians are the prevalent terrestrial vertebrates utilizing Carolina bays (Patterson 1978, Bennett et al. 1979, Semlitsch 1981) and are a major contributor to secondary productivity, other vertebrates may be important in these communities as well. The American alligator (*Alligator mississippiensis*), six species of aquatic turtles (Table 12; Gibbons 1970), and several species of snakes (Table 12; Gibbons et al. 1977, Gibbons and Patterson 1978, Gibbons and Semlitsch 1990) are reptiles common to bays. Though quantitative data are unavailable, mammals such as deer, raccoons, skunks, and opossums may use bays for water or feeding sites. Beaver (*Castor canadensis*) have been noted in Thunder Bay and several other sites and could be an important agent in hardwood species composition and abundance. In sandhills regions of the Carolinas, many bird species including hawks, egrets, and migratory waterfowl use the bays during at least part of the year. Wood storks, an endangered bird species, have been observed foraging in Ellenton Bay. In bays with standing water and mature trees with cavities for nesting sites, wood ducks (*Aix sponsa*) may also be found (Mayer et al. 1986). The use of wood duck boxes placed as nesting sites in Carolina bays is common in some years (Brisbin and Hepp, personal observation). Again, quantitative estimates for all waterfowl species are lacking, but personal observations indicate the presence of such vertebrates in all water-containing Carolina bays that have been studied on the SRP.

Quantitative data are available for many small mammals using the periphery of Carolina bays (Table 12). Though shrews (*Blarina brevicauda* and *Sorex longirostris*) and small rodents (*Sigmodon hispidus, Peromyscus gossypinus*, and *Microtus pinetorum*) may be abundant, only certain species, e.g., the rice rat (*Oryzomys palustris*), actually inhabit the marshy areas. Many small mammals captured by drift fences and pitfall traps (Figure 24 in Gibbons and Semlitsch 1982) around Carolina bays are equally abundant in strictly terrestrial habitats in the region (Briese and Smith 1974, Brown 1980).

RECOMMENDATIONS FOR RESEARCH AND CONSERVATION

Additional research is needed before we achieve a comprehensive perspective of Carolina bays with respect to hydrology, soil and water characteristics, community composition, population distributions and dynamics, primary productivity and trophic dynamics, and ecological succession and stability; and before we understand their contribution to larger-scale processes of the southeastern Coastal Plain. Some features will be revealed only through long-term monitoring of representative sites and through extensive comparative surveys of undisturbed and human-disturbed sites. Much of the present knowledge of Carolina bay ecology has derived from studies using Carolina bays of the SRP, especially Ellenton (Site 176), Rainbow (Site 189), Sun (Site 45), and Thunder (Site 83) Bays. Comparisons of a wider variety of sites, particularly on an elevational gradient across the Coastal Plain, would be extremely useful for the development of models relating biotic structure and processes to hydrology and human alteration.

Sharitz and Gibbons (1982), after surveying existing information on shrub bogs (pocosins) and Carolina bays, concluded that certain research areas could provide the most useful information on basic ecology and perturbation responses: (1) measurement of specific hydrologic parameters such as transpiration and evaporation rates, groundwater exchanges, and soil permeabilities in representative sites (including both peat and clay-based bays); (2) more comprehensive studies of the physical-chemical limnology of bay surface waters and responses to commercial activities such as agriculture and silviculture; (3) regional analyses of the relationships between vegetation patterns and hydrology, soils, and land use history; (4) studies of the relationships of low pH, water level fluctuations, and low nutrient availability to bay fauna; and (5) the short- and long-term effects of fire on various ecosystem properties. Emerging remote sensing technologies offer an excellent method for initial regional surveys of Carolina bay water levels, vegetational composition and dynamics, and perturbation responses. Such approaches, coupled with additional intensive studies of selected sites, could significantly enhance our understanding of these unique coastal plain ecosystems.

The local and regional abundance of bays, their relative isolation from surface hydrologic exchanges, and difficulties in conversion of some sites to agriculture or silviculture afford good opportunities for protection and conservation of a significant representation of bay community types. Currently, Ellenton Bay and Steel Creek Bay (Site 143) are designated as set-aside habitat reserves on the SRP. Additional conservation efforts at the SRP and elsewhere would facilitate research efforts and could help to preserve upland ecosystem processes and attributes such as local groundwater recharge, nutrient retention, enhanced primary production, maintenance of species diversity and habitat structures, wildlife watering and foraging, and vertebrate reproduction. Such processes may have critical but still poorly-understood values to coastal plain ecology.

