Proceedings of the

BACK BAY ECOLOGICAL SYMPOSIUM

Editors

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and
Mitchell D. Norman

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PREFACE

Back Bay represents a unique and dynamic habitat where the influence of natural phenomena has been augmented by the impact of an increasing amount of human activity. Numerous studies and articles about Back Bay have documented these events over the years; however, there has been little past effort to assemble this work in a single volume or under one theme. It was during an early morning collection trip to Back Bay that the concept and value of bringing together individuals interested in this region was first discussed.

This was in February, 1987, and although cold and windy, the broad splendor of this natural resource provided the appropriate background for the steps that followed. At that time, the two of us and Ron Southwick recognized the diversity of interests and studies that were associated with Back Bay, but were concerned about the need to bring together data regarding the Bay and to have current projects discussed in an open forum.

This early discussion eventually resulted in the steps leading to the Back Bay Ecological Symposium held in November, 1990. We established three major objectives for this symposium. These were:

1. to provide an opportunity for current investigators and other interested parties to discuss together their studies and concerns about Back Bay;
2. to publish the proceedings of this Symposium, which would emphasize water quality, fauna, flora and management topics so this publication could be a basic reference source for future investigators of this habitat; and
3. to encourage and stimulate more cooperative and coordinated ecological studies of this habitat in the future.

With the realization of this proceedings volume, we want to express our thanks to the contributors of this work and to all the participants of the Symposium for their interest and enthusiasm. We also want to acknowledge the financial support provided by the Virginia Department of Game and Inland Fisheries and the College of Sciences at Old Dominion University, plus the facilities provided by the Virginia Marine Science Museum in Virginia Beach, Virginia.

July, 1991

Harold G. Marshall
Mitchell D. Norman

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Introductory remarks to the Symposium by Mrs. Barbara M. Henley, a long time resident and former council woman of the city of Virginia Beach.

The Preface of Mann's (1984) *A Management Plan for Back Bay* begins: "Virginia Beach's Back Bay is a remote, untamed estuary lying in the lee of False Cape, a landscape and seascape of marshes and open water, dune ridges and islands, watermen and anglers going for large-mouth bass, ducks and geese carving flight formations against the open sky. It is also a thousand other things to thousands of other people..."

When on Back Bay, one has the feeling that here indeed is one of the world's most beautiful, unspoiled spots. I am reminded of the image that is often portrayed in the comic strip "Family Circus." Little Billy discovers some new, hidden spot and he calls to his Father, "Hey, Dad. Here's a place where nobody has ever been before." And then the strip silhouettes the little Indian boy who played there, followed by the Colonial boy, and all of the other little boys who also discovered and played in that place. So it is with the system of bays, marshes and creeks that compose the Back Bay system, and the lands of the watershed that drain into the bays.

One of the earliest sources to help us know the history of this area are the autobiographical accounts of a Methodist minister, the Rev. D. Butts, who served the Princess Anne Circuit over a century ago in 1886-87. In his book (Butts, 1922), *From Saddle to City, By Buggy, Boat and Railway*, he describes his visits along the Princess Anne Circuit which included churches on Knotts Island, Wash Woods and Currituck Inlet, along with other sites in the County. This is a fascinating account of his work in the churches and with people of this area. We are treated to firsthand accounts of visits with the life savers at the beach stations, his hunting experiences, and an account of the effects of the Charleston, S.C. earthquake of August 31, 1886 on the bay area and Knotts Island.

I particularly like his description of the marsh road to Knotts Island. He wrote: "There are eleven bridges and twenty-two bends in that road. It is said that if you see a person travelling on that road a long way off you cannot tell which way the person is travelling till you get opposite on a parallel stretch! This may be a severe tax on the imagination, but of this I am sure, the road is about as crooked as the proverbial ward politician, and as rough as corduroy can make it."

He also describes the rescue of sailors from the bark "Clythia" and of the last to be rescued; he wrote, "a large market basket, and in the basket a beautiful brown haired ducking dog." This splendid animal became the brood dog for scores of ducking dogs throughout that region, and died at last of old age.

Of one of his hunting trips, he writes: "About 3:30 p.m. that day a large bunch of Red Heads were seen from our blind, coming toward us with the speed of the 'Fast Mail.'"

"We made ready to shoot, and when this cloud of flying life almost reached our decoys, each of us let them have a load...After they passed we gave them the other barrel. Ducks fell all around. It rained ducks for about a minute."

By the turn of the century, the secrets of the bounty of Back Bay had spread, and Back Bay was projected into national prominence as a wild fowler's paradise. The Munden Point Branch of the Virginia Beach, Norfolk and Southern Railway had increased travel access to the area, and wealthy Northern industrialists and financiers built fashionable private gunning clubs on the islands and along the shoreline of the bay area. It is safe to say that the tourist industry was going strong around Back Bay when the present strip was just a fledgling beach resort. Among those who made annual trips to the area at the turn of the century was President Grover Cleveland, an honorary member of the Back Bay Gunning Club.

The activities of the area were tied to the land and the bays. Farming or fishing were emphasized in the spring and summer, with local men supplementing that income as guides or in other capacities for the gunning clubs in winter. Regulations were quite different in those days. Food for the fowl was not left to chance. At least one hunt club purchased two carloads of corn at the start of the season. Market hunting of wildfowl provided income for many watermen. An account in the ledger of the Sandbridge Gunning Club, December 4, 1904 reads: "Arrived and rowed to the bay, baiting the blinds east and west. Many geese and ducks in the meadows and bay." "December 7th; Rest Day - L.H. Dixon arrived. Made a new gate for the East Dam and put it in place. Baited the blinds and saw many ducks. Fished with net in Sande Broad and caught the finest lot of white perch ever seen."

Barbour (1946) made this interesting technical observation: "The water just misses being fresh. The degree of salinity is about six percent that of sea water. If, as happens from time to time, because of storms and high tides, sea water invades the area, the salt content will, of course, be intensified. When the degree of salinity exceeds nine percent, a growth of barnacles appears, which symptom is viewed with alarm, because it means that the widgeon grass and wild celery are in jeopardy."

In his writings, Barbour gives us the real flavor of what the glory of the hunting days was like: "Old gunners can recall, as recently as the early 1930's, when they came to their blinds or batteries at dawn, a veritable cloud of ducks and geese over the waters of Back Bay..." "Guides - they were good ones - bore surnames that are a delight to the ear. I will mention a few to make this point clear: Whitehurst, Lovett, Hill, Carroll, Dozier, Roe, Bassnight, Lee, Land and Waterfield. In nearly every instance their English grass roots were apparent from the curious transposition in their pronunciation of "w" for "v." Thus, "very" became "wery," "warnish" for "varnish," and the like." "I have never seen a guide who owned a duck call...When it came to honking in geese, most of these guides were past masters. They may have had their peers elsewhere, but I am sure they never were surpassed."

Barbour continues, "During the winter months, the bays would freeze tight, with the exception of an airhole here and there. I recall a wildfowling friend of mine considering himself quite fortunate in knocking off one hundred and six Ruddies in such an airhole. Today, of course, such slaughter seems absolutely indefensible. But as I have said before, at the time these performances were chalked up they were regarded merely as outstanding days with thousands of birds available. The Raised Eyebrow Department was conspicuous by its absence."

"Let me now acquaint you with an old-timer's daily routine. You would be awakened about three-quarters of an hour before sunrise and sit down to a breakfast that left nothing to be desired. After stowing away, let us say, hot cereal, ham and eggs, some pancakes and several cups of coffee, you would go down to the dock and impatiently await the first showing of the sun, which, to mix a metaphor, constituted the green light to start you on your way for whatever the day might hold in store. Other gunners, too, of course, would be getting under way. In a few minutes the sunrise sky would be laced with ducks and geese flying hither and yon because of the disturbance (Barbour, 1946)."

"In this mind's-eye project of ours, let us say we are going to tie out in the northwest head of Fisher's Cove. The two gunners would install themselves in the blind and the guide would get busy with the greatest possible dispatch in staking out the decoys. Twelve to fourteen live birds would soon start to dabble and preen themselves. Their number would be supplemented by a varying number of block decoys, and soon all would be in readiness. If a goodly number of birds had been using the cove, at least three-quarters of the birds to be killed on that day would be in hand by ten o'clock. Our shooting tapers off, and we toy with the idea of lunch. It is pretty hard to resist the impulse to gnaw on a cold roast Teal or to have a cup of hot soup long before the noon hour has struck. Even though our sport has begun to taper off, it is always a pleasure to watch the antics of the live decoys and observe the ruthless routine of the marsh, where an eagle soars on high, watching for a crippled duck, and perhaps a marsh hawk or two are engaged in their never-ending search for prey (Barbour, 1946)."

"By this time, a goodly number of wildfowl have been garnered. The live decoys, with their wheezy 'crate calls,' are serving notice that the time is at hand to consider returning to the clubhouse. On our return to our spacious living room the day's doings are reviewed with our confreres. Such discussion is enlivened by a toddy or two, designed, presumably, to dispose of the day's chill."

The evening meal was described by Barbour (1946) as follows: "Dinner was indeed a gastronomic hurly-burly. Lynnhaven Bay oysters were forthcoming as a matter of course. Perhaps some side bets would be made on the number of oyster crabs that might be found ensconced in their hosts. Before their virtual disappearance, a dish of terrapin might brighten the occasion. With the terrapin now about gone, perhaps a six- or eight-pound rockfish, taken offshore the same day with a drag seine, would put in an appearance. This, together with a roast duck apiece, with a side dish of collards and sweet potatoes, would almost forestall any keen inquiry in the matter of dessert. If some member were to be so kindly as to furnish a bottle or two of Burgundy, so much the better. Again we repair to the living room. After a somewhat labored bit of chit-chat on the day's sport, we are off to bed."

As Barbour (1946) summarized: "The Back Bay area undoubtedly will provide sport for wildfowlers for many years to come, unless conditions become more severe and the regulations affecting duck shooting are increased. While the abolition of baiting and the discontinuance of live decoys was unquestionably necessary because of the reduction in the number of birds, it is to be hoped that the stock will increase in due course of time and once more the wildfowler's heart will be gladdened by the sight of thousands of ducks over Back Bay, as he wends his way toward his blind in the glory of the dawn."

Any history must include mention of the storms of the past. Old timers emphasize that overwash from the sea was not an abnormal occurrence. The Granddaddy of storms seems to be the hurricane of August 1933. My mother-in-law was at the Horn Point Gunning Club at that time. At first light the next morning, they saw the house of one of the beach families floating in North Bay. Watermen rescued the family of Coast Guardsman Toler. Mr. Toler had rushed home the evening before to take his family back to the Number 4 Station for safety, but it was too late. As the house broke up, Mr. and Mrs. Toler and their three young children clung to the house top all night, one young child clutching a puppy and another hanging on to his kitten, as they listened to sounds of horses and cows and other livestock floating by throughout the night. The wave of seawater inundated the western bay shore, and each person who experienced that storm has his own tale to tell.

Just as there are many silhouettes to be drawn of people who have known and loved the Bay in the past, undoubtedly there are many silhouettes to be drawn in the future.

In our chapter in the history book on Back Bay, perhaps it will be written that we took very seriously our role as true caretakers of this wonderful resource. For instance, one of the guides who lived those marvelous experiences on the Bay said to me: "I've had my day, and I've enjoyed it. I would like for my grandchildren to know it, too."

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Description of Study Area

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Back Bay is the northern most of a series of bays along the Atlantic seaboard of North Carolina and Virginia. Other large bays in this complex include Currituck, Pamlico and Albemarle Sounds in North Carolina. Back Bay is confined within the City of Virginia Beach, Virginia and located between 75 deg. 52-58 sec. W log. and 36 deg. 32-45 sec. N lat. The Back Bay system is divided by islands into seven smaller segments: Back , Buzzards, Half Moon, Sand, Redhead, Shipps and North Bays (Figure 1).

Physiographically, Back Bay lies in the Atlantic Coastal Plain and in the section of Virginia referred to as Tidewater. The physiography of the watershed was first defined by Clark and Miller (1906, 1912) as lying within the Talbot terrace, which extended east from the Atlantic Ocean to a scarp near Suffolk. Stephenson (1912, 1926) subdivided the Talbot terrace into the Chowan terrace in the west, between elevations of 12.1 m and 15.2 m, and the Pamlico terrace in the east, below 12.1 m. Wentworth (1930) later subdivided the Pamlico terrace into the Dismal Swamp terrace in the west and the Princess Anne terrace in the east and north. Wentworth described the Princess Anne terrace, in which Back Bay was located, as a low, flat plain to an elevation of 3.0 m and entirely east of a prominent northward-trending ridge to Oceana, except for a small reentrant that extended westward in the vicinity of the community of Princess Anne. Wentworth named this ridge the Princess Anne scarp. However, Oaks and Coch (1973) pointed out that the Princess Anne scarp was actually two intersecting ridges of different ages, which they named Oceana ridge on the north and Pungo ridge on the south. Oaks and Coch abandoned the morphologic subdivisions of Dismal Swamp terrace, Princess Anne terrace and Princess Anne scarp submitted by previous researchers because of their confused definitions and their failure to adequately describe the morphology in detail. They redefined the Princess Anne scarp and Princess Anne terrace of Wentworth as simply "Sand-ridge and Mud-flat complex." The barrier dunes, marsh, swamp and stream sediments within the Back Bay watershed were redefined as "undivided sediments."

The Back Bay watershed system consists of approximately 27,024 ha (Mann, 1984). Upland vegetative communities and wetlands compose approximately 40% and 22%, respectively, of the watershed. Lakes, ponds and the waters of Back Bay comprise the remaining 38%. The eastern margin of the watershed consists of a narrow zone of marshlands and sand dunes which form a barrier between the bay and the Atlantic Ocean. This marsh-sand dune barrier varies in width from approximately 200 m along the bay's northeastern section (Sandbridge) to 1.1 km in the southeastern section where an extensive marsh system was formed by the shoaling in of Old Currituck Inlet during the early 1700's. Extensive wetlands, composed of slightly brackish to fresh water plants, border the western margin. The wetland plants of Back Bay are discussed in detail by other authors in this proceedings.

Hatch et al. (1985) mapped the soils of Virginia Beach as a revision of a soil survey done by Simmons and Shulkcum (1945). Hatch et al. reported six soil types within the Back Bay watershed. These were: 1) Back Bay-Nawney - very poorly drained soils with a thin organic surface layer over a loamy substratum; formed in fluvial sediments; consists of nearly level, frequently flooded soils on the floodplains of Back Bay and its tributaries; found in the marshes, floodplains and wooded drainageways of Back Bay, 2) Newhan-Duckston-Corollla - excessively drained to poorly drained soils with a sandy substratum; formed in marine and aeolian sediments; consists of nearly level to steep, very rapidly permeable soils on grass- and shrub-covered sand dunes, flats, and depressions along coastal areas; found in the barrier sand dunes, 3) Acredale-Tomotley-Nimmo - poorly drained soils that have a loamy subsoil; formed in marine and fluvial sediments; consists of nearly level soils in broad flat areas; found between Pungo Ridge and the Back Bay-Nawney soils, 4) State-Tetotum-Augusta - well drained, moderately well drained, and somewhat poorly drained soils that have a loamy subsoil; formed in marine and fluvial sediments; consists of nearly level to gently sloping soils on broad ridges and side slopes; found mainly in the northern part of the watershed, 5) Dragston-Munden-Bojac - somewhat poorly drained, moderately well drained, and well drained soils that have a loamy subsoil;

formed in marine and fluvial sediments; consists of areas of nearly level soils on narrow ridges and side slopes; found scattered along the western and northern portions of the Back Bay watershed above the Back Bay-Nawney soil type, and 6) Udorthents- Urban Land - well drained or moderately well drained soils over a loamy substratum and are covered by buildings and roads; consists of nearly level to steep soils in urban areas that have been excavated and graded or covered by impervious material.

The climate at Back Bay is temperate and oceanic, eg. it is moderated by the proximity of the Atlantic Ocean and Chesapeake Bay. The annual mean temperature, as determined at the nearest US Weather Station (Norfolk, Va), is 15.2 C. The coldest and warmest months are February and July with mean temperatures of 5.2 and 25.7 C, respectively. The average frost free season is 245 days, March 20 to November 20 (Simmons and Shulkcum, 1945). Rainfall is moderate (113.5 cm) and well distributed throughout the year (Norfolk station records). Months with the greatest rainfall are July and August (14.5 and 15.0 cm, respectively). Wind direction and speed determined at Oceana Naval Air Station was presented by Mann (1984). From April and continuing into October, wind direction is predominantly from the south-southwest. Wind direction from October through March is predominantly from the west-southwest and north. Wind velocities of 48 kph are uncommon. The average annual wind speed is 9.2 kph. Average monthly wind speed is highest in March (11.1 kph) and lowest in August (7.2 kph).

Major tributaries of Back Bay include Nawney Creek, Beggards Bridge Creek, and Ashville Bridge Creek with its Hell Point Creek diversion canal. Mann (1984) calculated the water budget for each subwatershed within the Back Bay system. The three major tributaries comprised the following percentages of the annual water budget for the total watershed: Ashville Bridge/ Hell Point Creek, 30.4%; Nawney Creek, 17.1%; and Beggars Bridge Creek, 7.7%.

Back Bay is an expansive, flat-bottomed, shallow-water aquatic ecosystem. It is comprised of approximately 9960 ha of open water and 4596 ha of emergent vegetated wetlands (Mann, 1984). Estimated maximum dimensions are 11.7 km in length by 9.6 km in width at southern end and 1.2 km in width at northern end. Shoreline irregularities cause considerable variance from these dimensions. The average depth of the entire Back Bay complex is 1.3 m. The maximum depth is 3.0 m, which is found in the channel (Great Narrows) separating North Bay and Redhead Bay. The remainder of the bay is less than 2.5 m. deep. Water depth is greatly influenced by winds, especially from the northeast, which may alter the depth by as much as 1.0 m. Lunar tides have little if any effect on the water level in Back Bay.