SUMMARY

Carolina bays are a major feature of the SRP landscape. The 194 bays identified in this survey range from less than 0.1 ha to about 50 ha in size and support a variety of aquatic and wetland communities. Most of the bays have limited development of organic or peat substrates; soils are typically sandy clay loam underlain by clay hardpan. Many were ditched and drained for agricultural purposes prior to the SRP. However, few have been actively disturbed since the early 1950s and most altered sites have undergone successional recovery.

Several physical characteristics of these wetlands dictate the development and status of their biota. Carolina bays are typically isolated wetlands that are largely fed by rain and shallow, low solute groundwater. Thus, they have a nutrient-poor, softwater, acidic chemistry which, in turn, restricts primary and secondary productivity and utilization of these systems to tolerant species. In addition, severe oscillations of their hydrology make these bays relatively unpredictable habitats. Although unexamined, the role of fire in these ecosystems may be very important. Interpretations of successional status or development of the biota must take this unpredictability into account and long-term observations will be necessary to understand the role of these bays in supporting aquatic and wetland organisms.

Much of the research to date on the Carolina bays of the SRP and elsewhere has focused on certain species or on environmental features. Different levels of detail exist for different groups of organisms and reflect the diverse interests of previous investigators. This report summarizes aspects of research to date and presents data from numerous studies, but it does not attempt to synthesize. The most complete ecosystem study and synthesis of the biotic and abiotic properties of a single bay is the study of Thunder Bay (Site 83) by Schalles and Shure (1989). The most extensive comparison of SRP bays with those found throughout the Southeast was provided by Sharitz and Gibbons (1982). Coordinated efforts to integrate research in these systems and to relate properties and functions of these wetlands to those of other seasonal wetland systems are needed to understand and evaluate the role of these abundant ecosystems in the ecology of the southeastern Coastal Plain.

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Appendix I. Areas and locations of Carolina bays at the SRP. Bay numbers correspond to those in Figure 1.

Bay Number	Bay Name	SRP Grid Coordinates East	SRP Grid Coordinates North	SRP Patrol Coordinates	Area Acres*	Habitat Type
1	Sweet Gum Bay	61000	98500	D-15	3.7	forested/herbaceous
2+		62000	99000	D-15	9.3	forested
3	Flamingo Bay	64000	93000	E-16	14.0	herbaceous**
4	Fire Pond	64000	96500	D-15	3.2	forested/herbaceous
5		33000	103000	C-8	2.4	herbaceous
6		33000	101500	C-8	11.2	forested
7		32500	96000	D-8	6.2	herbaceous
8+		34500	96500	D-8	2.5	herbaceous
9		35000	97000	D-8	4.3	herbaceous
10		35500	97500	D-8	0.3	herbaceous
11	Bird Bath Bay	36500	98000	D-9	1.9	herbaceous
12+		36500	96000	E-9	1.9	herbaceous
13+		37000	95000	E-9	3.7	forested/herbaceous
14		36000	94500	E-9	3.7	herbaceous
15	Odum Bay	35500	95000	E-8	2.5	herbaceous
16	Golley Bay	35000	95000	E-8	5.0	herbaceous
17+	Ginger's Bay	36500	104500	B-9	3.7	herbaceous
18+		30000	90000	F-7	<0.3	herbaceous/forested
19+		29500	89500	F-7	0.3	forested
20+		28500	90500	F-7	3.7	herbaceous

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* Data from Shields et al., 1982. (Area detection limit for planimeter was <0.3 acres.)

\+ Sites tentatively identified as bays.

** Known to have standing water at least part of most years.

Appendix I. Continued

Bay Number	Bay Name	SRP Grid Coordinates East	SRP Grid Coordinates North	SRP Patrol Coordinates	Area Acres*	Habitat Type
21+		27000	89500	F-6	1.9	herbaceous
22+		26000	90000	F-6	<0.3	forested/herbaceous
23	Snake and Mosquito Bay	25500	89000	F-6	3.7	herbaceous
24		26500	88500	F-6	1.6	forested/herbaceous
25	Fern Bay	28500	84500	G-7	2.5	forested/herbaceous
26	Caroline's Bay	26500	81500	H-6	1.2	herbaceous
27	Morse Code Bay	27000	81500	H-6	1.9	herbaceous
28	Lost Lake	47000	101500	C-11	5.0	
29		48000	102000	C-11	0.3	
30		61000	84500	G-15	1.9	herbaceous**
31	Dry Bay	29000	80000	H-7	12.4	herbaceous**
32+		71000	76000	H-17	9.3	forested
33+		73000	76000	J-18	12.4	forested/herbaceous
34+		78000	68000	L-19	4.3	forested
35		72000	65000	L-17	3.1	herbaceous
36+		83500	62000	M-18	3.1	herbaceous
37+		71500	62000	M-17	2.5	forested
38+	Huffin-Puff Bay	71000	63500	M-17	20.5	forested/herbaceous
39+		69000	59000	N-17	1.2	forested
40	Enchantment Bay	67000	60000	M-16	13.0	herbaceous**

Appendix I. Continued

Bay Number	Bay Name	SRP Grid Coordinates East	SRP Grid Coordinates North	SRP Patrol Coordinates	Area Acres*	Habitat Type
41		66000	63000	M-16	0.3	herbaceous/forested**
42	Marine Bay	64500	61500	M-16	9.3	herbaceous**
43+		68000	56500	N-16	5.0	forested
44	Siple Bay	66500	56000	N-16	5.0	forested/herbaceous
45	Sun Bay	66500	76500	J-16	5.0	(under construction) ex-forested/herbaceous**
46		63500	69000	K-15	4.3	herbaceous
47+		58000	60500	M-14	5.6	forested/herbaceous
48		58000	59500	N-14	0.6	forested
49+		56500	62000	M-14	4.3	forested
50+		53000	68000	K-13	5.0	forested
51		90000	64500	L-22	4.3	herbaceous
52		91500	61500	M-22	0.6	herbaceous/forested
53+		101000	55000	O-25	0.6	forested
54+		102000	53500	O-25	0.3	forested
55		98000	49000	P-25	1.2	forested
56		86000	58500	N-21	8.1	herbaceous**
57	Sunset Bay	83000	59500	N-20	9.9	herbaceous
58		83500	57500	N-20	8.1	herbaceous
59		76000	54500	O-18	0.7	herbaceous/forested**
60	Chorus Bay	81000	50000	P-20	9.9	herbaceous**

Appendix I. Continued

Bay Number	Bay Name	SRP Grid Coordinates East	SRP Grid Coordinates North	SRP Patrol Coordinates	Area Acres*	Habitat Type
61		72500	53500	O-18	13.0	forested/herbaceous
62	Janell's Bay	81000	45500	Q-20	1.9	herbaceous**
63		92000	39000	S-22	1.7	
64	Little Cypress Bay	91000	37500	S-22	1.7	
65		111500	53000	P-27	2.5	herbaceous
66	Mona Bay	110000	52000	P-27	27.9	herbaceous**
67	Woodward Bay	109000	52000	P-27	17.4	herbaceous**
68		107000	51500	P-26	3.7	herbaceous
69		106500	51000	26	2.4	herbaceous
70		105500	49500	P-26	6.8	forested/herbaceous
71		107000	49000	P-26	4.3	herbaceous
72		108000	47500	Q-26	3.1	herbaceous
73		107000	47500	Q-26	4.3	herbaceous
74		105500	45000	Q-26	0.3	herbaceous
75		98000	50000	P-24	0.6	
76		105000	43000	R-26	0.6	herbaceous**
77	Craig's Pond	102500	43500	R-25	124.0	herbaceous**
78	Sarracenia Bay	101500	45000	Q-25	9.9	herbaceous**
79		100500	44500	Q-25	1.2	herbaceous
80	Buttress Bay	100000	44000	R-24	5.0	forested
81		95500	39500	S-23	9.3	herbaceous
82		93500	38000	S-23	1.9	
83	Thunder Bay	88000	29500	U-22	10.9	herbaceous**
84	Par Pond Bay	80000	39000	S-20	5.0	open water (Michael's Marsh of Par Pond)

Appendix I. Continued

Bay Number	Bay Name	SRP Grid Coordinates East	SRP Grid Coordinates North	SRP Patrol Coordinates	Area Acres*	Habitat Type
85		73000	43000	R-18	8.1	herbaceous**
86		78500	33000	T-19	2.5	forested
87		80000	26000	V-20	4.3	herbaceous**
88		74500	29500	U-18	1.9	herbaceous/forested
89+		71500	33000	T-17	1.2	forested
90		70000	31500	U-17	2.5	forested
91		68500	28500	U-17	1.9	forested
92	Cypress Bay	68500	27500	V-16	3.1	forested
93+		67500	28000	U-16	8.1	forested
94		66500	41000	R-16	2.5	forested
95		67000	40500	R-16	1.2	forested
96	Dunbarton Bay	66000	38000	S-16	91.1	forested**
97+	Dunbarton Bay	66000	33000	T-16	79.4	forested**
98	Dunbarton Bay	68000	38000	S-16	104.9	forested**
99+		62000	405000	R-15	3.7	herbaceous
100+		63500	39000	S-15	0.6	forested