By strict definition Back Bay would be presently classified as an oligohaline estuary. The salinity presently ranges from 0.5 to 1.0 ppt The only saltwater influence is water blown north from Currituck Sound. Back Bay's nearest outlet to the ocean is approximately 43 km south at Oregon Inlet. The only significant connection between Back Bay and Currituck Sound is Knotts Island Channel, east of Knotts Island which sits astride the Virginia-North Carolina border. An insignificant connection is Corey's Ditch, which cuts through a vegetated wetland west of Knotts Island. Corey's Ditch was excavated in 1920 to permit water exchange between Back Bay and Currituck Sound west of Knotts Island, which had been cut off in 1890 by the construction of a causeway connecting Knotts Island with the mainland.

Public lands within the Back Bay watershed include two National Wildlife Refuges (Back Bay and Mackay Island), three Virginia Wildlife Mangement Areas (Trojan, Pocahantas, and Barbour's Hill Waterfowl Areas), one Virginia State Park (False Cape), and two Virginia Beach City Parks (Little Island and Creeds).

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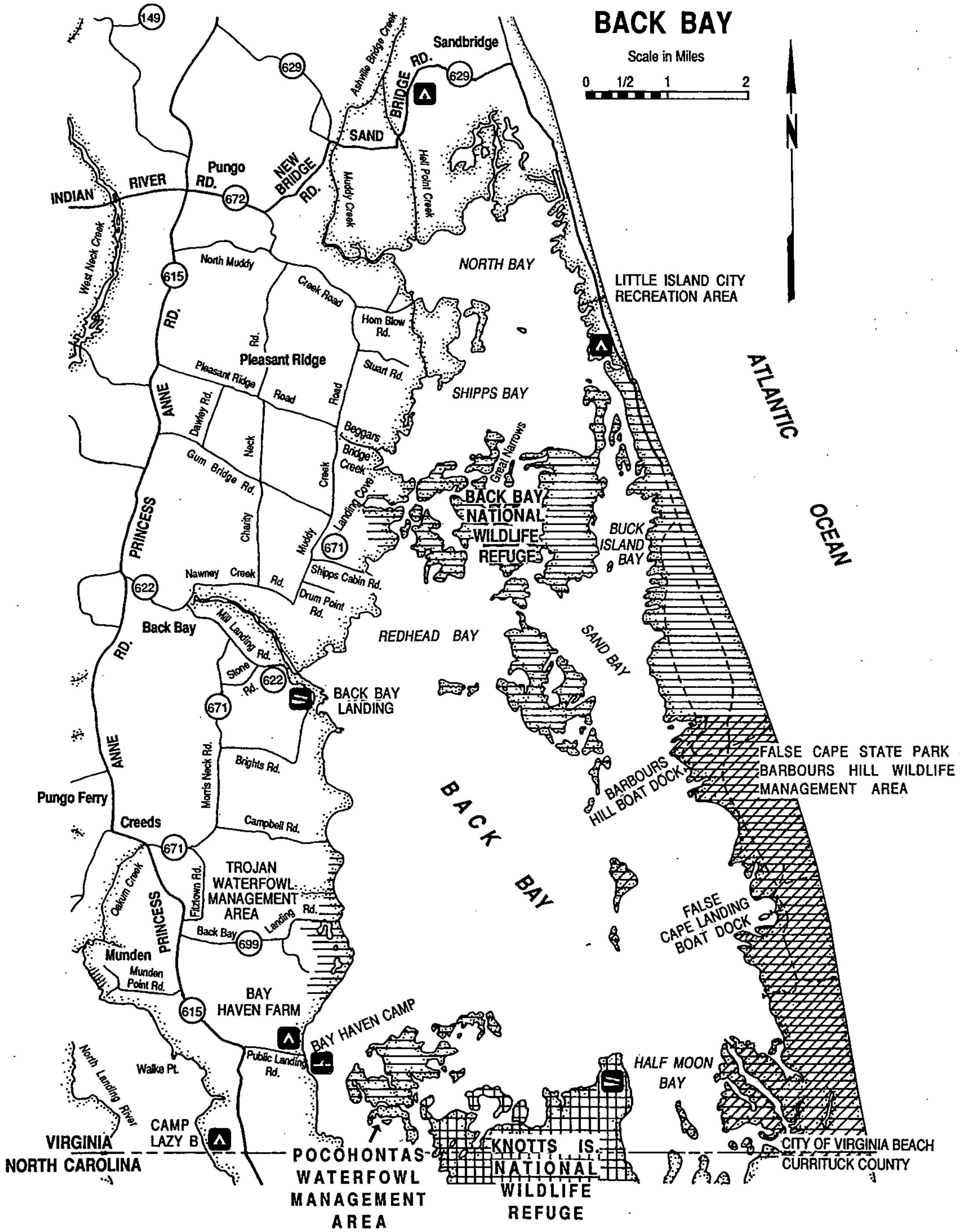

Figure 1. Map of Back Bay, Virginia.

I. Water Quality

Salinity and Secchi Disc Records for Back Bay, Virginia (1925-1989)

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Abstract: All available salinity and water clarity data for Back Bay, Virginia were edited for this manuscript. Quantitative salinity records commence in 1925. These are comprehensive and extend to 1989 except for a major interruption in the 1940's and 1950's. Quantitative water clarity records (Secchi disc visibility) commence in 1959 and are continuous to 1989 with only a few years missing.

Since 1925 the water in Back Bay has fluctuated from fresh (less than 0.5 ppt) to brackish (generally oligohaline, 0.5-3.0 ppt). Fresh to slightly brackish (less than 1.0 ppt) conditions existed from the late 1930's to early 1962, from 1975 to late 1978, and in 1989. For the remainder of this 65-year period, the salinity generally ranged from 2.0 to 4.0 ppt. The higher salinity periods were 1933-34, 1936 and 1962. These were caused by voluminous intrusions of ocean water induced by hurricanes or northeastern storms.

Secchi disc visibility was generally 20 to 30 inches from 1959-60 and 1965-80. During most of this period, the frequency of occurrence of submerged aquatic vegetation (SAV) in transect samples was more than 50%. From 1981 to 1989, water clarity greatly deteriorated with Secchi disc readings of only 6 to 12 inches. This increase in turbidity is attributed to the suspension of soil particles by increased wave action following a decline in SAV. Since 1980 the frequency of occurrence of SAV has been less than 5%. Without rooted, aquatic plants to stabilize the substrate, the sediment is kept in suspension by wave action.

Introduction

The scientific literature was thoroughly reviewed for all available salinity and water clarity data for Back Bay. In this search, the literature review by Sincock (1965 and 1966) for the Back Bay-Currituck Sound Study was invaluable. Sincock presented the results of all Back Bay researchers prior to and inclusive of the Back Bay-Currituck Sound Study. The reader is referred to this report for maps of the sampling stations and tables of empirical data of the various researchers. The salinity data in Sincock's report is presented in various units of measurement. For this manuscript, Sincock's salinity data was converted to ppt and averaged for all stations to provide monthly means. Salinity and Secchi disc data collected since 1965 were added to that collected by earlier researchers to provide a long term data base for this report.

The earliest quantitative salinity records for Back Bay commence in March, 1925 when the Game Preservation Association contracted for the Norfolk Testing Laboratory to analyze water samples from nine stations around Knotts Island. Six of these stations were in Back Bay; the remainder were in Currituck Sound. For this manuscript, the data for the six stations in Back Bay were averaged. Water samples were generally collected on a monthly basis from March, 1925 through 1934. Thereafter, the frequency of sampling declined (6 samples in 1935; 4 in 1936; 3 in 1937; and 1 in 1938). The amount of sampling in this survey, especially during the early years, provides a large data base. However, the location of the stations in the extreme southern area of Back Bay limits the merit of the data as representative of the entire bay.

The next quantitative record for salinity in Back Bay was reported by Chamberlain (1948) who studied the submerged aquatic vegetation and monitored salinity at several stations on the Back Bay National Wildlife Refuge in 1946. Chamberlain monitored salinity at nine stations on a weekly basis in June and July and at 15 stations on a weekly basis from August through November and one week in December. This data base can be considered indicative of the entire bay due to the location of the stations and frequency of sampling.

A limited amount of salinity monitoring was done by the US Army Corps of Engineers from 1949 through 1955. The only known record of this is by Robin (1955) who presented salinity as annual means for two stations (north end of Knotts Island and North Bay). Not knowing the frequency of sampling and considering the existence of only two sampling stations widely separated over the bay, this data base is of limited value.

An uncited reference in Sincock (1966) presented salinity data at Warden's Headquarters (Redhead Bay) on four occasions between August, 1953 and August 1956. The merit of this data is limited and must be used with caution when applied to the entire bay.

The next salinity data base and first Secchi disc records were collected as part of the Back Bay-Currituck Sound Study. Salinity was monitored at three stations along eight transects across the bay. This monitoring was performed from May, 1958 through August, 1963 and generally on a monthly basis.

The US Fish and Wildlife Service (USFWS) monitored salinity and Secchi disc visibility at 22 stations throughout the bay from May, 1965 through 1977 (Figure 1). The data was generally collected on a monthly basis through 1973, after which the frequency of sampling declined. Salinity was monitored for the following number of months in 1974-1977: 5, 4, 1 and 1, respectively. This data was never published.

The Virginia Department of Game and Inland Fisheries commenced salinity and Secchi disc monitoring in March, 1978 and continued through the term of this manuscript. Salinity and Secchi disc visibility were monitored at the same 22 stations used previously by the USFWS. Two additional stations were added in 1986 to better represent the bay (Figure 1). Sampling was conducted almost every month. Results were reported by Norman and Southwick (1987) and Southwick (1989).

Results and Discussion

Salinity records are presented as monthly means from 1925 through 1989 in Figure 2. Secchi disc records are presented as monthly means from 1959 through 1989 in Figure 3.

Salinity

The mean salinity from 1925 through 1930 was generally less than 2.0 ppt and fairly constant (Sincock, 1966 citation of Game Preservation Assoc. records). The mean salinity ranged from 1.2 ppt (December, 1928 and February, 1929) to 3.6 ppt (December, 1925 and November, 1930). Starting in the summer of 1930, the mean salinity increased to approximately 7.0 ppt by the summer of 1931 and then remained between 6-8 ppt through spring, 1933. Presumably this increase was due to ocean water intrusions across the barrier dunes. Sincock (1966) speculated that this freshening of the bay may have been due to the closing of the Great Bridge locks on the Albemarle and Chesapeake Canal. The locks had been open from April, 1917 to August, 1932. During this period salty water from Norfolk Harbor (Elizabeth River) flowed South along the Albemarle and Chesapeake Canal into Currituck Sound. Southerly winds prevalent during the summer months in this area would have pushed this salty water into Back Bay. However, we believe that this freshening was a natural occurrence.

A hurricane in August, 1933 breached the barrier dunes and dumped a vast quantity of ocean water into Back Bay. This increased the mean salinity to approximately 10 ppt where it remained until the following spring. The highest mean salinity found after the hurricane was 11.4 ppt on August 31, 1933. The bay freshened to 3-4 ppt by spring, 1934 and remained relatively constant for the rest of the year.

Salinity records are limited for the last four years of these Game Preservation Association records. However, these records are sufficient to show that the bay freshened further in 1935 and early 1936. By spring, 1936 the mean salinity was less than 1.0 ppt.

Another hurricane breached the barrier dunes in October, 1936. Immediately after the hurricane, the mean salinity was 6.5 ppt. The effect of this 1936 hurricane relative to the 1933 one was probably lessened by the sand fences completed in 1933-35. The salinity in the bay was not increased nearly as high in 1936 as in 1933 and the bay freshened much quicker. The last record in this data set (March, 1938) showed a mean salinity of 1.2 ppt.

Few salinity records exist for Back Bay during the 1940's and 1950's. These records indicate that the bay was fresh to slightly brackish. The most comprehensive and authentic record for this decade is from Chamberlain (1948). He found that salinity in 1946 ranged from 0.6 to 1.0 ppt with little spatial or temporal variation. Another salinity record for the late 1940's - early 1950's is Robin (1955). Robin wrote that from January, 1949 to September 1950 the average salinities at the north end of Knotts Island and North Bay were 0.7 and 0.5 ppt, respectively. This was prior to a storm induced break in the barrier dunes approximately 1.5 miles north of the Currituck Beach Light, which brought in a considerable amount of ocean water. However, this influx of ocean water caused only a slight increase in salinity. According to Robin, the salinities from September, 1950 to August, 1951 averaged 1.2 ppt (north end of Knotts Island) and 1.0 ppt (North Bay). Sincock cited an unpublished reference which gave the salinity at Warden's Headquarters (Redhead Bay) as 0.7 ppt in August, 1953; 1.0 ppt in September, 1953; 1.4 ppt in July, 1956; and 1.6 ppt in August, 1956. Although these records for the 1950's are not extensive, they do indicate that the bay was fresh to slightly brackish during this period.

Salinity data gathered during the Back Bay-Currituck Sound Study showed that the bay remained fresh to slightly brackish until March

7, 1962 when the "Ash Wednesday storm" breached the barrier dunes and washed a voluminous amount of ocean water into the bay. The ocean water did not immediately mix with the fresh water of the bay. Rather, it was stratified in the water column and varied greatly from East to West. Differences as great as 12 ppt were found between surface and bottom samples. Bay salinity near the breaches on March 8, 1962 was as high as 26 ppt. After two weeks of mixing, the salinity averaged 4.7 ppt on March 22, 1962. Following this peak, the salinity gradually declined until spring, 1963 when it tapered off at 1.6 ppt. The salinity remained approximately at this level through summer, 1963 when this data set terminates. The last record in this study was taken on August 21, 1963 and showed a bay average of 1.9 ppt.

The earliest record in the survey conducted by the USFWS was made on May 27, 1965 and showed an average salinity of 0.7 ppt. The salinity rapidly increased following this reading. The explanation for this was the introduction of seawater into Back Bay via a pump located at Little Island. This seawater pumping into Back Bay was initiated and conducted by the City of Virginia Beach. The objective for pumping seawater into Back Bay was to flocculate suspended sediment in the water, thereby allowing sunlight penetration to the bottom for growth of submerged aquatic vegetation. It was locally believed that the principle of soil particles binding to the cations common in seawater and settling out of suspension could be applied to Back Bay. This artificial introduction of seawater raised the salinity from 0.7 ppt in May to 3.9 ppt in August, 1965. Over the next ten years the salinity varied considerably but generally ranged from 2.0 to 3.0 ppt until late 1974 (Norman and Southwick, 1987). Factors influencing the monthly fluctuations included the amount of seawater pumped, rainfall, and salt water blown north from Currituck Sound. There were no storm induced breaches in the barrier dunes during this period. The decline in salinity commencing in late 1974 was due to an extended shutdown of the Little Island pump. Pump operation records are not available after 1972 for this initial pumping period. Apparently any seawater pumped in 1975 and 1976 must have been negligible since the available salinity data showed that the bay was fresh to slightly brackish. The salinity from January to October, 1975 ranged from 0.4 to 0.5 ppt. The salinity did not exceed 0.9 until seawater pumping was resumed. The pump had been destroyed by a fire in May, 1977 and was not replaced until August, 1978. Renewed introduction of seawater had an immediate and pronounced effect on salinity. The salinity increased to 3.0 ppt by September, 1978. The pumping was continued for the next nine years except for pump breakdowns and maintenance shutdowns. The latter were generally done annually during January through March. During this nine year period, the salinity was kept higher than during the previous pumping period. From 1979 through 1987, the salinity was generally between 3.0 and 4.0 ppt. Monthly peaks of 4.0 ppt were common. The highest monthly average was 5.4 ppt in June, 1980. During the periods of maintenance shutdown, the salinity declined to approximately 2.0 ppt. The seawater pump operation was terminated in September, 1987. Following this shutdown, the salinity gradually declined with minor fluctuations due to rainfall and salt water input from Currituck Sound. By December, 1989 the mean salinity had declined to 0.7 ppt.

Secchi disc readings

Secchi disc readings prior to 1965 are limited (only six records from 1959 through 1961). These records are insufficient to draw any conclusion regarding water clarity, except to note that Secchi disc visibility ranged from 8 to 35 inches. Commencing in 1965, the data base for Secchi disc readings is quite extensive and provides a comprehensive record for water clarity. From 1965 through 1980, Secchi disc visibility generally ranged from 20 to 30 inches. Commencing in 1981, water clarity started to deteriorate. From 1981 through 1984, Secchi disc readings averaged about 10 inches. With continued deterioration in water clarity, Secchi disc readings were routinely less than 10 inches during the last four years of this data set. This decline in water clarity is attributed primarily to a decline in the abundance of submerged aquatic vegetation in the bay. With reduced abundance of rooted, aquatic plants to stabilize the substrate in the bay, the wind driven wave action maintained the sediment in suspension. This can be seen very graphically in Figure 4. Other sources of sediment were from land use practices. Residential and commercial development in the watershed intensified in the early 1980's. On a seasonal basis, water clarity was the poorest during the winter and spring. The explanation for this is greater wind activity during these seasons, which resuspended the bottom sediment.

Acknowledgments

We sincerely thank Richard Eades for his constructive editorial comments and assistance in computer graphics.