Appendix I. Continued

Bay Number	Bay Name	SRP Grid Coordinates East	SRP Grid Coordinates North	SRP Patrol Coordinates	Area Acres*	Habitat Type
101		62000	37000	S-15	1.2	forested
102+		60000	32000	T-15	1.2	herbaceous
103+		58500	32000	T-14	4.3	herbaceous
104+		54000	28500	U-13	6.8	
105		56000	19000	X-13	5.6	herbaceous/forested
106		53000	17000	X-13	6.2	forested
107		56000	14000	Y-13	5.0	herbaceous/forested
108+		66000	49500	P-16	3.1	herbaceous/forested
109+		66000	48500	P-16	7.4	herbaceous
110		64500	46000	Q-16	1.9	herbaceous
111		61000	47500	Q-15	0.3	forested/herbaceous
112		61500	47500	Q-15	0.3	forested/herbaceous
113+		59000	47000	Q-14	3.1	herbaceous***
114		61500	44000	Q-15	1.2	herbaceous
115+		62000	47000	Q-15	9.9	forested
116		57000	46000	Q-14	1.2	herbaceous**
117+		61500	41000	R-15	1.2	forested/herbaceous
118	Hal's Bay	57000	39000	S-14	2.5	herbaceous
119+		61000	42000	R-15	2.5	forested
120	Rt. 9 Bay	53000	35500	T-13	1.9	herbaceous**

Appendix I. Continued

Bay Number	Bay Name	SRP Grid Coordinates East	SRP Grid Coordinates North	SRP Patrol Coordinates	Area Acres*	Habitat Type
121		55000	57000	N-13	3.7	forested
122		53500	61500	M-13	5.6	forested
123		48500	64500	L-12	1.9	herbaceous**
124		47000	61500	M-11	3.5	forested/herbaceous
125		48000	61500	M-11	5.0	forested/herbaceous
126		49000	61000	M-12	0.6	forested/herbaceous
127	Castor Bay	48000	59000	N-11	8.7	herbaceous**
128+		49000	58500	N-12	5.0	forested/herbaceous
129		51000	58000	N-12	1.2	forested
130		46500	58000	N-11	6.8	herbaceous
131		49500	58000	N-12	2.5	herbaceous
132	Wells Bay	45000	53500	O-11	7.4	forested
133+		39000	43000	R-9	1.2	
134		38000	42500	R-9	1.2	forested/herbaceous
135		36000	43000	4-8	2.5	forested
136		31500	40500	R-7	1.7	herbaceous**
137+		29500	38000	S-7	1.8	herbaceous**
138	Small Robbin's Bay	31500	37500	S-7	1.9	herbaceous
139	Big Robbin's Bay	31500	36500	S-7	1.2	herbaceous
140		33500	35500	T-8	3.7	

Appendix I. Continued

Bay Number	Bay Name	SRP Grid Coordinates East	SRP Grid Coordinates North	SRP Patrol Coordinates	Area Acres*	Habitat Type
141		33500	35000	T-8	1.0	
142	Peat Bay	35000	33000	T-8	14.3	
143+	Steel Creek Bay	32500	28000	V-8	1.2	
144+		45000	23000	W-11	1.9	forested
145+		45000	21500	W-11	3.1	herbaceous/forested
146+		45000	20000	W-11	1.9	herbaceous
147		37000	22500	W-9	5.0	
148		32500	20000	X-8	0.3	
149		33000	19500	X-8	1.2	
150		35000	18500	X-8	0.3	
151		30500	18000	X-7	0.3	
152+		26000	40000	R-6	3.7	herbaceous
153+		25000	41500	R-6	2.5	herbaceous
154+		24500	41500	R-6	1.9	forested
155+		24500	41500	R-6	5.0	herbaceous**
156+		30000	44500	Q-7	1.9	herbaceous
157		29000	44000	Q-7	<0.3	herbaceous/forested
158		29000	44500	Q-7	<0.3	herbaceous/forested
159		29000	45000	Q-7	<0.3	herbaceous/forested
160+		28000	45000	Q-7	1.2	forested

Appendix I. Continued

Bay Number	Bay Name	SRP Grid Coordinates East	SRP Grid Coordinates North	SRP Patrol Coordinates	Area Acres*	Habitat Type
161+		21500	51000	P-5	3.7	herbaceous
162+		24000	52000	P-5	0.6	herbaceous/forested
163		24000	52500	O-6	1.9	herbaceous
164		25500	54500	O-6	2.5	herbaceous/forested
165	Buell Bay	22500	54500	O-5	2.5	herbaceous
166+		22500	54500	O-5	<0.3	forested
167+		18000	54000	O-4	2.0	forested/herbaceous
168	Frey Bay	20000	56000	N-4	2.0	herbaceous
169+		21000	57000	N-5	0.5	forested
170	Prouty Bay	28000	59000	N-6	3.1	herbaceous/forested**
171	Johnson Bay	34000	57000	N-8	1.7	herbaceous**
172	Barbara's Bay	40000	59000	N-10	1.9	forested**
173	Seal Oil Bay	23000	67500	L-5	3.1	herbaceous
174	Idlewild Bay	23000	69000	K-5	7.4	herbaceous/forested
175	Woods Bay	21000	70500	K-5	3.7	herbaceous**
176	Ellenton Bay	22000	72000	K-5	27.9	herbaceous**
177+		43000	58500	N-10	5.2	herbaceous
178	Asphalt Bay	24000	66500	L-5	5.1	herbaceous** (paved)
179		19000	73000	J-4	2.5	herbaceous
180		19000	76000	J-4	0.6	forested

Appendix I. Continued

Bay Number	Bay Name	SRP Grid Coordinates East	SRP Grid Coordinates North	SRP Patrol Coordinates	Area Acres*	Habitat Type
181+		36500	91000	F-9	0.6	herbaceous
192+		35000	89000	F-8	2.5	forested
183+		36000	92000	F-8	6.6	forested
184+	Diane's Bay	68000	105000	C-17	0.4	herbaceous/forested**
185		23500	82500	H-5	6.0	herbaceous (cultivated)
186+		29000	43500	R-7	0.3	forested
187+		62500	67500	L-15	<0.3	forested**
188+		20000	54500	O-5	<0.3	forested
189	Rainbow Bay	59300	62000	M-14	2.4	herbaceous
190	Willow Bay	234000	69500	K-5	2.0	herbaceous**
191		19000	68500	K-4	2.0	herbaceous
192+		21500	53000	O-5	<0.3	forested
193+		22500	53000	O-5	<0.3	forested
194+		23500	53500	O-5	<0.3	forested

Appendix IIa. Correlation matrix for physical-chemical data collected in the survey of 16 SRP Carolina bays in the summer of 1979. [Values of correlation coefficient r, n = 32, significant r (p = 0.01) = 0.514]

	Ca++	Mg++	Na+	K+	Fe++	Mn++	Cond	$\frac{Na+K}{Ca+Mg}$	TOC
Mg++	.763								
Na+	.176	.289							
K+	.107	.170	.008						
Fe++	.331	.338	.246	-.195					
Mn++	.176	.156	.429	-.290	.450				
Cond	.542	.491	.621	.360	.317	.323			
$\frac{Na+K}{Ca+Mg}$	-.613	-.644	.097	.423	-.363	-.146	-.067		
TOC	.652	.577	.215	.095	.580	.220	.587	-.403	
Elev	.122	-0.85	-.169	.363	-.070	-.125	.028	.101	-.052

Variables: (6 Cations), Cond = conductivity, $\frac{Na+K}{Ca+Mg}$ = ratio of major monovalent and divalent cations, TOC = total dissolved organic carbon, Elev = elevation of bay depression.

ΣCat	.628	.738	.884	.550	.457	.281	.080		
								ΣCat	
$\frac{Na+K}{Ca+Mg}$	.429	-.561	-.371	-.261	-.052	.264	.041	-.210	
									$\frac{Na+K}{Ca+Mg}$
Cond	.437	.265	.519	.292	.107	.321	-.114	.467	.104
TC	.172	.654	.819	.701	.307	.294	-.002	.769	-.387
TIC	.047	.162	.148	.229	.290	-.027	-.074	.159	-.152
TOC	.071	.579	.801	.583	.265	.264	.097	.765	-.427
RDX	-.108	-.269	-.113	-.167	-.194	-.329	.415	-.088	-.085
Temp	-.311	-.024	-.173	.049	.212	-.258	.241	-.067	-.194
Oxy	-.063	-.141	-.226	-.172	-.219	-.063	-.233	-.314	.095
Elev	.237	.300	.325	.209	.054	.130	-.090	.319	.115
	Cond								
TC	.366	TC							
TIC	-.347	.171	TIC						
TOC	.171	.998	.104	TOC					
RDX	-.155	-.227	.179	-.135	RDX				
Temp	.700	.012	.461	.089	.075	Temp			
Oxy	-.088	-.363	-.338	-.444	-.101	-.106	Oxy		
Elev	.211	.306	-.302	.221	-.249	-.016	.219		