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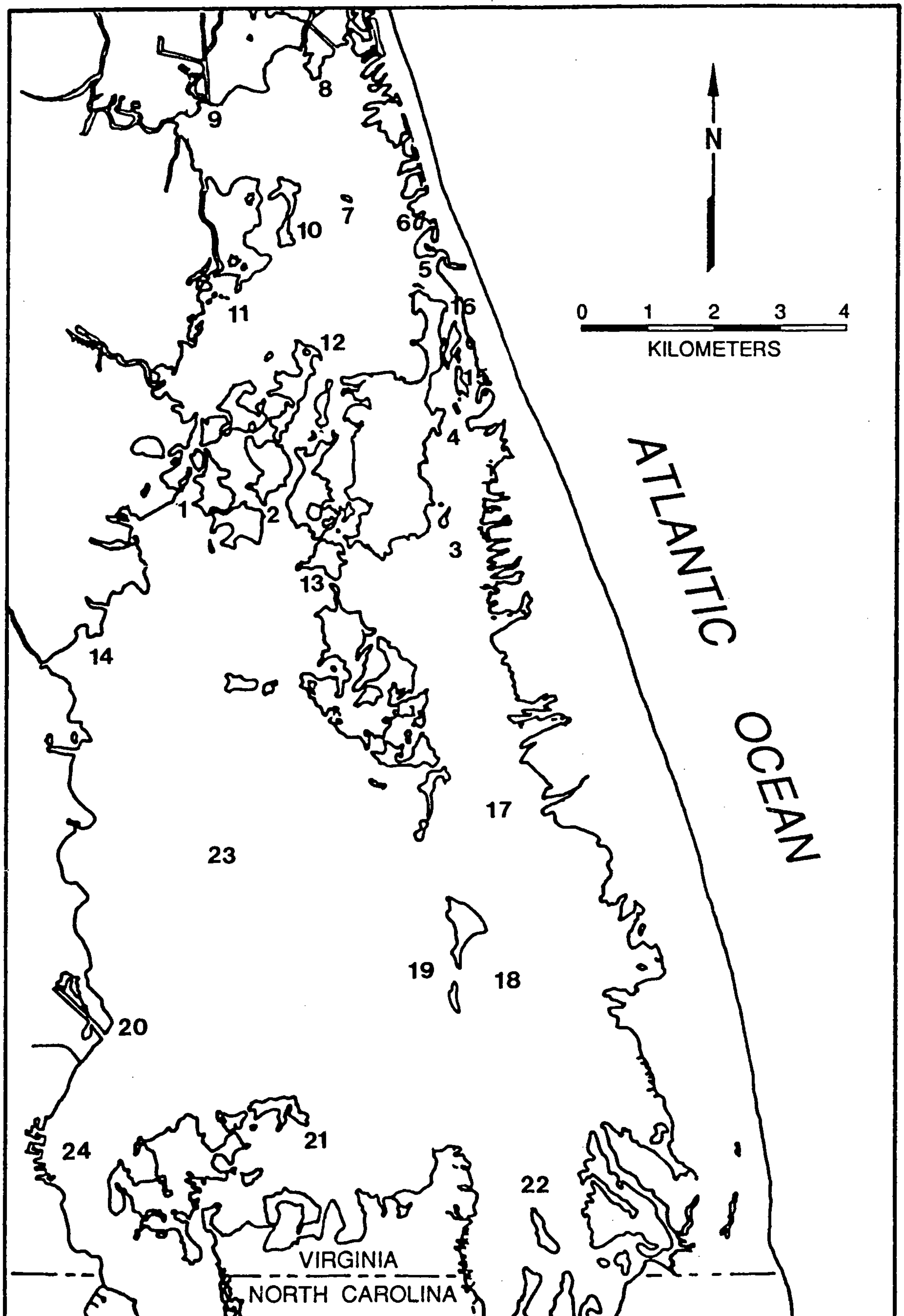

Figure 1. Map of Back Bay showing location of 24 salinity/Secchi disc monitoring stations.

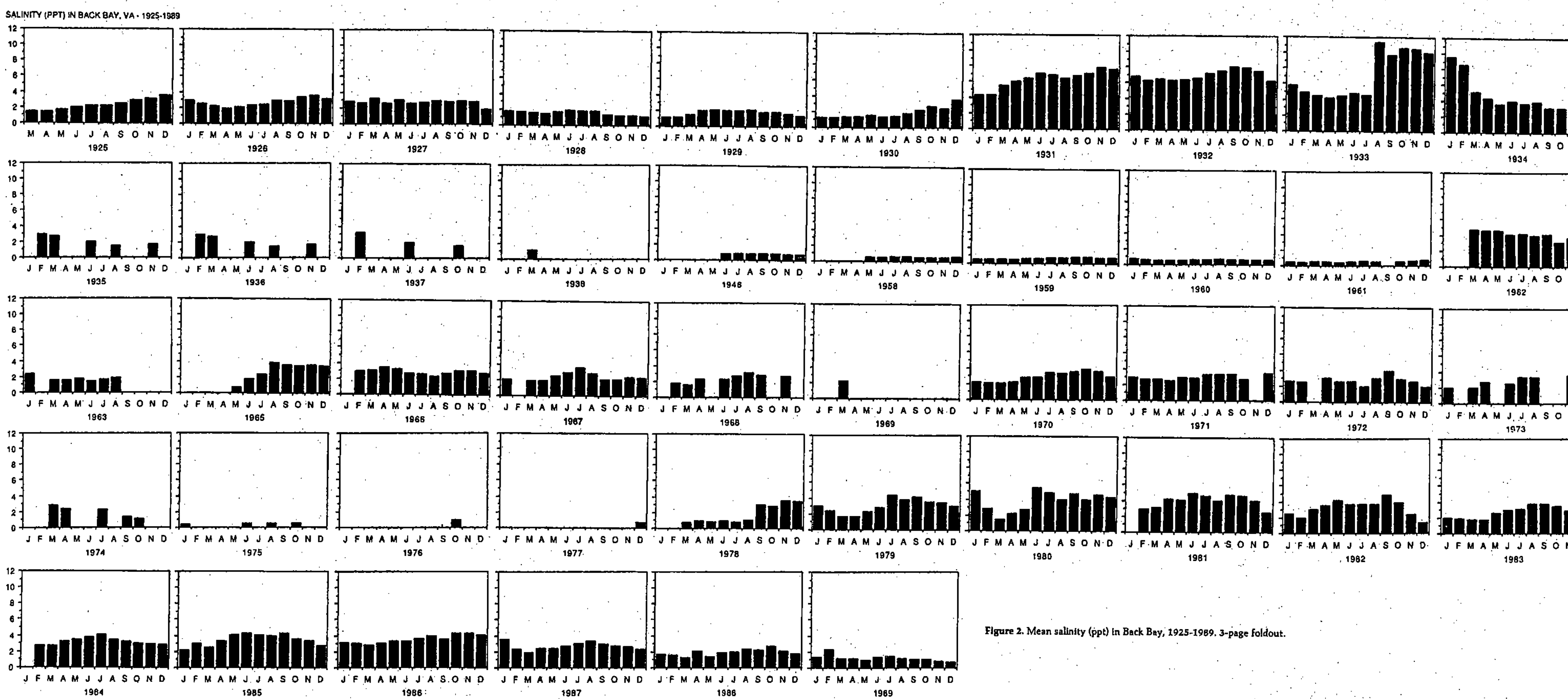

Figure 2. Mean salinity (ppt) in Back Bay, 1925-1989. 3-page foldout.

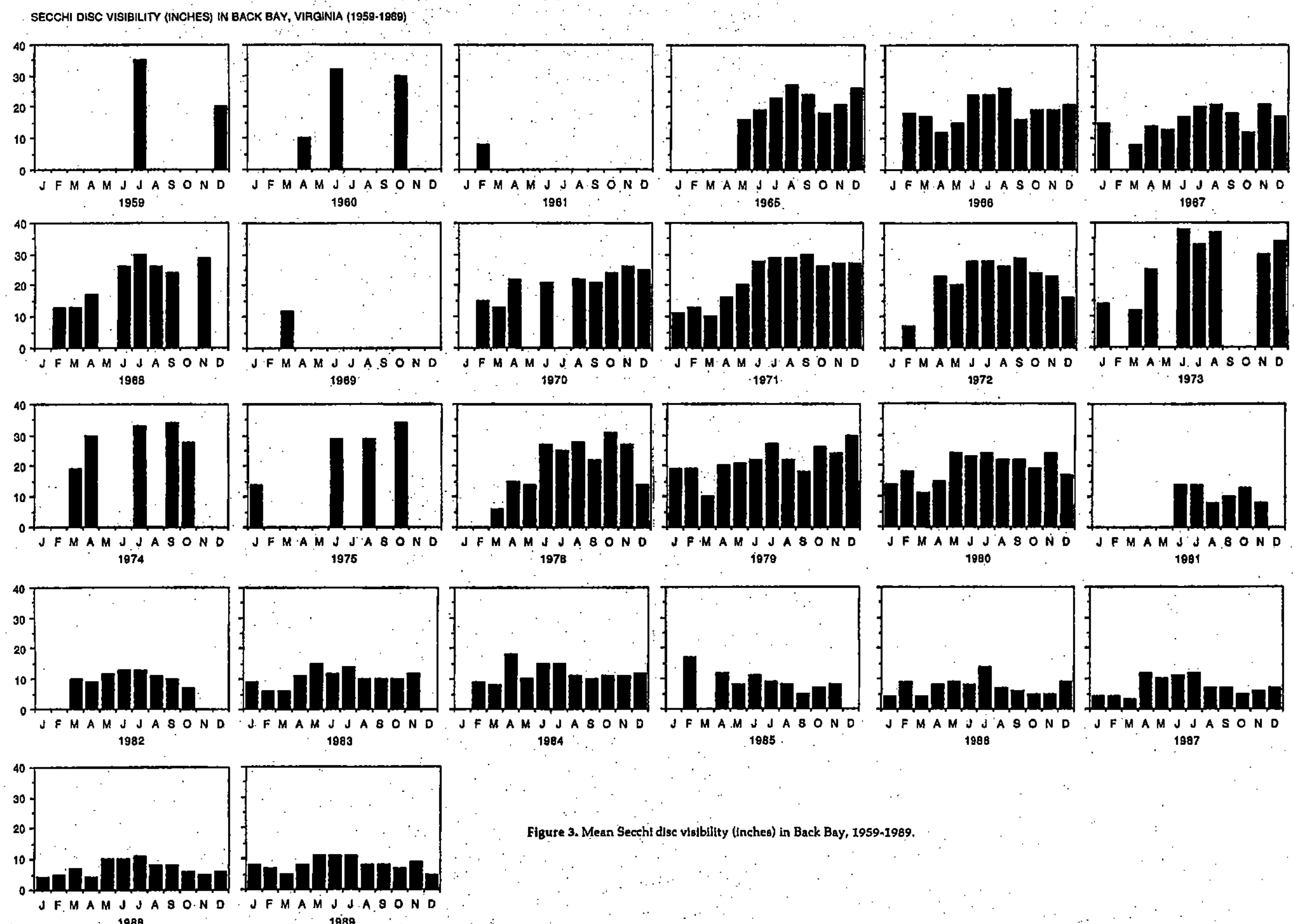

Figure 3. Mean Secchi disc visibility (inches) in Back Bay, 1959-1989.

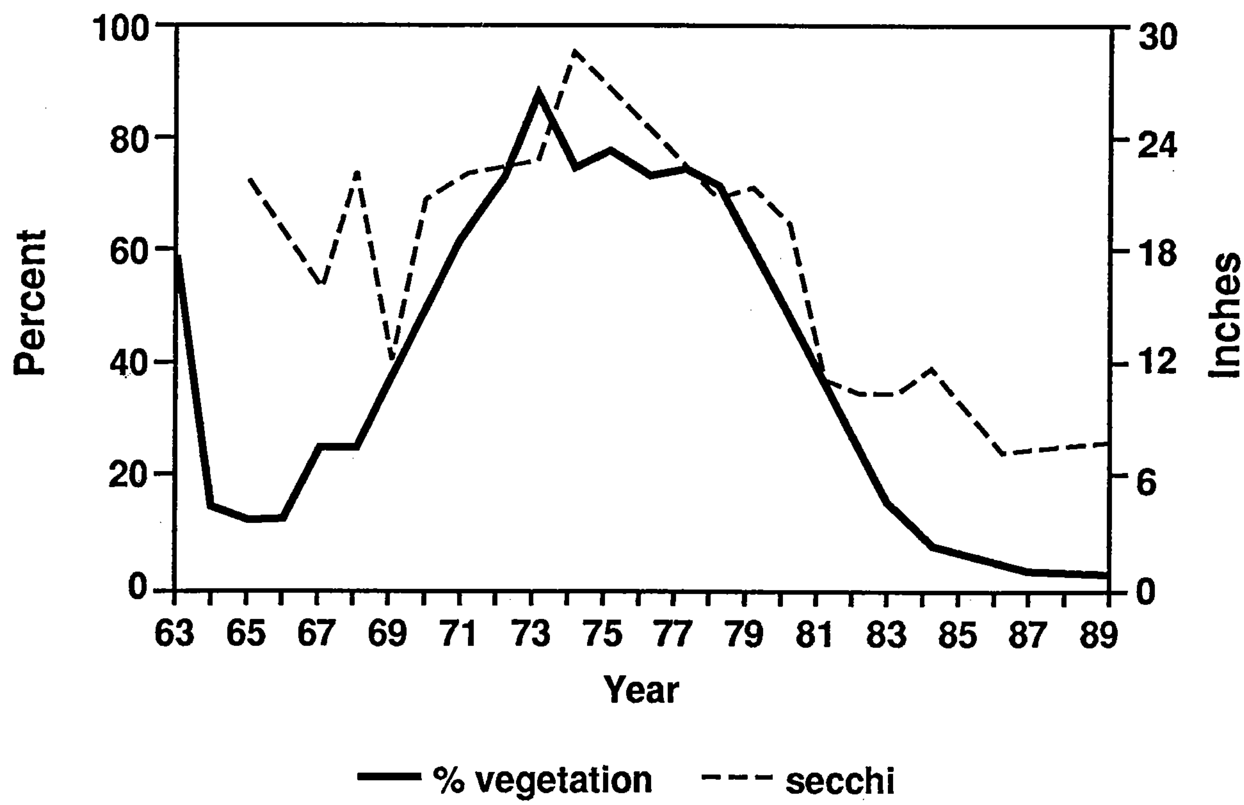

Figure 4. Comparison of mean Secchi disc visibility (inches) with abundance of submerged aquatic vegetation (percent of occurrence at sampling stations).

Light Attenuation in Back Bay, Virginia

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Abstract: In order to help assess the cause of the recent decline in submersed macrophytes, light attenuation was measured at selected stations in Back Bay, Virginia, in July 1987 and April 1988, using an underwater spectroradiometer. Secchi depth and concentrations of total suspended solids and chlorophyll-*a* were measured simultaneously. In July 1987, extinction coefficients ranged from 2.7 to 5.7 m^{-1} and Secchi depths ranged from 0.26 to 0.44 m. Total suspended solids ranged from 27 to 64 mg/L—37 to 80% of the suspended material was organic matter. Chlorophyll-*a* concentrations ranged from 43 to 71 µ g/L, indicating the presence of large numbers of algae. Water clarity was least in North Bay and greatest at the North Carolina border. In April 1988, during a period of strong wind, total suspended solids were extremely high, ranging from 78 to 214 mg/L, whereas the organic fraction ranged from 20 to 30%. Chlorophyll-*a* concentration ranged from 34.5 to 88 µ g/L. Secchi depth ranged from 0.16 to 0.33 m and K ranged from 3.7 m^{-1}at the North Carolina line to 19.9 m^{-1} in a canal near Pellitory Point. Comparison of the conditions in Back Bay in 1986-88 with those in the tidal Potomac River and Estuary indicate that the decline in submersed macrophytes in Back Bay is related to high light attenuation.

Introduction

The distribution and abundance of submersed aquatic macrophytes in tidal waters such as Back Bay are controlled by numerous factors, including the availability of light (Carter et al. 1985; Carter and Rybicki, 1990; Kemp et al. 1983; Batiuk et al. 1991). Light attenuation in the water column increases as total suspended solids (TSS) and chlorophyll-a concentrations increase; increases in chlorophyll-a are often the result of nutrient enrichment that encourages algal growth (Phillips et al. 1978; Moss 1983; Kemp et al. 1983; Carter et al. 1983, 1985; Haramis and Carter 1983). Submersed macrophyte populations in Back Bay have fluctuated dramatically during the 1900s (Sincock 1965; Mitchell Norman, Virginia Department of Game and Inland Fisheries, personal communication, 1990). Recently, there has been a serious decline in those populations (Mitchell Norman, Virginia Department of Game and Inland Fisheries, personal communication, 1990) and several theories, including changing salinity, decreases in water clarity, and increasing nutrients, have been advanced to explain this decline.

In 1987, the Virginia Department of Game and Inland Fisheries asked the U.S. Geological Survey (USGS) to ascertain the cause of the recent decline in submersed macrophytes in Back Bay. The USGS measured light attenuation at selected stations in July 1987 and in April 1988. Secchi depth and TSS and chlorophyll-a concentrations were measured simultaneously. This paper summarizes the results of the study.

Methods

Measurements were made at seven stations in North Bay and Back Bay in July 1987 and at five stations in Back Bay in April 1988 (fig. 1). Light attenuation was measured with a portable Licor[1] submersible scanning spectroradiometer equipped with a hemispherical silicon detector, a holographic grating monochrometer and filter wheel to select narrow bandwidths, and an internal computer that handles all data collection and storage. Light energy, in watts per square meter Wm^{-2}, was measured at 5-mm intervals from 400 to 800 nm; each measurement represents the average of either 5 or ten complete scans. Measurements were made about 1 m from the boat on the side facing the sun. Secchi depth measurements were also made at each site.

Extinction coefficients were calculated from;

$$I_z = I_o e^{-kz}$$

where I_z = average irradiance at depth z, in Wm^{-2};
I_o = average irradiance just below the water surface;
K = extinction coefficient (m^{-1}).