Variables: (7 Cations), ΣCat = total cations (meq/l), $\frac{Na+K}{Ca+Mg}$ = ratio of major monovalent and divalent cations,
Cond = conductivity, TC = total dissolved carbon, TIC = total dissolved inorganic carbon,
TOC = total dissolved organic carbon, RDX = redox potential, Temp = water temperature,
Oxy = dissolved oxygen (previous 3 measured near surface with portable hydrolab),
Elev = elevation of bay depression.

Appendix III. Tree, shrub, herb, and Sphagnum species collected or observed in Carolina bays of Aiken and Barnwell Counties, SC on or adjacent to the SRP (Hodge 1985).

TREES

Acer rubrum L.
Diospyros virginiana L.
Liquidambar styraciflua L.
Nyssa sylvatica Marsh var. *biflora* (Walt.) Sarg.
Pinus palustris Mill.
Pinus serotina Michx.
Pinus taeda L.
Quercus nigra L.
Taxodium ascendens Brongon.

SHRUBS

Callicarpa americana L.
Cephalanthus occidentalis L.
Cyrilla racemiflora L.
Gaylussacia frondosa (L.) T. and *G. frondosa* var. *tomentosa* Gray
Hypericum stans (Michx.) Adams and Robson
Ilex cassine L. var. *myrtlifolia* (Walt.) Sarg.
Ilex glabra (L.) Gray
Ilex opaca Ait.
Leucothoe racemosa (L.) Gray
Lyonia ligustrina (L.) DC
Lyonia lucida (Lam.) Koch
Lyonia mariana (L.) D. Don
Magnolia virginiana L.
Myrica cerifera L.
Persea borbonia (L.) Spreng.
Rhododendron viscosum (L.) Torr. var. *serrulatum* (Sm.) Ahles

SHRUBS--Continued

- *Rhus copallina* L.
- *Salix nigra* Marsh.
- *Sassafras albidum* (Nutt.) Nees.
- *Sorbus arbutifolia* (L.) Heynhold
- *Stillingia aquatica* Champ.
- *Vaccinium amoenum* Ait.
- *Vaccinium arboreum* Marsh.
- *Vaccinium corymbosum* L.
- *Vaccinium stamineum* L.

HERBS

- *Agrostis hyemalis* (Walt.) BSP.
- *Ampelopsis arborea* (L.) Koehne
- *Andropogon ternarius* Michx.
- *Andropogon virginicus* L.
- *Aristida affinis* (Schult.) Kunth
- *Bacopa caroliniana* (Walt.) Robins
- *Bartonia verna* (Michx.) Muhl.
- *Boltonia asteroides* (L.) L'Her.
- *Brasenia schreberi* Gmel.
- *Carex complanata* Torr. and Hook
- *Carex glaucescens* Ell.
- *Carex walteriana* Bailey
- *Centella asiatica* (L.) Urban
- *Chondrophora nudata* (Michx.) Britt.
- *Coreopsis rosea* Nuh.
- *Croton elliottii* Chapm.
- *Diodia virginiana* L.
- *Drosera capillaris* Poir.
- *Drosera intermedia* Hayne in Schrad.
- *Eleocharis acicularis* (L.) R. and S.
- *Eleocharis equisetoides* (Ell.) Torr.
- *Eleocharis obtusa* (Willd.) Schultes in R. and S.
- *Eleocharis quadrangulata* (Michx.) R. and S.

HERBS--Continued

Eleocharis tricostata Torr.
Echinodorus parvulus Engelm.
Erianthus alopecuroides (L.) Ell.
Erianthus brevibarbis Michx.
Erianthus giganteus (Walt.) Muhl.
Erianthus strictus Baldw.
Erigeron vernus (L.) T. and G.
Eriocaulon compressum Lam.
Eriocaulon decangulare L.
Eupatorium album L.
Eupatorium capillifolium (Lam.) Small
Eupatorium leucolepis (DC.) T. and G.
Eupatorium leptophyllum DC.
Fimbristylis autumnalis (L.) R. and S.
Fimbristylis dichotoma (L.) Vahl
Fimbristylis spadicea Roth
Fuirena pumila (Torr.) Spreng.
Habenaria cristata (Michx.) R. Br. in Ait
Helenium brevifolium (Nutt.) Wood
Helenium flexuosum Raf.
Helenium pinnatifidum (Nutt.) Rydb.
Helianthus angustifolius L.
Hibiscus moschuetos L.
Hydrochloa caroliniensis Beauv.
Hydrocotyle americana L.
Hypericum cistifolium Lam.
Hypericum virginicum L.
Hypericum walteri Gmelin
Iris virginica L.
Juncus acuminatus Michx.
Juncus biflorus Ell.
Juncus canadensis *J*. Gay ex Laharpe
Juncus coriaceus Mack.
Juncus debilis Gray

HERBS--Continued

Juncus diffusissimus Buckl.
Juncus effusus L.
Juncus marginatus Rostk.
Lachnanthes caroliniana (Lam.) Dandy
Lachnocaulon anceps (Walt.) Morong
Leersia hexandra Sw.
Lobelia boykinii T. and G.
Lobelia nuttallii R. and S.
Ludwigia arcuata Walt.
Ludwigia alternifolia L.
Ludwigia decurrens Walt.
Ludwigia palustris (L.) Ell.
Ludwigia spathulata T. and G.
Ludwigia sphaerocarpa Ell.
Ludwigia suffruticosa Walt.
Lycopodium alopecuroides L.
Lycopus virginicus L.
Manisuris rugosa (Nutt.) Kunte
Myriophyllum heterophyllum Michx.
Myriophyllum laxum Shuttlew
Myriophyllum pinnatum (Walt.) BSP.
Nelumbo lutea (Willd.) Pers.
Nymphaea odorata Ait.
Nymphoides cordata (Ell.) Fern.
Osmunda cinnamomea L.
Osmunda regalis L. var. *spectabilis* (Willd.) Gray
Oxypolis canbyi (Coult. and Rose) Fern.
Panicum anceps Michx.
Panicum commutatum Schultes
Panicum dichotomiflorum Michx.
Panicum dichotomum L.

HERBS--Continued

Panicum ensifolium Baldw. ex Ell.
Panicum hemitomon Schultes
Panicum hians Ell.
Panicum lanuginosum Ell.
Panicum laxiflorum Lam.
Panicum leucothrix Nash
Panicum longifolium Torrey
Panicum ravenelii Scribner *ex* Merrill
Panicum verrucosum Muhl.
Panicum virgatum L.
Panicum wrightianum Scribner
Paspalum notatum Flugge
Pluchea foetida (L.) DC.
Polygala cymosa Wah.
Polygala lutea L.
Polygonum hirsutum Walt.
Pontederia cordata L.
Potamogeton diversifolius Raf.
Proserpinaca palustris L.
Proserpinaca pectinata Lam.
Psilocarya nitens (Vahl.) Wood.
Ptilimnium nodosum (Rose) Mathias
Pycnanthemum flexuosum (Walt.) BSP.
Rhexia aristosa Britt.
Rhexia lutea Walt.
Rhexia mariana L. var. *exalbida* Michx.
Rhexia mariana L. var. *mariana* Michx.
Rhexia mariana L. var. *purpurea* Michx.
Rhynchospora corniculata (Lam.) Gray
Rhynchospora globularis (Chapm.) Small
Rhynchospora inexpansa (Michx.) Vahl
Rhynchospora inundata (Oakes) Fern.

HERBS--Continued

Rhynchospora macrostachya Torrey
Rhynchospora rariflora (Michx.) Ell.
Rhynchospora tracyi Brih.
Rubus spp.
Sabatia sp.
Sagittaria graminea Michx.
Sagittaria isoetiformis J. G. Sm.
Sagittaria latifolia Willd.
Sarracenia minor Walt.
Scirpus cyperinus (L.) Kunth
Scirpus etuberculatus (Steud.) Kuntze
Scleria ciliata Michx.
Scleria georgiana Core
Scleria reticularis Michx.
Sclerolepis uniflora (Wah.) BSP.
Smilax bona-nox L.
Smilax glauca Walt.
Smilax laurifolia L.
Smilax smallii Morong.
Smilax walteri Pursh
Solidago leavenworthii T. and G.
Spiranthes laciniata (Small) Ames
Spiranthes vernalis Engelm. and Gray
Sporobolus sp.
Tofieldia racemosa (Walt.) BSP.
Typha latifolia L.
Utricularia fibrosa Walt.
Utricularia inflata Walt.
Utricularia olivacea Wright ex Griseb.
Utricularia purpurea Walt.
Viola lanceolata L.
Viola villosa Walter

HERBS--Continued

Woodwardia virginica (L.) Sm.
Xyris caroliniana Walt.
Xyris platylepis Chapm.