Depth-integrated water samples were collected at all sites. Phytoplankton were filtered onto glass-fiber filters, chlorophyll-*a* was extracted with 95% acetone, and chlorophyll-*a* and phaeophyton were determined fluorometrically (Blanchard et al. 1982). TSS samples were vacuum-filtered through tared glass-fiber filters, freeze dried for 3 h, and reweighed to obtain total suspended solids. Ash-free dry weights and organic matter content of the suspended solids were determined after combustion at 500°C in a muffle oven for 2 to 3 hrs.

Regressions of K with TSS and chlorophyll-*a* concentration were run with Minitab (Minitab 1986).

Results

Water clarity was very poor in Back Bay in 1987 and no submersed macrophytes were observed. Light-extinction coefficients ranged from 2.7 m^{-1} at Pellitory Point to 5.7 m^{-1} in North Bay and Secchi depths at the stations ranged from 0.26 to 0.44 m (table 1). TSS ranged from 37 to 64 mg/L—37 to 80% of the suspended material was organic matter. Chlorophyll-*a* concentrations ranged from 42.8 to 70.9 μ g/L, indicating the presence of relatively large numbers of phytoplankton. Water clarity was least in North Bay and greatest near the Virginia-North Carolina border. Water clarity was less in April 1988 than in July 1987 because of high winds that resuspended phytoplankton and sediments. Extinction coefficients ranged from 3.7 m^{-1} at the North Carolina line to 19.9 m^{-1} in a canal near Pellitory Point and Secchi depth ranged from 0.16 to 0.33m (table 1). *Myriophyllum spicatum* was only found near the North Carolina site. TSS ranged from 78 to 214 mg/L—only 20 to 30% of the suspended material was organic matter—and chlorophyll-*a* concentration ranged from 34.5 to 88.0 μ g/L.

Figure 2A shows the extinction coefficients by wavelength between 400 and 800 nm (visible plus near infrared) for stations 20 (Pellitory Point), 14 (Drum Point) and 9 (North Bay) in July 1987. Figure 2 also shows TSS and chlorophyll-*a* concentration for these stations. In these coastal waters, blue light (400 to 500 nm) hardly penetrates into the water, and the wavelength of maximum light penetration is shifted from the blue-green found in clear near-coastal waters to the orange (570 to 590 nm) or the near-IR (>700 nm) (Carter and Rybicki 1990). Chlorophyll-*a* and TSS concentrations were highest at station 9 and lowest at Station 22 in 1987 (table 1). Extinction coefficients for three of the five stations sampled in April 1988 are shown in figure 2B. Changes in extinction coefficient from station to station were caused primarily by differences in TSS concentration.

Regression analysis showed that TSS concentration explained 72.7% of the variation in K in 1987 and 95.6% of the variation in K in 1988 (table 2). When all data were combined, TSS concentration explained 85.1% of the variability in K. Chlorophyll-*a* concentration explained 75.6 percent of the variability in K in 1987, but was overwhelmed by the effect of the TSS concentration in 1988 and did not explain a significant part of the variability in K when data were combined.

Discussion

The above results support the hypothesis that poor water clarity is a major cause of the near absence of submersed aquatic macrophytes in Back Bay. Our Secchi depth and TSS measurements (table 3) are within or slightly higher than the ranges reported by Southwick and Norman (1987). Our TSS data for April were higher than the reported range for 6 Back Bay stations in April 1986 (15 to 56 mg/L), however, our samples are probably representative of extreme wind conditions in the bay. We have seen no published data on chlorophyll-*a* concentrations for Back Bay for comparison with our data; however, chlorophyll-*a* concentrations are unusually high for an oligohaline tidal environment.

The K values measured at the Back Bay station 22, the station with the greatest water clarity in 1987, were compared with K values measured at two mainstem sites in the tidal Potomac River (fig. 3). Elodea Cove is a freshwater site with dense macrophyte beds. Wades Bay is an oligohaline site with patchy beds limited to the shallow (<1.5 m) margin along the shoreline. Extinction coefficients were generally lower in the entire visible range (400 to 700 nm) at Elodea Cove than at Wades Bay or Back Bay station 22. Wades Bay extinction coefficients in the spectral region between 400 to 550 nm (the blue to green region) are also lower than those at station 22. The chlorophyll-*a* and TSS concentrations shown with the curves demonstrate that K is a function of both TSS and chlorophyll-*a* concentrations. Other factors probably influence K as well. Mean growing-season K values of ≤ 2.2 m^{-1} have been associated with good growth of submersed macrophytes in the freshwater reach of the tidal Potomac, but in the oligohaline zone of the Potomac Estuary, however, submersed macrophytes grow along the shallow margins at mean seasonal K values of ≤ 2.7 m^{-1} (Carter and Rybicki 1990). This suggests that light conditions are marginal for submersed macrophytes at station 22 and the station at the North Carolina Line.

We compared Secchi depth and TSS and chlorophyll-*a* concentrations for Back Bay in 1986-88 with data from the Potomac River at Quantico, Virginia, where salinities are similar to those in Back Bay in dry years (table 3). These data are from several sources, including water-quality data collected by the USGS in 1980 (Blanchard et al. 1982; Coupe and Webb 1984) and data collected by the Maryland Department of the Environment from 1983-89 (Batiuk et al. 1991). Median seasonal (April-October) Secchi depth at Quantico was 0.51 m in 1980 when there were no plants at this station. Median growing seasonal Secchi depth was 0.8 m in 1987 when there were dense beds of submersed macrophytes at the station. The range of Secchi depths found in Back Bay in 1986-88 is below the 1980 value for Quantico. A recent analysis of TSS and chlorophyll-*a* data from the Potomac River and Estuary for the period 1980-89 showed that growing-season median chlorophyll-*a* concentrations $\leq$ 15 to 20 μ /L and median suspended-sediment concentrations $\leq$15 to 20 mg/L could be correlated with survival and spread of submersed aquatic macrophytes (Batiuk et al. 1991). Median growing-season TSS concentrations at six stations in Back Bay in 1986 (calculated from Southwick and Norman 1987) ranged from 38 to 53 mg/L—a concentration considerably higher than the above limit—whereas the median growing-season TSS concentration in the tidal Potomac River at Quantico, Virginia, was 11.5 mg/L (table 3). Chlorophyll-*a* concentrations in Back Bay are similar to those in the Potomac River at Quantico in 1980 when there were no plants (table 3).

Because high nutrient concentrations are commonly associated with an increase in phytoplankton and a decline in submersed aquatic macrophytes, we compared median growing-season nutrient concentrations in Back Bay in 1986 (calculated from Southwick and Norman 1987) with median concentrations in the tidal Potomac River at Quantico (table 4). The comparison showed differences between the two sites, but insufficient information is available to establish a cause and effect relation. Ammonia, total phosphorus, and orthophosphate concentrations, which are often responsible for increased numbers of phytoplankton, were similar at both locations. Nitrate plus nitrite concentrations were higher in the tidal Potomac River than in Back Bay; higher total Kjeldahl nitrogen concentrations were found in Back Bay than in the total Potomac River (table 4). The nutrient concentrations in the tidal Potomac River support algae blooms when other factors such as sunlight, water temperature, and discharge are favorable (Bennett et al. 1986). It is possible that the poor tidal flushing in Back Bay provides favorable conditions for development of large phytoplankton populations at the present nutrient concentrations.

[1] Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

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Table 1. Extinction coefficient (K), Secchi depth, mean TSS and chlorophyll-*a* concentrations in Back Bay, Virginia, July 1987 and April 1988. (Stations are listed by date in order of increasing K; n.d. is no data; n is number of samples.)

Sampling Date/Station Number Location	K (m^{-1})	Secchi depth (m)	TSS (n) (mg/L)	Chlorophyll-*a*(n) (μ g/L)
July 1987				
20-Pellitory Pt.	2.7	0.30	44(2)	49.1(2)
NC-North Carolina line	2.9	0.30	44(2)	43.9(2)
22-Half Moon Bay	2.9	0.40	43(2)	54.0(2)
3-Sand Bay	2.9	0.44	44(2)	51.2(1)
14-Drum Point	4.7	0.26	51(2)	54.7(2)
5-Bread Island	5.0	0.34	62(2)	62.2(2)
9-North Bay	5.7	0.26	61(2)	70.9(1)
April, 1988				
NC-North Carolina line	3.7	0.33	88(2)	73.5(2)
D-Long Island	6.7	0.28	99(2)	84.4(2)
B-Cedar Island	8.3	0.23	116(3)	34.5(2)
E-Canal	19.9	n.d.	214(1)	88.0(1)
20-Pellitory Pt.	n.d.	0.16	149(3)	44.0(2)

Table 2. Results of regression of K with suspended sediment and chlorophyll-*a* concentration for July 1987, April 1988, and both dates combined. (P is probability; N is number of samples)

Regression	Coefficient of determination (r^2)	P	N
July 1987	0.727	0.000	10
K vs TSS	0.756	0.721	10
K vs chlorophyll-*a*			
April 1988	0.956	0.000	8
K vs TSS	0.000	0.721	8
K vs chlorophyll-*a*			
Both Dates	0.851	0.000	18
K vs TSS	0.086	0.143	18
K vs chlorophyll-*a*			

Table 3. TSS, chlorophyll-*a* and Secchi depth in Back Bay and the Potomac River at Quantico, Virginia. Data for 1986 are the ranges of growing-season medians for 6 Back Bay stations calculated from data in Southwick and Norman (1987) and Norman and Southwick (1987). Potomac River data are growing-season medians (Batiuk et al. 1991). (TSS is mg/L; chlorophyll-*a* in μ g/L; Secchi depth in m; n.d. is no data).

	Back Bay			Potomac R. at Quantico	
	1986	1987	1988	1980 (no plants)	1987 (plants)
TSS	38-53	37-64	78-214	9.5	11.5
Chlorophyll-*a*	n.d.	42.8-70.9	31.0-88	41.9	5.14
Secchi Depth	0.15-0.30	0.26-0.44	0.16-0.33	0.51	0.8

Table 4. Median growing-season (April-October) nutrient concentrations for six stations in Back Bay (1986) (Southwick and Norman 1987) and the Potomac River at Quantico, Virginia in 1987.

(Concentrations in mg/L)

	Back Bay, 1986 (no plants)	Potomac River at Quantico, 1987 (plants)
Total phosphorus as P	0.1	0.07
Orthophosphate as P	0-0.04	0.03
Total Kjeldahl nitrogen as N	2.4-3.0	0.78
Ammonia as N	0.1	0.1
Nitrate plus nitrite N	0.6-0.07	1.35

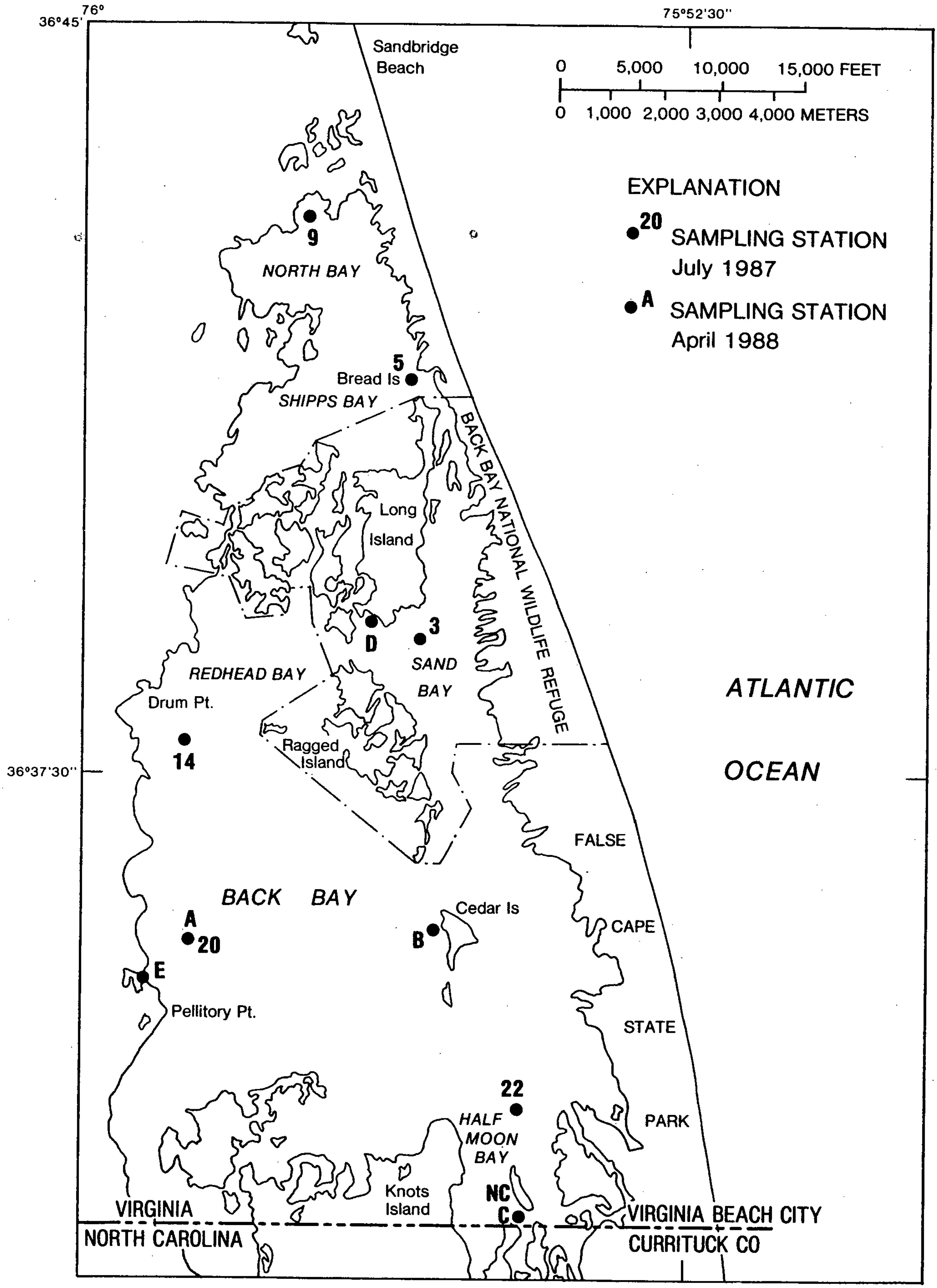

Figure 1. Map of Back Bay showing sampling stations for July 1987 (numbered stations) and April 1988 (stations with letters).

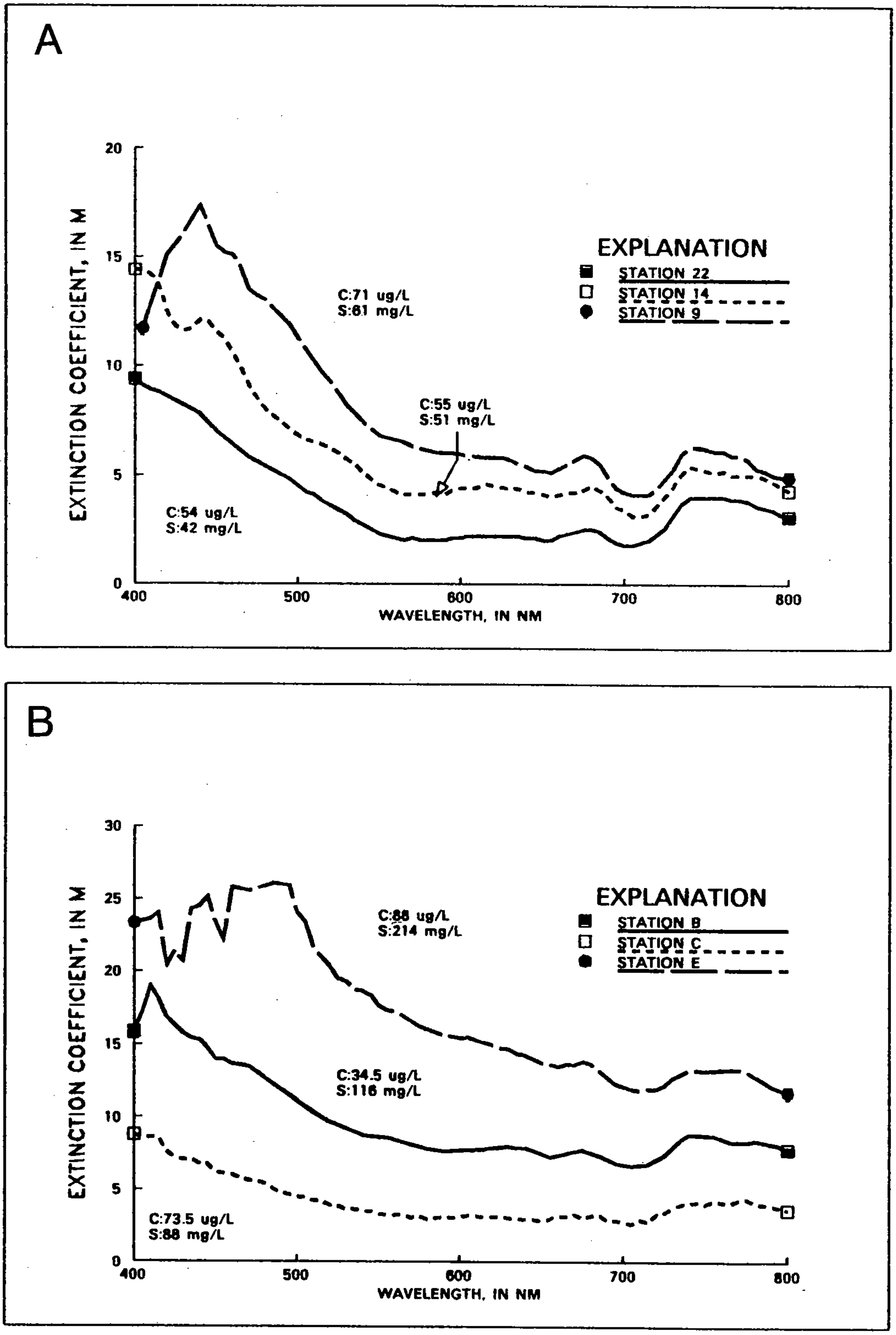

Figure 2. Extinction coefficients, in m^{-1}, at three Back Bay stations in July 1987 (A) and April 1988 (B). (C is chlorophyll-*a* concentration; S is TSS; NM is nanometers).

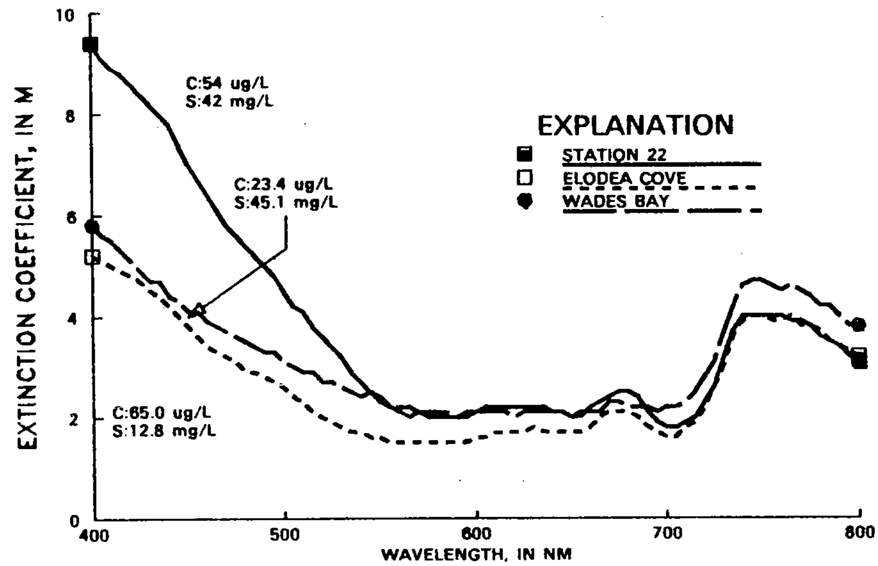

Figure 3. Comparison of extinction coefficients at Back Bay station 22 with extinction coefficients at Elodea Cove, in the tidal freshwater Potomac River, and Wades Bay, in the oligohaline Potomac Estuary. (C is chlorophyll-*a* concentration; S is TSS; NM is nanometers).

Nutrient and Total Susupended Solids Data for Back Bay (1986-1989)

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Abstract: Surface water samples from Back Bay, Virginia were analyzed for nutrient and total suspended solids on a monthly basis from April, 1986 through December, 1989. The concentrations of total phosphorus, orthophosphate, nitrite and nitrate nitrogen, and total ammonia generally fell within the "normal" range and did not indicate high nutrient loading. However, the concentrations of total suspended solids and total Kjeldahl nitrogen were high, exceeding EPA reference levels. Soil particles kept in suspension by wind driven wave action was the primary factor for the high concentration of total suspended solids. The high concentration of total Kjeldahl nitrogen was due to an abundance of organic matter, primarily plant detritus and plankton. Seasonal patterns were noted for nitrite and nitrate nitrogen, total ammonia, total suspended solids and total Kjeldahl nitrogen.

Introduction

Water quality has been perceived to be poor in Back Bay for several years. However, there has not been a comprehensive study of water quality in Back Bay since the period 1959-1963 (Sincock, 1966). The Virginia Water Control Board (VWCB) has monitored selected water quality parameters on some of the bay's tributaries on an irregular basis; but no sampling in the open bay was conducted. Mann (1984) reported the results of water quality monitoring at 20 stations (8 in open bay and 12 in tributaries) in 1983. However, this sampling effort was limited to two dates following a 0.73 inch rainstorm. Results of this survey showed high concentrations of phosphorus, nitrate nitrogen, and suspended solids. However, the limited amount of sampling and its occurrence shortly after a rainstorm invalidates Mann's data as representative of the bay's water quality over an extended period. Our study was initiated in 1986 to ascertain nutrient levels in Back Bay and establish a comprehensive long term data base for future reference. Results of the first year's nutrient analyses were reported by Southwick and Norman (1987).

Methods

Surface water samples were collected at six stations on Back Bay (Figure 1) on a monthly basis from April, 1986 through December, 1989. Samples were sent to the Virginia Consolidated Laboratory in Richmond for analyses. Water quality parameters analyzed by the lab were suspended solids, ammonia, nitrite, nitrate, total Kjeldalh nitrogen, total phosphorus, and orthophosphate. For this manuscript, the data were averaged to provide monthly and annual means. These were compared with the literature, particularly with EPA reference levels (VWCB, 1976)

Results and Discussion

Total Suspended Solids - Total suspended solids (TSS) include: 1) "fixed" matter which is inorganic colloidal clay and course suspensions of soil particles, and 2) "volatile" matter which is organic. The concentration of suspended solids varies greatly between waters, depending on numerous factors including geomorphology of the watershed, atmospheric sources, equilibrium-exchange with sediments within the water body, evapotranspiration,and human activity within the watershed. Evaporation from waters in closed basins raises the concentration of dissolved solids as does saltwater infusion. Due to the host and complexity of factors influencing TSS, a meaningful comparison for this water quality parameter cannot be made between Back Bay and other waters. Therefore, we compared the concentration of TSS in Back Bay only with the EPA reference level (80 mg/1).

Annual means for TSS were: 50 mg/1, 1986; 69 mg/1, 1987; and 84 mg/1, 1988 and 1989 (Figure 2). These values exceed the EPA reference level for two of the four study years. On an individual station basis, TSS exceeded the EPA reference level in 33.3% of the samples. The primary sources for this high level of TSS were: 1) an abundance of inorganic material in suspension, (Southwick and Norman, 1987) and 2) an abundant plankton population (Marshall, 1988 and

Marshall, et al., 1988). The monthly levels followed a distinct seasonal trend (Figure 3) with a peak in late winter-early spring and a low in summer. Total suspended solids was generally highest from January through March when the level routinely exceeded 75 mg/1 and reached as high as 216 mg/1 (March, 1987). The more intense winds at Back Bay during the winter and spring (Mann, 1984) increased the wave action which increased the amount of sediment in suspension. As the winds subsided during the summer, TSS declined to levels generally ranging from 40 to 50 mg/1. With increased wind velocity in the fall, the level of TSS increased to approximately 50-100 mg/1.

Total phosphorus - Phosphorus is a major cellular constituent and key metabolic element. It is essential for energy transfer within the living cell. Phosphorus is usually considered to be the element which most frequently limits aquatic production.

The total phosphorus concentration in natural, unpolluted waters ranges widely from 0.01 to more than 200 mg/1 in some closed, saline lakes (Wetzel, 1975). However, the concentration in most unpolluted, surface waters is between 0.1 and 0.5 mg/1 with the level seldom exceeding 1.0 mg/1 (Boyd, 1979). Even in fertilized fish ponds, the concentration averaged only 0.17 mg/1 (Boyd, 1976). Rulifson (1990) stated that the concentration in the lower Roanoke River ranged from 0.14 to 0.17 mg/1. The EPA reference level for total phosphorus is 0.3 mg/1.

The concentration of total phosphorus in Back Bay averaged 0.1 mg/1 each year of this study (Figure 4). There was little spatial or temporal difference. The highest individual reading was 0.3 mg/1 which occurred only twice during this 45-month study (Stations 5 and 9; December, 1989). Since the annual means fell within the "accepted or normal" range and were less than the EPA reference level, it appears that Back Bay is not overloaded with phosphorus. However, the level did exceed the VWCB standard of 0.05 mg/1 for class II B waters.

Total phosphorus did not show any distinct seasonal trend (Figure 5). It was generally highest for a few months in late winter-early spring. Explanations for this could include 1) a decrease in phosphorus assimilation with the waning of the phytoplankton population and, 2) the re-suspension of sediment bound phosphorus by heavy wave action. When a phytoplankton population becomes senescent and declines, phosphorus is released from the dead cells. A portion of this is incorporated by other phytoplankton species, which become more abundant as others decline. But when the entire phytoplankton population declines, the concentration may increase considerably. Marshall (1988) noted that the phytoplankton population in Back Bay declined during the winter. Phosphorus very readily binds to soil particles and as such may flocculate to the bottom where it is utilized by various benthic organisms but is unavailable to plankton within the euphotic zone. The strong winds during the winter-spring period would bring this sediment bound phosphorus back into suspension. A second "peak" occurred in late summer-early fall. Sediment bound phosphorus washed into the bay from the watershed could be an explanation for this increase. In a normal year, the Back Bay watershed receives the greatest monthly rainfall in July and August (29.5 cm of an annual average of 113.5 cm). Most of the agricultural fertilizers used in the watershed are applied during the spring and have not been completely assimilated by agricultural crops by summer (personal communication, Louis Culipher). Therefore, the sediment bound agricultural phosphorus is available for rainfall erosion into the bay.

Orthophosphate - Orthophosphate is the simplest form of phosphorus in water and may be considered as ionization products of orthophosphoric acid. Orthophosphate is essential for energy transfer and other functions within the cell. It is an inorganic form of phosphorus and is soluble, thus making it readily available for plant utilization. As such, it is cycled very rapidly in the zones of utilization.

In natural, unpolluted waters orthophosphate is present in very minute quantities, usually ranging between 0.05 and 0.2 mg/1 but seldom exceeding 0.1 mg/1 even in highly eutrophic waters (Boyd, 1979). In fertilized fish ponds, orthophosphate averaged 0.2 mg/1 (Boyd, 1976). Rulifson (1990) reported that orthophosphate averaged 0.05 to 0.08 mg/1 in the lower Roanoke River. The EPA reference level is 0.1 mg/1.

The annual mean for orthophosphate in Back Bay during this study ranged from 0.04 mg/1 in 1988 to 0.07 mg/1 in 1989 (Figure 6). This concentration was within expected values (Boyd, 1979) and below the EPA reference level. Therefore, orthophosphate level was not excessively high during this study period.

There does not appear to be a distinct seasonal pattern in the orthophosphate concentration in Back Bay, except that it was generally higher during the latter half of each year (Figure 7). At least two factors could have contributed to the relatively high concentration during the summer. First, summer is the major period of algal growth in Back Bay (Marshall, 1988). Since ortho phosphate and organic esters constitute the majority of the phosphorus released into the water during active algal growth, one would expect the level of these forms of phosphorus to be higher during the summer. The second plausible explanation for the higher level in the summer is sediment bound ortho phosphate washed into the bay by rainfall.

The relatively low level of orthophosphate during the late winter-early spring is puzzling. This ion is very readily trapped in the sediment of aquatic systems by flocculation with positively charged soil particles. It is then released back into the water when the sediment is brought back into suspension. Since the wind intensity at Back Bay is greatest from December through April, one would expect the level to be seasonally high during this period. However, the reverse was true for Back Bay.

Orthophosphate constitutes a very small portion (considerably less than 5%) of the total phosphorus in natural waters (Wetzel, 1983). However, it constituted about 50% of the total phosphorus in Back Bay. The explanation for this could be a high level of non-point pollution, which is the primary source of orthophosphate in aquatic systems.

Total Kjeldalh Nitrogen - Total Kjeldalh Nitrogen (TKN) includes ammonia and organic (amino acids, polypeptides, urea, uric acid,etc.) nitrogen.

According to Boyd (1979), the concentration of TKN is usually well below 1.0 mg/1 in unpolluted waters. Rulifson (1990) reported values ranging from 0.34 to 0.45 mg/1 in the lower Roanoke River. The EPA reference level for TKN is 0.9 mg/1.

Annual TKN means during this study were: 2.5 mg/1, 1986; 2.2 mg/1, 1987 and 1989; and 1.8 mg/1, 1988 (Figure 8). Individual station readings were as high as 3.8 mg/1 (Station 3; August, 1986). These values were high relative to the literature cited. Since the ammonia nitrogen was not high in Back Bay, the explanation for the high TKN is the organic fraction. A lot of detritus is washed into Back Bay, where it sits for an extended period due to the slow flushing rate (1.51 years according to Mann, 1984). Much organic nitrogen is found in the sediment which is frequently re-suspended by wave activity.

Generally TKN was highest during the fall and winter (Figure 9). The most plausible explanation for this is re-suspension of organic nitrogen in the sediment by wave action during this windy season. However, it is very difficult to explain seasonal changes in nitrogen since the proportions of the various forms are likely to vary in association with seasonal fluctuations in the populations of several types of bacteria, with variations in oxygen content and temperature, and with changing populations of plants and animals. The nitrogen cycle is a very complex and inconstant one. Without a total ecological study, one can only speculate about the cause and effect relationships.

Nitrate as Nitrogen - Nitrate is normally the most common form of inorganic nitrogen in lakes and streams. The concentration and rate of supply of nitrate is intimately connected with land use practices within the watershed. Nitrate ions move easily through soils and are rapidly lost from the land even in natural drainage systems.

Concentrations of nitrate range from undetectable levels to nearly 10 mg/1 in unpolluted fresh waters, but are highly variable seasonally and spatially (Wetzel, 1983). Reid (1961) stated that the world average nitrate level was 0.3 mg/1. Boyd (1979) compared nitrate concentrations in unfertilized woodland ponds with fed catfish ponds; nitrate averaged 0.075 mg/1 in the former and 0.25 mg/1 in the latter. Rulifson (1990) reported that nitrate in the lower Roanoke River averaged 0.17 mg/1. The EPA reference level for nitrate is 0.9 mg/1.

The annual mean concentrations of nitrate were: 0.06 mg/1 1986; 0.11 mg/1, 1987; 0.05 mg/1, 1988; and 0.10 mg/1, 1989 (Figure 10). These values indicate relatively unpolluted water and fall well below the EPA reference level.

The mean nitrate level for most months of this 45-month study was 0.05 mg/1 (Figure 11). There were district peaks in late winter-early spring of 1987 and 1989 and again in December, 1989. These peaks were probably caused by decrease in primary production during periods of cold water temperature and high turbidity. Since nitrate is rapidly taken up by aquatic plants (after conversion to ammonia), the increased phytoplankton activity during the warmer months would account for the lower level during these periods.

Nitrite as Nitrogen - Nitrite is the partially reduced form of nitrate. In unpolluted oxygenated waters, it is present in only trace amounts. Wetzel (1975) stated that the concentration in natural waters ranged from undetectable levels to 0.01 mg/1. The nitrite level increases in waters receiving contamination from organic matter. Heavily polluted streams can contain up to 2 mg/1 nitrite. Nitrite accumulates in the bottom sediments, especially under cold temperature and anoxic conditions. Levels as high as 1.0 mg/1 were found in the interstitial waters of deep sediments of Lake Mendota (Konrad, et al. 1970). Rulison (1990) reported that nitrite in the lower Roanoke River averaged 0.007 mg/1. The EPA reference level for nitrite is 0.9 mg/1.

The annual means for nitrite in Back Bay varied only from 0.01 to 0.02 mg/1 (Figure 12). Many of the individual station readings were below the minimum detectable level (0.01 mg/1). The highest reading was 0.5 mg/1, which was found at stations 5 and 9 in March, 1987. This relatively high concentration could be due to sewage discharge. Station 9 is in North Bay near the mouth of Hell Point Creek, which has received considerable organic pollution in the past. Station 5 is immediately downstream of a large campground and housing development which depend on septic tanks for sewage disposal. Although the nitrite annual means are well below the EPA reference level, there is reason for concern since the individual readings routinely exceeded the maximum for the "normal" range.

Nitrite levels were generally higher during the fall and winter (Figure 13). Explanations for this could be reduced phytoplankton uptake and resuspension of nitrite bound sediment. A third factor could be ground water inflow. Evapotranspiration in the Back Bay area is so great in the summer months that there is essentially no ground water discharge (Mann, 1984). Rather, ground water discharge commences in the fall as the temperature decreases. This discharge continues to the following summer. Nitrite is readily transported with ground water and released in lakes or streams. Therefore, one would expect the level to increase with groundwater discharge.

Total Ammonia - Ammonia is present in aquatic systems primarily as the dissociated ammonium ion. It is very rapidly taken up by phytoplankton and other aquatic plants and persists in small quantities because it is the major excretory product of aquatic animals.

The concentration of ammonia in unpolluted, surface waters is usually less than 1.0 mg/1. With reduced oxygen due to organic pollution, the level of ammonia will increase. In extreme cases the concentration can increase to 12 mg/1. Boyd (1979) found ammonia levels of 0.052 mg/1 in unfertilized woodland ponds and 0.5 mg/1 in fed catfish ponds. Ammonia in the lower Roanoke River averaged 0.1 mg/1 (Rulifson, 1990). The EPA reference level for ammonia is 0.89 mg/1.

The annual mean concentration of ammonia ranged from 0.1 to 0.3 mg/1 (Figure 14). Although these values are considerably below the EPA reference level and fall within the expected range, there is cause for concern. Stations 5 and 9 generally had the higher ammonia levels, reaching 0.8 mg/1. This indicates some organic pollution from those watersheds, as was noted for nitrite. Also, the concentration for several months exceeded the VWCB standard (0.02 mg/1) for Class II B waters.

The ratio of nitrate to ammonia is also of concern. In unpolluted, calcareous sedimentary land forms, the ratio is generally 25:1 (Wetzel, 1983). With slight to moderate sewage contamination or agricultural application of nitrogen fertilizer influence in a water, the nitrate to ammonia ratio can be 1:10. The ratios for Back Bay from 1986-89 ranged 1:1 to 1:3. These ratios indicate some organic pollution in the bay.

Ammonia was highest each year during the winter and generally the lowest during the spring and summer (Figure 15). This seasonal trend with peak levels during the cold months was unexpected. Normally ammonia is higher in the summer than in the winter. Since ammonia is an end product of the bacterial decomposition of organic matter and an excretory product of aquatic animals, the concentration is generally higher during the warmer months as these activities are going on at an accelerated pace. However, the reverse was observed during this study period. A plausible explanation for the considerably higher ammonia concentration during the winter could be declined phytoplankton abundance, which allowed the ammonia to increase both through bacterial decomposition of the algal cells and reduced plankton assimilation.