SPHAGNUM

Sphagnum cyclophyllum Sull. and Lesq. ex. Sull.
Sphagnum cuspidatum Ehrh. ex Hoffm.
Sphagnum imbricatum Hornsch. ex Russ.
Sphagnum lescurii Sull.
Sphagnum macrophyllum Bernh. ex Brid.
Sphagnum perichaetiale Hampe
Sphagnum recurvum P.-Beauv.
Sphagnum strictum Sull.
Sphagnum subsecundum Nees ex Sturm var. *rufescens* Hub.
Sphagnum torreyanum Sull.
Sphagnum trinitens Sull.

Appendix IV. Reptile and amphibian species collected or observed in Carolina bays on the Savannah River Plant, South Carolina, based on records in Gibbons and Semlitsch (1990).

CLASS AMPHIBIA	
Order Caudata Salamanders	
Family: Amphiumidae	
Amphiuma means	two-toed amphiuma
Family: Sirenidae	
Siren intermedia	lesser siren
Siren lacertina	greater siren
Family: Ambystomatidae	
Ambystoma opacum	marbled salamander
Ambystoma talpoideum	mole salamander
Ambystoma tigrinum	tiger salamander
Family: Salamandridae	
Notophthalmus viridescens	eastern newt
Family: Plethodontidae	
Eurycea cirrigera	two-lined salamander
Eurycea longicauda	long-tailed salamander
Eurycea quadridigitata	dwarf salamander
Plethodon glutinosus	slimy salamander
Pseudotriton montanus	mud salamander
Pseudotriton ruber	red salamander
Order Anura Frogs and toads	
Family: Pelobatidae	
Scaphiopus holbrooki	eastern spadefoot toad
Family: Bufonidae	
Bufo quercicus	oak toad
Bufo terrestris	southern toad
Family: Hylidae	
Acris gryllus	southern cricket frog
Hyla avivoca	bird-voiced treefrog
Hyla chrysoscelis	Cope's gray treefrog
Hyla cinerea	green treefrog
Hyla femoralis	pine woods treefrog
Hyla gratiosa	barking treefrog

Hyla squirella	squirrel treefrog
Pseudacris crucifer	spring peeper
Pseudacris nigrita	southern chorus frog
Pseudacris ornata	ornate chorus frog
Family: Microhylidae	
Gastrophryne carolinensis	narrow-mouthed toad
Family: Ranidae	
Rana areolata	crawfish frog
Rana catesbeiana	bullfrog
Rana clamitans	green frog
Rana grylio	pig frog
Rana palustris	pickerel frog
Rana utricularia	southern leopard frog
Rana virgatipes	carpenter frog

CLASS REPTILIA

Order Crocodilia Crocodilians	
Family: Alligatoridae	
Alligator mississippiensis	American alligator
Order Chelonia Turtles	
Family: Chelydridae	
Chelydra serpentina	common snapping turtle
Family: Kinosternidae	
Kinosternon bauri	striped mud turtle
Sternotherus odoratus	stinkpot
Kinosternon subrubrum	eastern mud turtle
Family: Emydidae	
Pseudemys floridana	Florida cooter
Chrysemys picta	painted turtle
Trachemys scripta	slider turtle
Clemmys guttata	spotted turtle
Deirochelys reticularia	chicken turtle
Order Squamata	
Suborder Serpentes Snakes	
Family: Colubridae	
* *Cemophora coccinea*	scarlet snake
* *Coluber constrictor*	racer (black racer)
* *Diadophis punctatus*	ringneck snake
* *Elaphe guttata*	corn snake
Elaphe obsoleta	rat snake

Farancia abacura	mud snake
Farancia erytrogramma	rainbow snake
* *Heterodon platirhinos*	eastern hognose snake
* *Lampropeltis getulus*	common kingsnake
Nerodia cyclopion	green water snake
Nerodia erythrogaster	red-bellied water snake
Nerodia fasciata	banded water snake
Regina rigida	glossy crayfish snake
* *Rhadinaea flavilata*	yellow-lipped snake
Seminatrix pygaea	black swamp snake
* *Storeria dekayi*	brown snake
* *Storeria occipitomaculata*	red-bellied snake
* *Tantilla coronata*	southeastern crowned snake
Thamnophis sauritus	eastern ribbon snake
Thamnophis sirtalis	common garter snake
* *Virginia valeriae*	smooth earth snake
Family: Viperidae (=Crotalidae)	
Agkistrodon piscivorus	cottonmouth

* Species is normally terrestrial in periphery of bays and other aquatic habitats