Acknowledgments

We sincerely thank Richard Eades for his constructive editorial comments and assistance in computer graphics.

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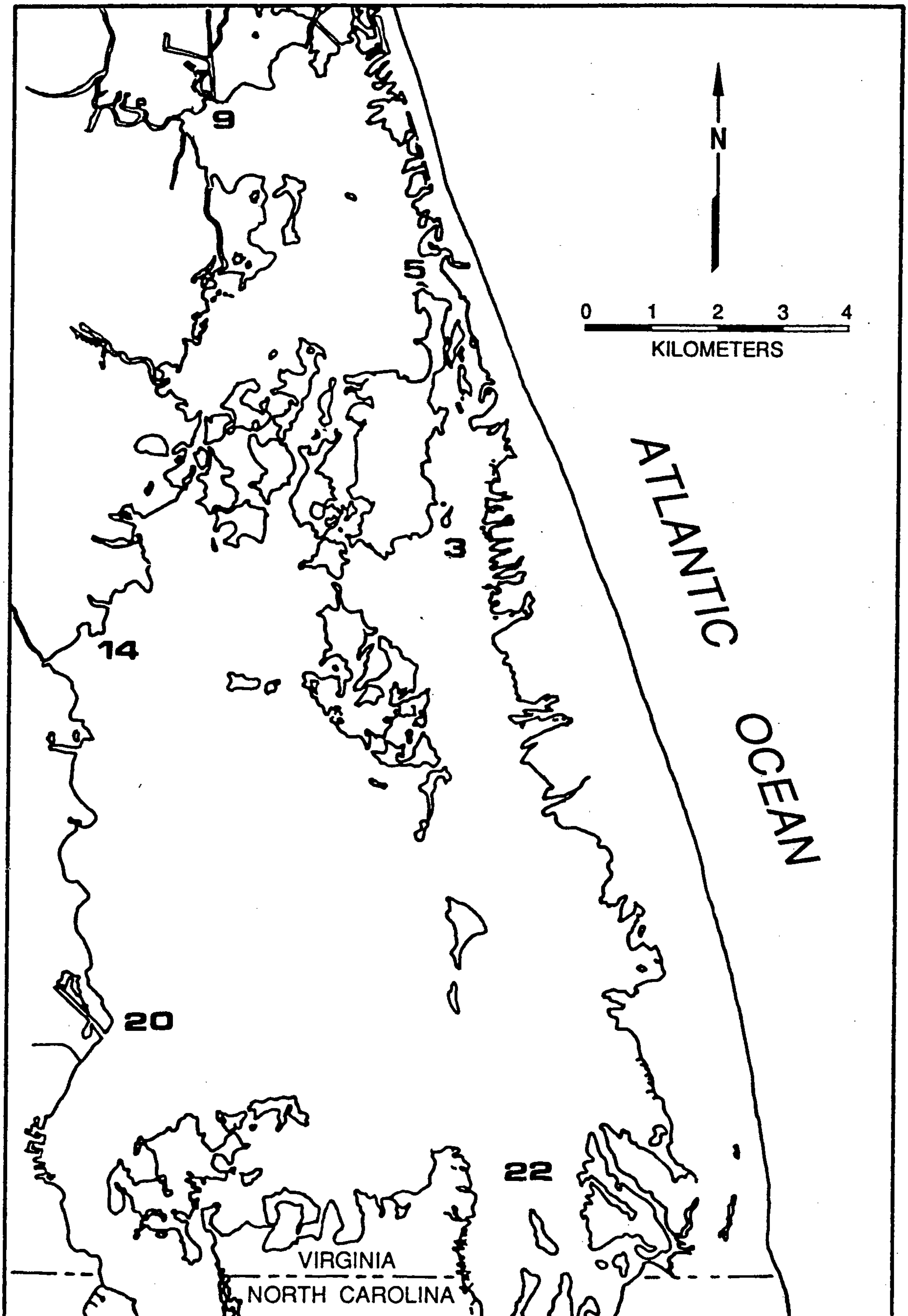

Figure 1. Map of Back Bay showing the location of nutrient sampling stations, April, 1986 - December, 1989.

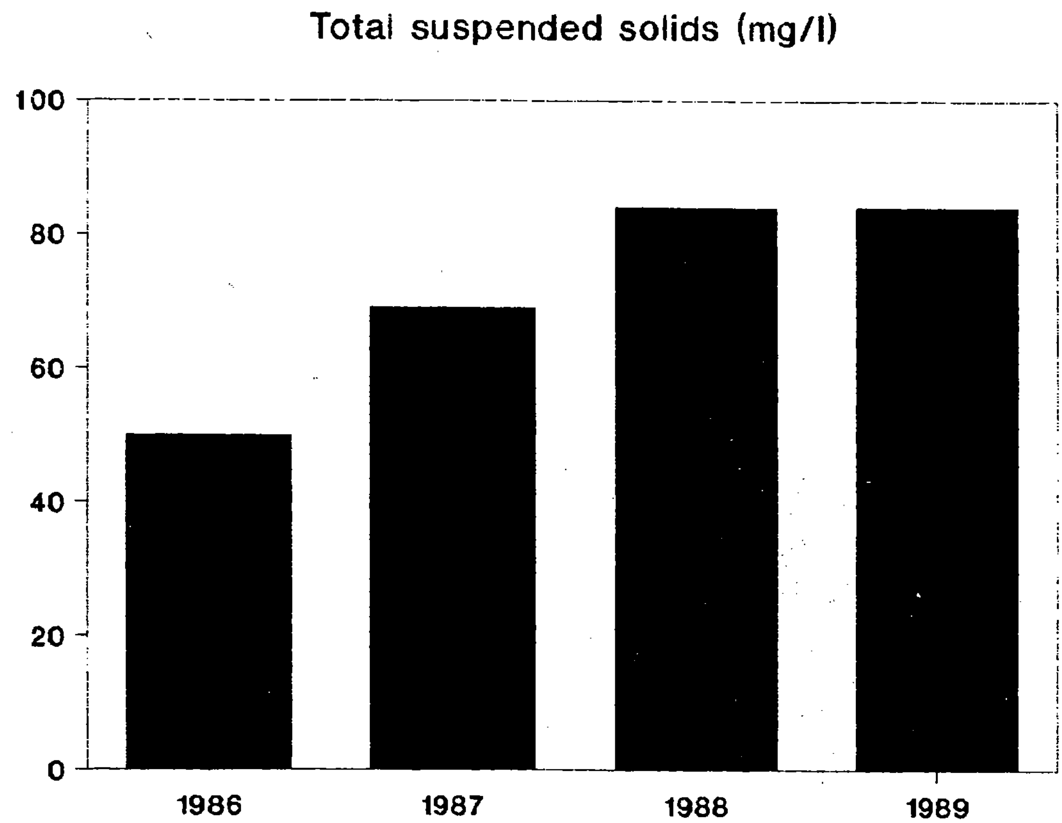

Figure 2. Annual mean concentration (mg/1) of total suspended solids in Back Bay, 1986-1989.

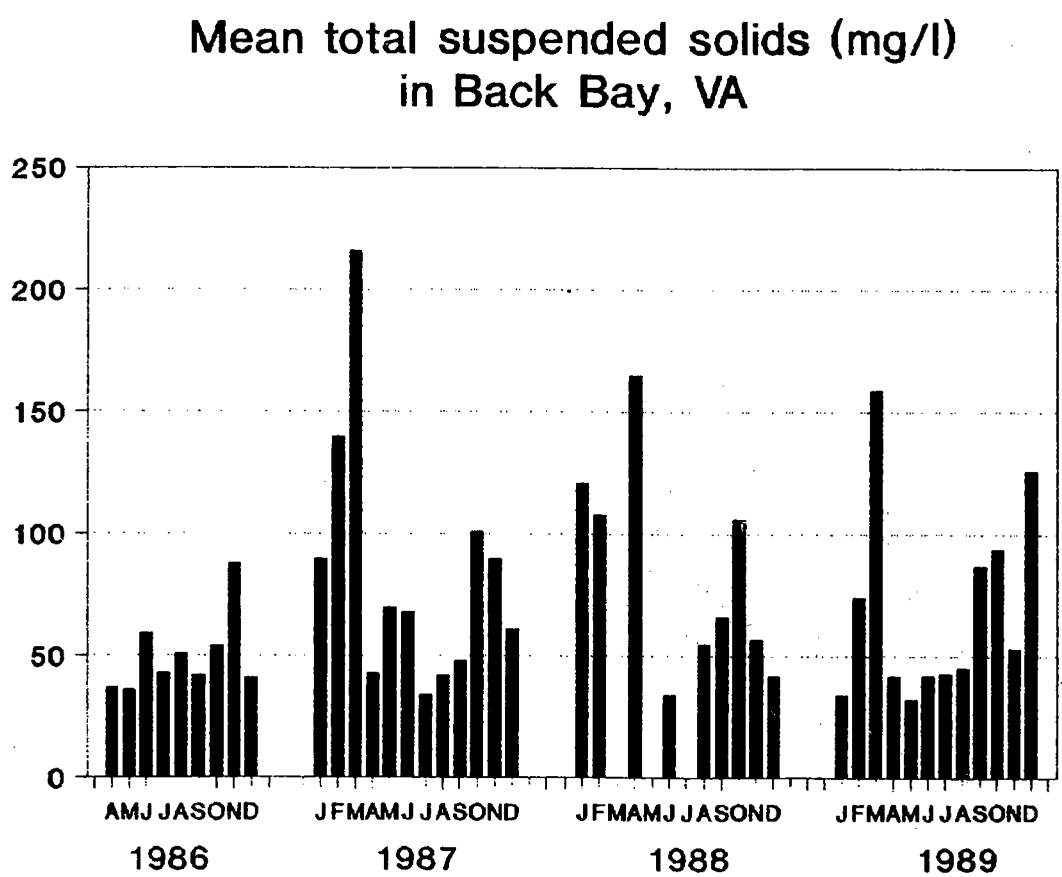

Figure 3. Monthly mean concentration (mg/1) of total suspended solids in Back Bay, 1986-1989.

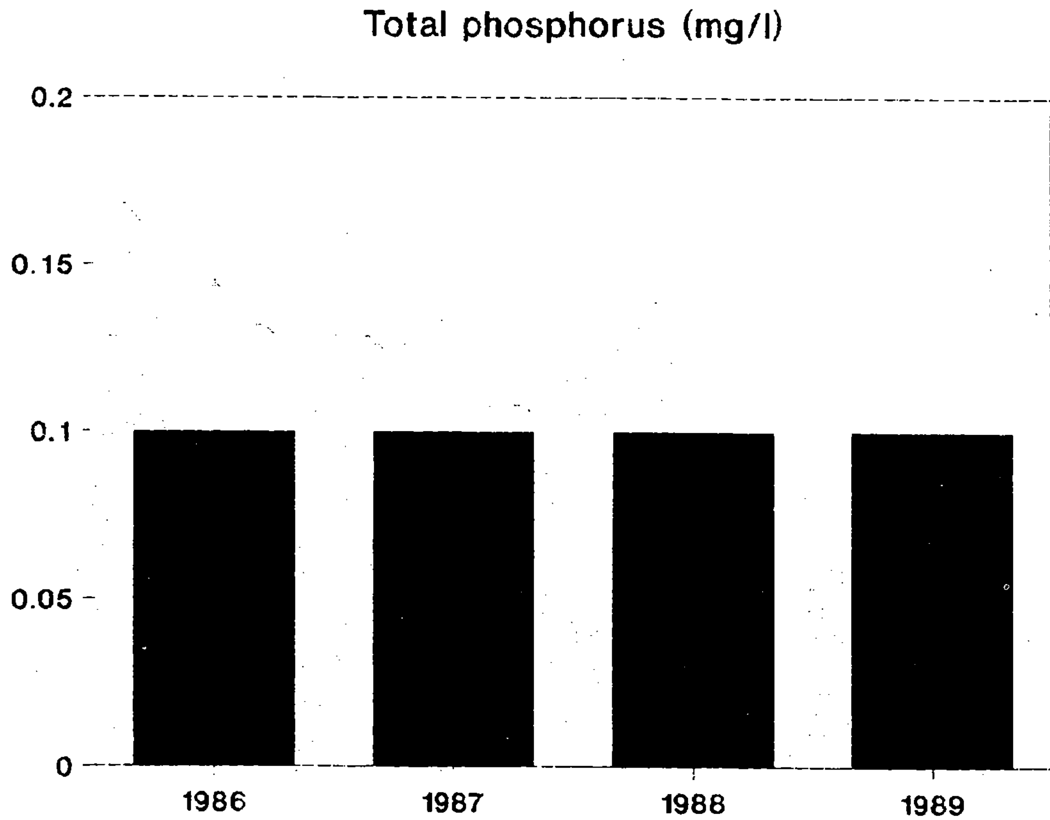

Figure 4. Annual mean concentration (mg/1) of total phosphorus in Back Bay, 1986-1989.

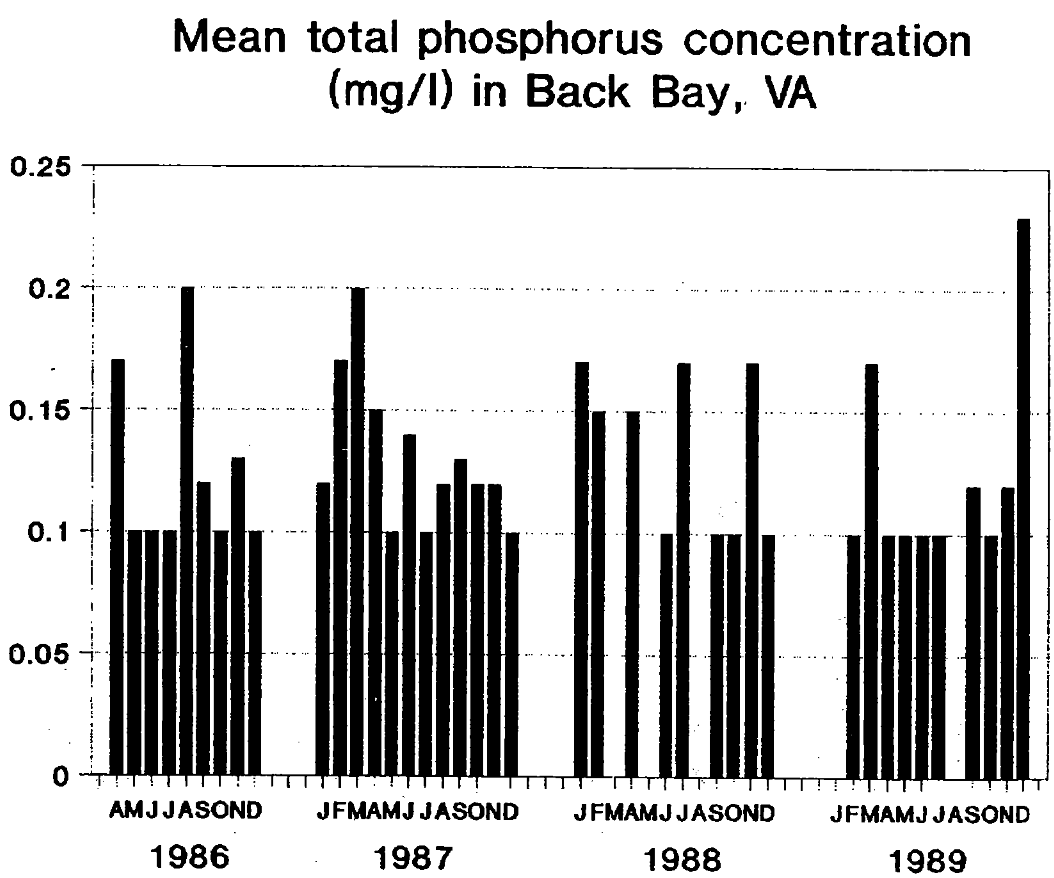

Figure 5. Monthly mean concentration (mg/1) of total phosphorus in Back Bay, 1986-1989.

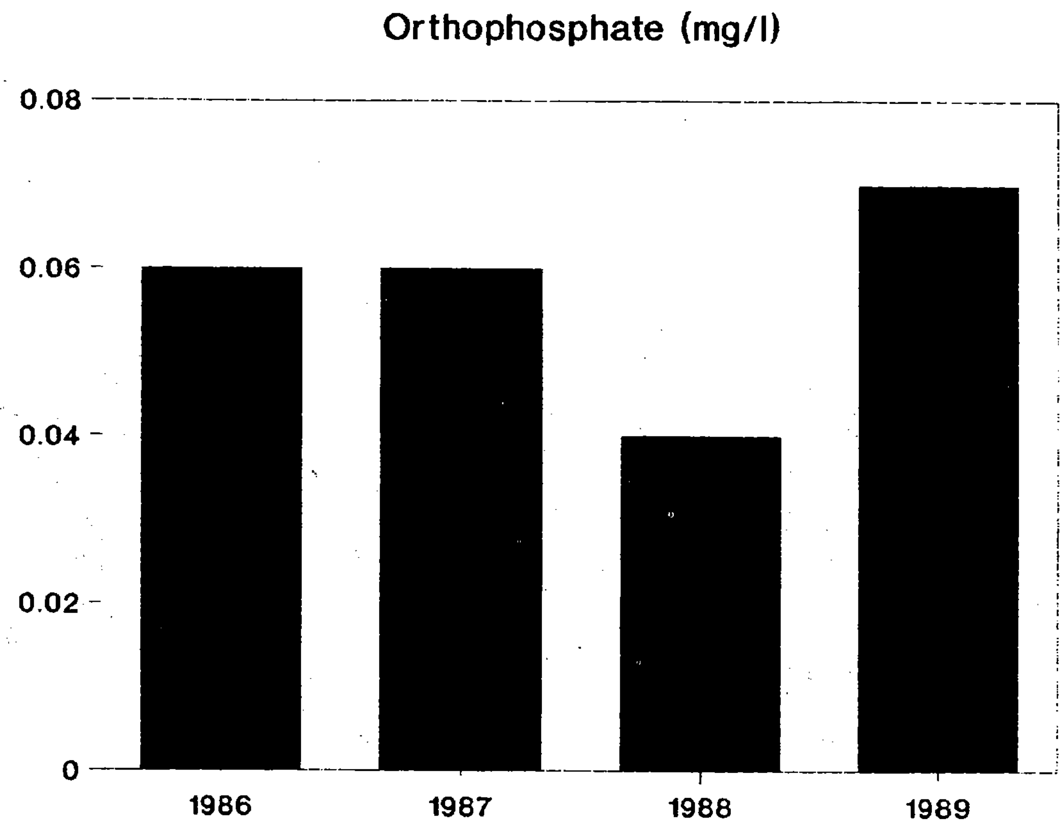

Figure 6. Annual mean concentration (mg/1) of total ortho phosphorus in Back Bay, 1986-1989.

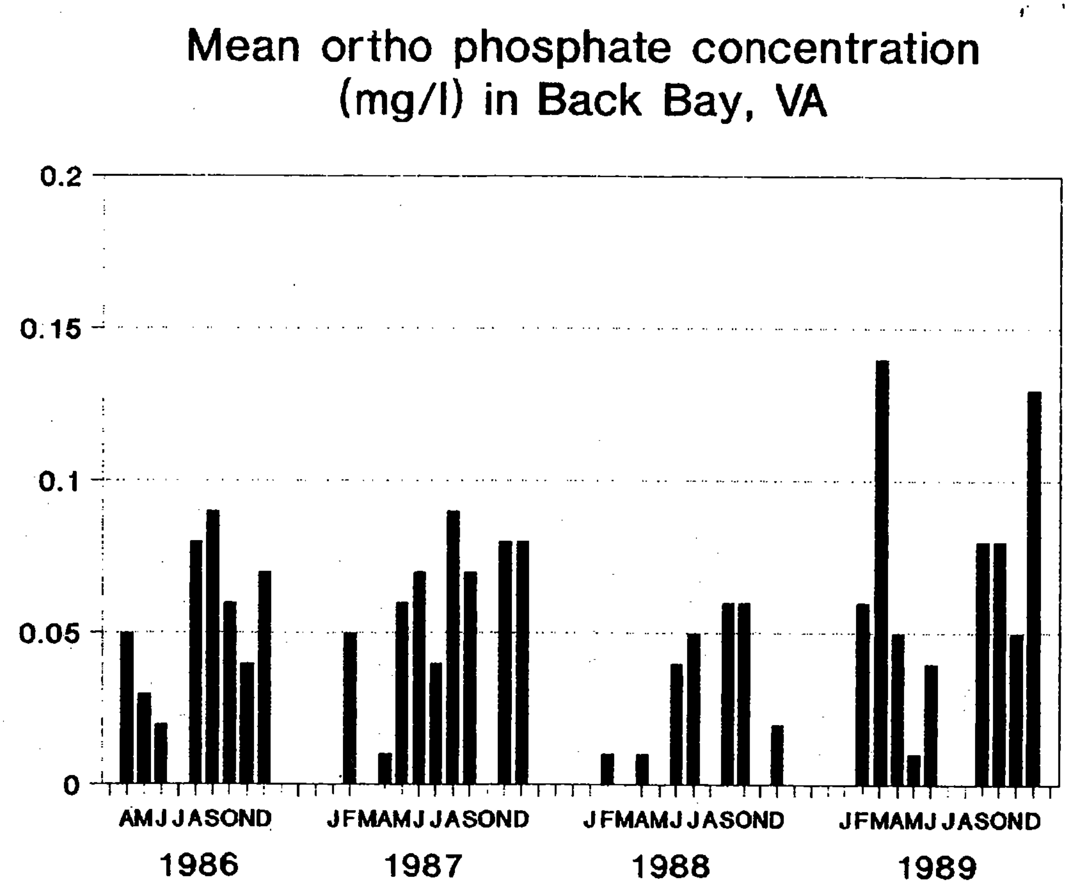

Figure 7. Monthly mean concentration (mg/1) of total ortho phosphorus in Back Bay, 1986-1989.

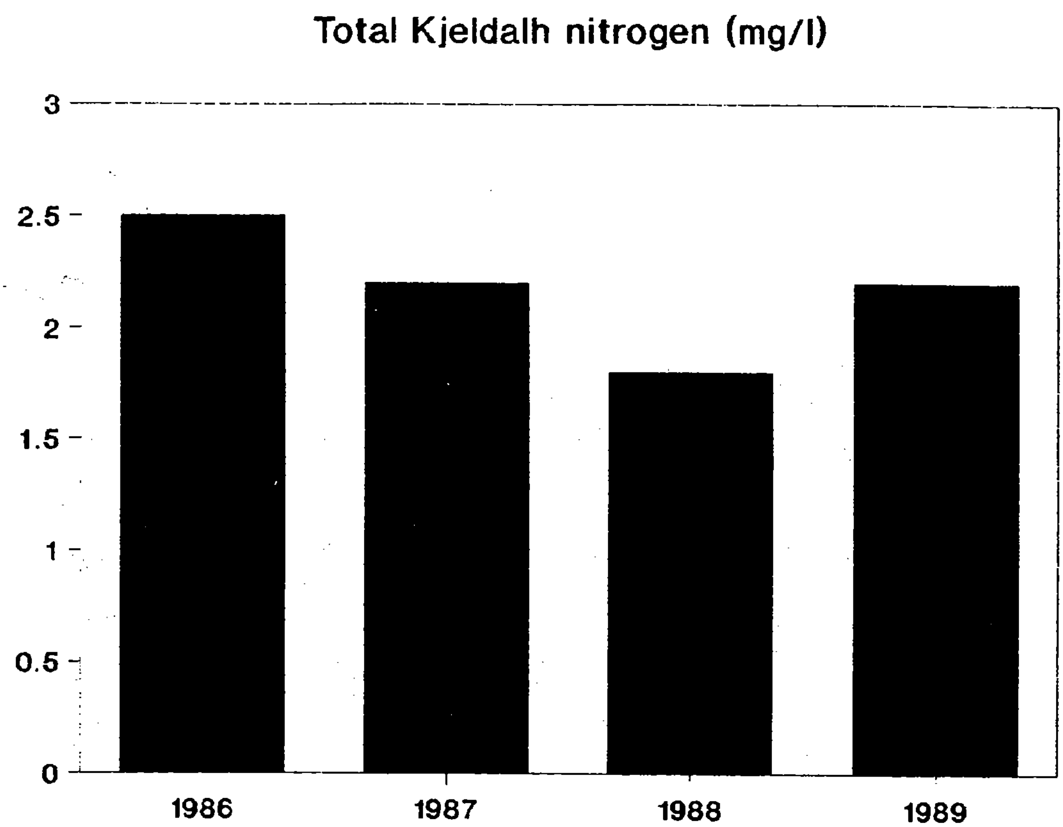

Figure 8. Annual mean concentration (mg/1) of total Kjeldalh nitrogen in Back Bay, 1986-1989.

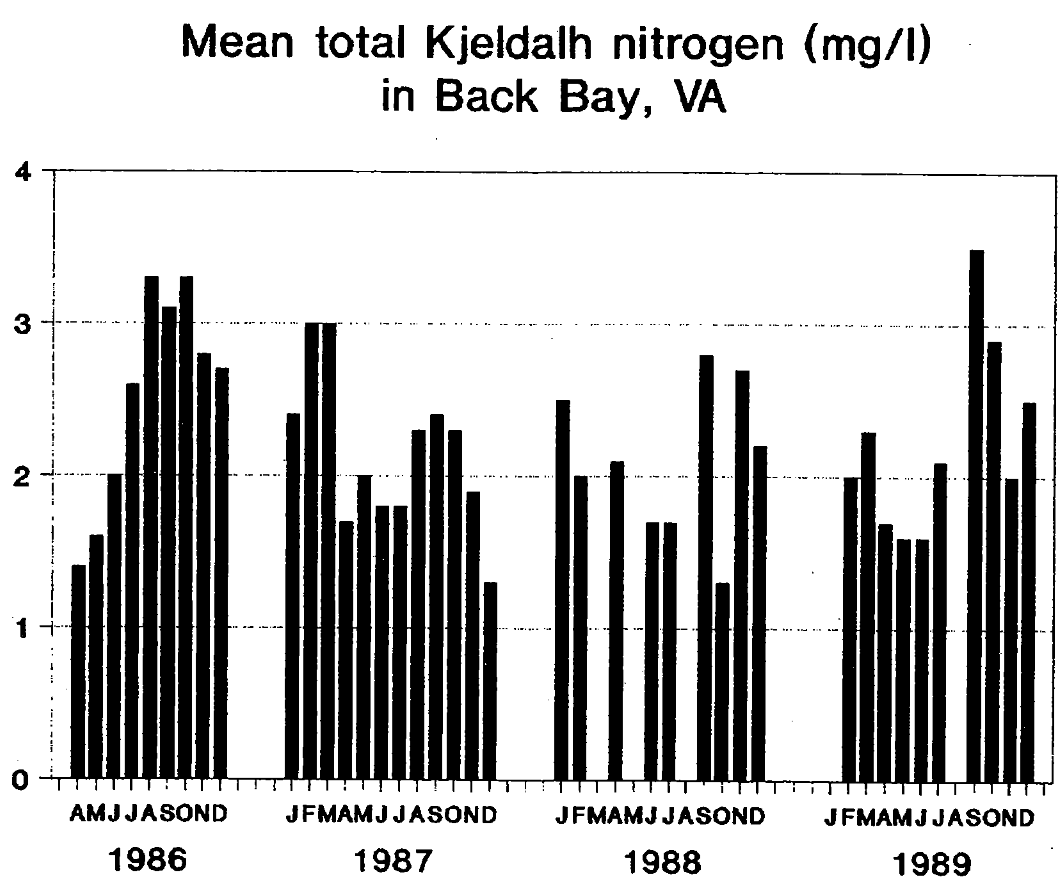

Figure 9. Monthly mean concentration (mg/1) of total Kjeldalh nitrogen in Back Bay, 1986-1989.

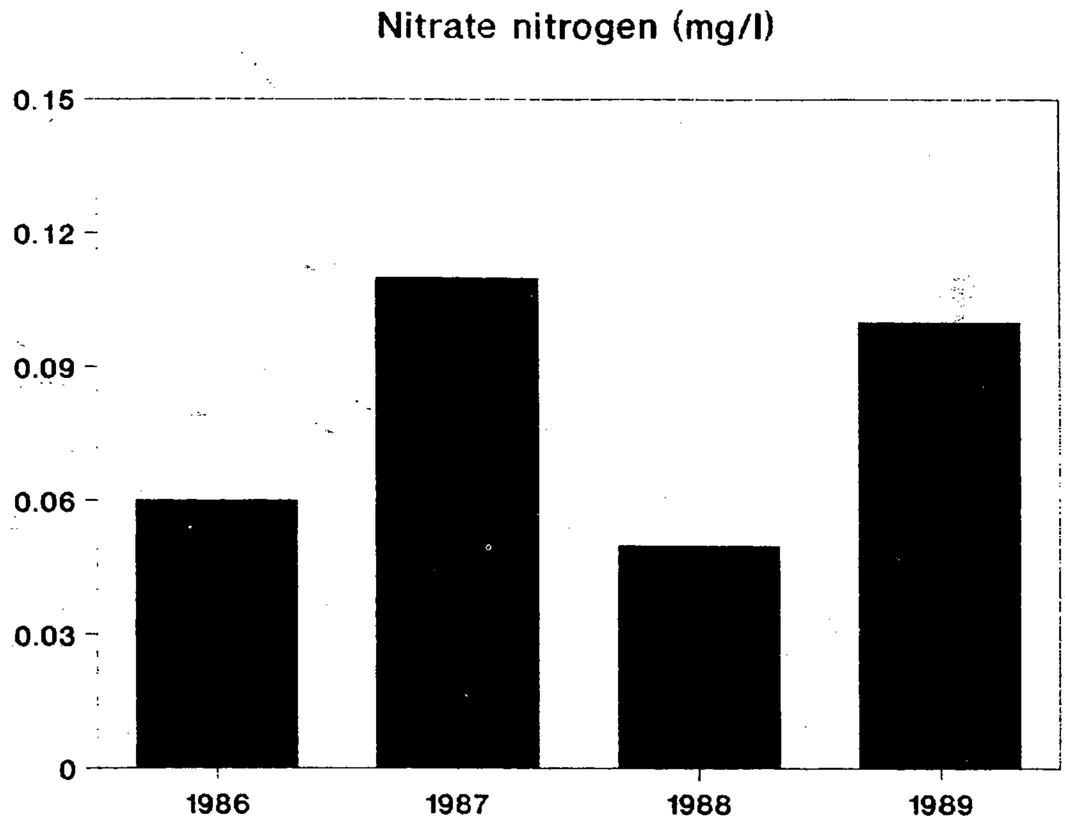

Figure 10. Annual mean concentration (mg/1) of total nitrate nitrogen in Back Bay, 1986-1989.

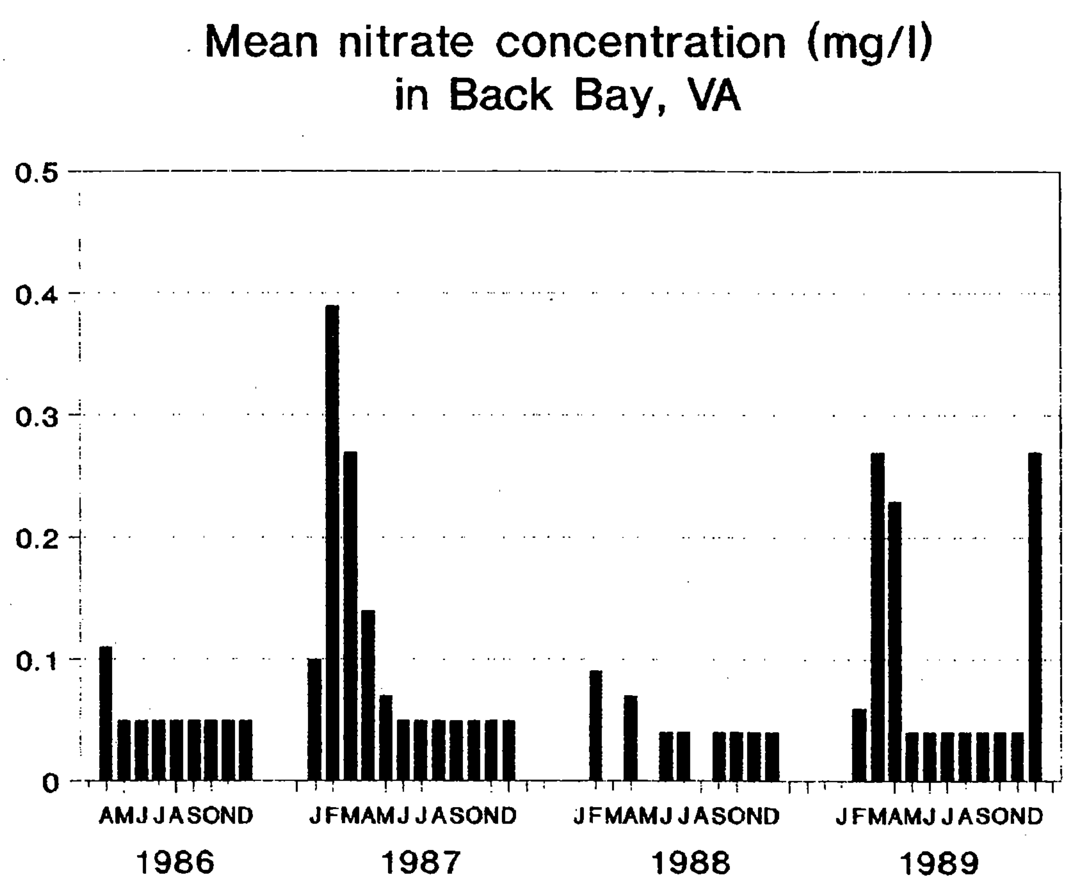

Figure 11. Monthly mean concentration (mg/1) of total nitrate nitrogen in Back Bay, 1986-1989.

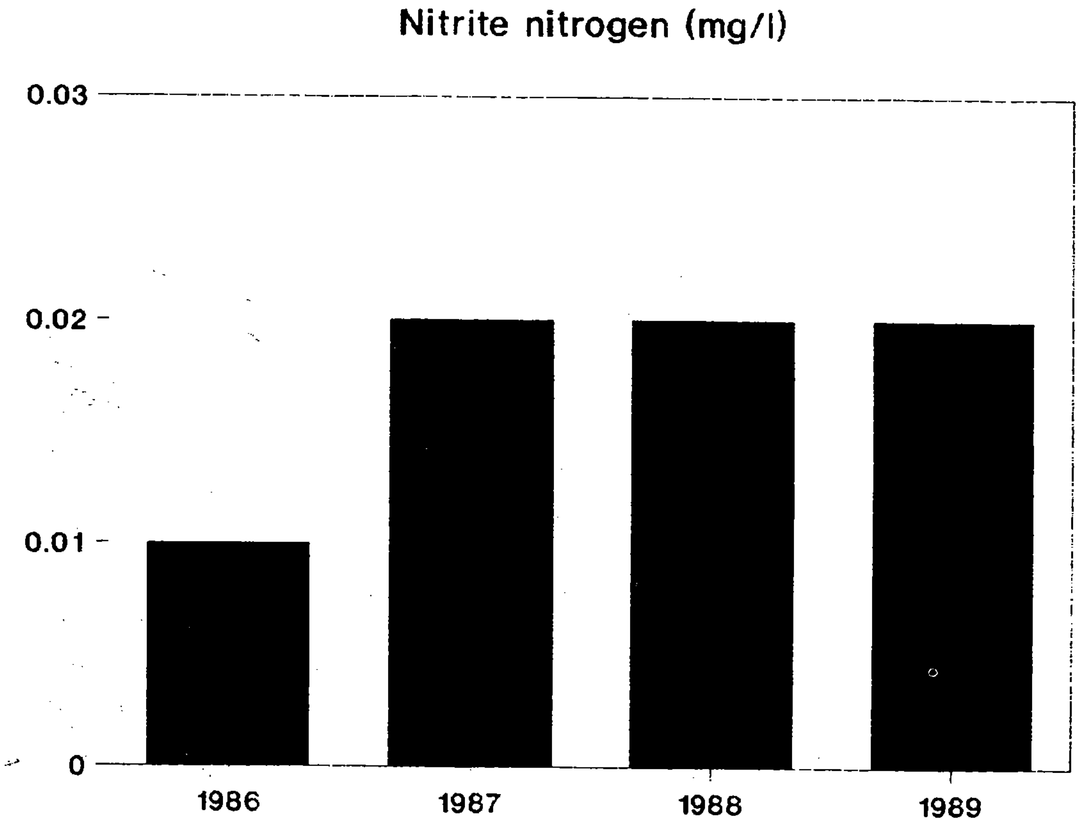

Figure 12. Annual mean concentration (mg/1) of total nitrite nitrogen in Back Bay, 1986-1989.

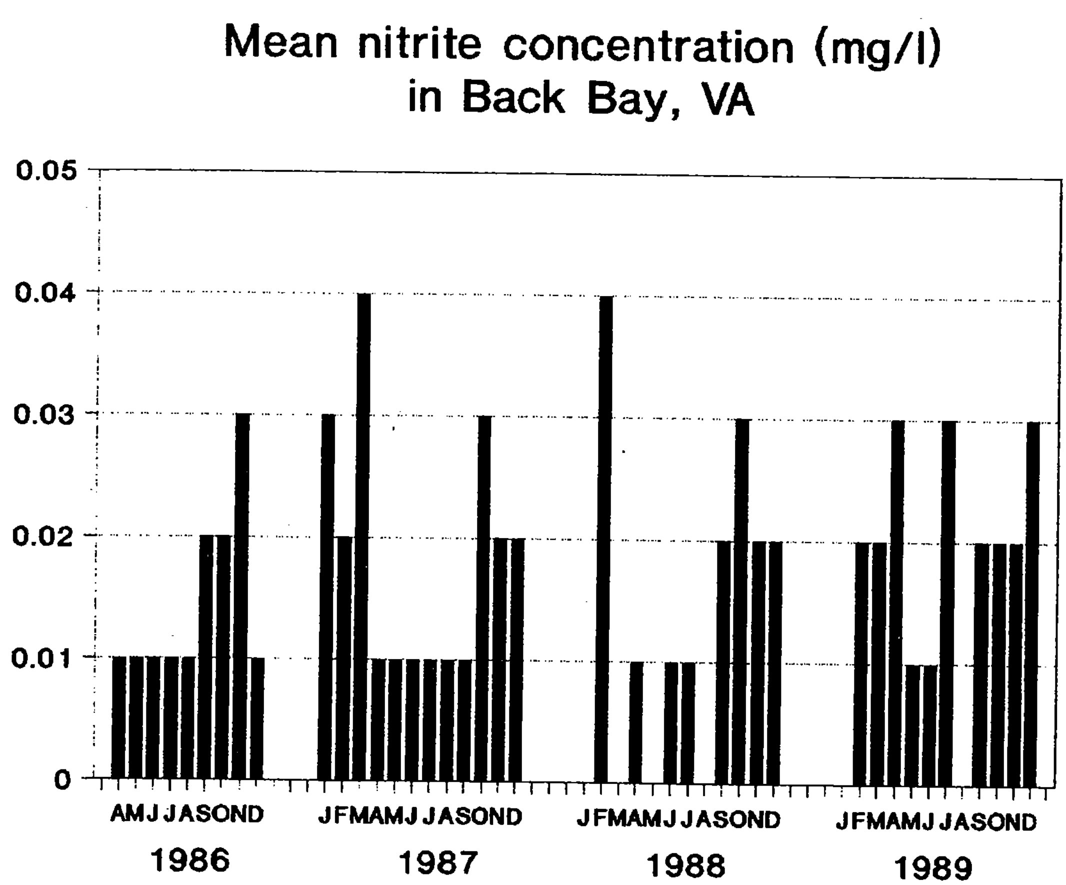

Figure 13. Monthly mean concentration (mg/1) of total nitrite nitrogen in Back Bay, 1986-1989.

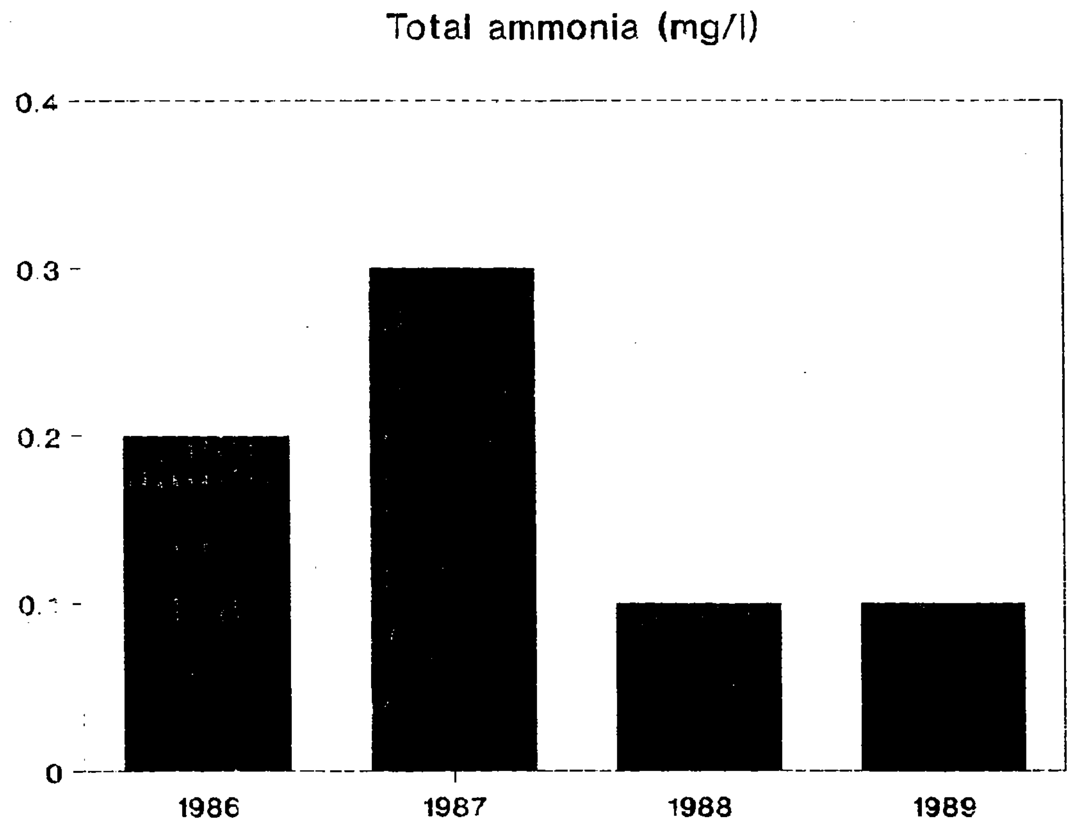

Figure 14. Annual mean concentration (mg/1) of total amonia nitrogen in Back Bay, 1986-1989.

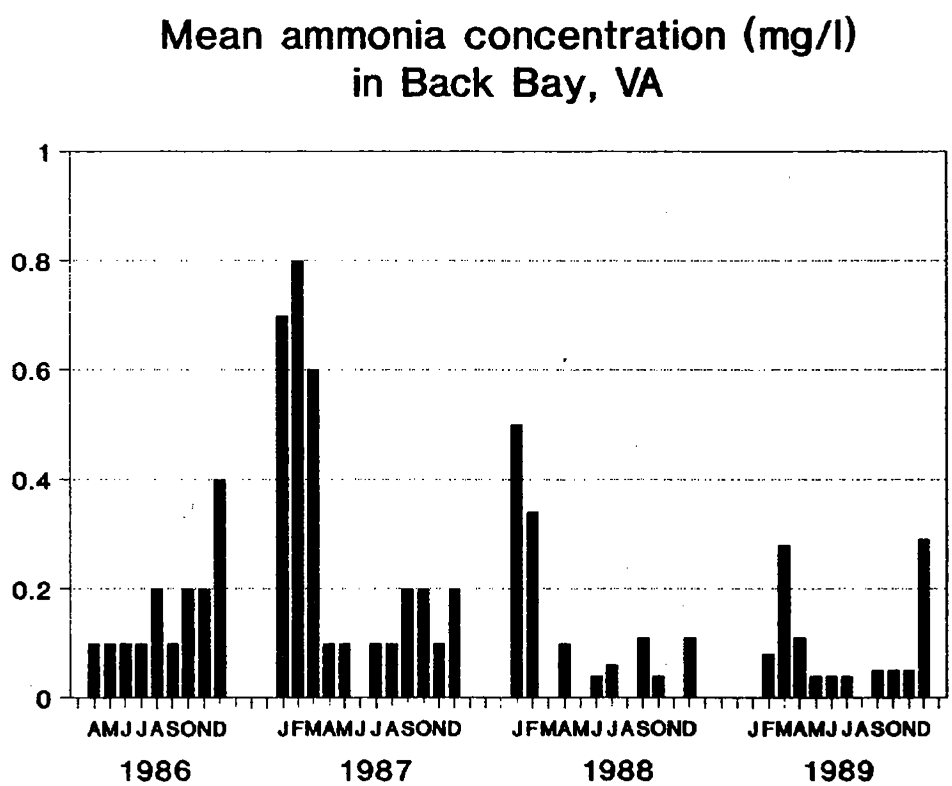

Figure 15. Monthly mean concentration (mg/1) of total amonia nitrogen in Back Bay, 1986-1989.

Rates of Sediment Accumulation, Bioturbation and Resuspension in Back Bay, Virginia, a Coastal Lagoon

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Abstract: Back Bay is the northernmost section of the Albemarle-Pamlico lagoon-estuary system. Back Bay lagoon and its associated barrier (Currituck Spit) are moving landward in response to post-glacial sea level rise (2.6 mm yr^{-1}). The long term (100 year time scale) landward migration rate of Currituck Spit may be on the order of a meter per year.

Sediment accumulation, resuspension and bioturbation are processes in Back Bay that control the residence time of organic matter in the bay floor. and therefore, effect the rate of nutrient release. As burial proceeds, nutrients in the zone of mixing may be remineralized and recycled back to to water column, or may pass downwards into the zone of permanent burial.

X-radiographs indicate that Back Bay sediments are bioturbated by the community of insect larvae, polychaetes and oligochaetes that constitute the benthic infauna of this oligohaline water body. However, analysis of wind records suggests that in some respects, wave resuspension is a more important mixing process. Under mild to moderate conditions, waves in the bay are fetch limited. However, under hurricane conditions the bay surface saturates with breaking waves before peak winds are attained. For a 6 km fetch (a typical long fetch for the Bay), the resuspension threshold is 6 ms^{-1} (13.5 knots). This value is exceeded 35.7 percent of the time, and sediment is resuspended in about 40 events in a year. Radiogeochemical analyses suggest that long term (100 yr) accumulation rates are of the order of 2-3 mm yr^{-1}.

The Bay is floored by mud (silt and clay), with an admixture of sand. Sediment introduction probably occurs largely as a result of 'wind pumping'. During winter storms, strong southerly winds set down southern Back Bay, and drive turbid water from Currituck Sound through the Knotts Island Passage. As the storm progresses, the wind shifts to the north and northwest, sets up lower Back Bay against the Knotts Island Passage, and flushes sediment and water back into Currituck Sound.

In this model, Back Bay is a sediment-accumulating sink. The shallow (1-2 m) floor of Back Bay is controlled by an equilibrium between the rate of sediment supply and mean annual wave power. Concentration profiles of ^{210}Pb and ^{137}Cs measured in 1984 indicate that the short term (30 year) accumulation rate was then twice that of sea level rise. The period of record corresponds with Eurasian Milfoil invasion. The historically dense growth of this plant would have modified the equilibrium by damping wave currents, accelerating the sedimentation rate and shifting the Bay floor to a shallower equilibrium depth. The Bay floor appears to presently be undergoing a reduced rate of sedimentation with some local erosion, perhaps in conjunction with a return to an earlier regime.

Introduction

Physical Setting. Back Bay is the oligohaline northernmost portion of the Albemarle-Pamlico estuarine system (Fig. 1). It differs from the larger lagoons and estuaries to the south in its shallow depths, low salinities and susceptibility to wind tides. The average depth is 1.1 m. Time-averaged salinities measured during a 1983 study ranged from 5 to 21 ‰ (Anonymous, 1984). At this time, salt water was being pumped into the Bay in order to improve water clarity. Since the pumping of salt water has ceased, salinity has dropped to less than 2.0 ‰. Astronomical tides are negligible in the Bay ($<$ 8 cm). Wind tides up to 1m amplitude, accompanied by resuspension of bottom sediment, occur throughout the winter period of frequent storms. More intense resuspension events, associated with extreme northeaster storms and hurricanes, occur at somewhat longer recurrence intervals.

The present physical state of Bay must be understood in terms of processes occurring at long time scales. The barrier-estuary-lagoon system of the North Carolina—Virgina Coast has shifted some 200 km across what is now continental shelf, since the beginning of post glacial sea level rise, at 18,000 years ago (Niedoroda et al., 1985). Back Bay lagoon and its associated barrier (Currituck Spit) are presently moving landward in response to a sea level rise rate of 2.6 mm yr^{-1} (Nichols et al., 1989). The consequent long-term (100 yr time scale) landward migration rate of the Currituck Spit-Back Bay system may be on the order of a meter per year. (Swift et al., 1972). Migration of Currituck spit is accomplished by storm erosion of the barrier face (an annual to decadal process), by storm washover of sand (a decadal process) and by inlet breaching (at intervals greater than a century) The mainland coast of the lagoon migrates landward by extension of marsh over the subaerial surface in response to sea level rise, and by storm wave erosion of the marsh face (annual processes).

Management problem. Back Bay is relatively pristine portion of the Albemarle-Pamlico estuarine system. Nevertheless, it has experienced a series of environmental problems associated with sport fisheries and wildlife management. The bass fishery and waterfowl populations have declined through a period which saw the advent and cessation of salt water pumping, and also the accidental introduction, proliferation, and abrupt decline of non-native aquatic vegetation (Eurasian Milfoil). Salinity, water clarity, and primary productivity changes are implicated in these events, but their roles are not well understood (Anonymous, 1984). In this paper, we examine the sedimentation history of the lagoon floor, and compute sediment resuspension frequencies and accumulation rates, in order to better understand physical processes controlling water clarity and nutrient cycling in Back Bay.

The Physical Problem. Sediment resuspension and accumulation are aspects of the Back Bay ecosystem which need to be better resolved for environmental management purposes. Sediment resuspension by wind events effects the ecosystem directly, by decreasing the amount of light available for photosynthesis, and indirectly, by controlling the release of regenerated nutrients from the bottom to the water column. The cycling of nutrients controls the trophic state of the bay and resuspension, together with accumulation and bioturbation determine the dynamics of the nutrient cycle.

Nittrouer and Sternberg (1981) describe the uppermost portion of the seabed as a zone of temporary storage, characterized by resuspension and mixing. The zone of storage is underlain in turn by a zone of permanent burial (Fig. 2). These zones move upward with the aggrading water-sediment interface, so that a sediment particle passes first through the zone of storage, and finally into the zone of permanent burial. From the geological point of view, the zone of storage and mixing is important as the zone in which the stratal record is formed. In geological terms, sequence of storm-created strata (beds) is a signal impressed on the sediment as it passes downwards through the zone of mixing. The zone of mixing is thus the 'recording head' for the unreeling tape of the stratigraphic record, as it accumulates in the zone of permanent burial (Fig. 2).

From the ecological point of view, the zone of mixing in the lagoonal floor is a critical "valve" or regulating mechanism in the nutrient cycle. The schematic diagram in Fig. 3. illustrates the processes that we believe to be most important in explaining nutrient cycling in Back Bay. Rates of primary productivity by both salt marsh plants (Morris, 1987; Priest, 1991) and phytoplankton in the Bay water column (Marshall, 1991) are high. These rates, plus high rates of nutrient regeneration in the shallow lagoonal (Nixon, 1987; in press), will lead to rapid nutrient cycling through the bay system.

The zone of mixing regulates the nutrient cycle by controlling the rate of remineralization. As burial proceeds, nutrients must either be remineralized from organic matter and released back to the water column, or pass downwards into the zone of permanent burial. Thus the rate of nutrient release is a function of the residence time of organic matter in the mixed layer, and therefore of the sediment accumulation rate. Our goal in this study is therefore to examine biogenic mixing intensities, compute resuspension frequencies and intensities, and measure the accumulation rate.

Sediment Types, the Benthic Community, and Biogenic Mixing

The Bay is floored by sand, and by mud (silt and clay), with an admixture of sand (Fig. 4). Sediment types vary continuously across the Bay floor, but have been divided for convenience in Fig. 4 into three facies, a sand facies, a silt facies and a mud facies. The bottom is sandiest on the ocean side, indicating that the sand comes from storm washover across Currituck Spit. The mud source is problematic. Supply from the main lagoonal system is limited because the lower Bay is blocked off by Knotts Island from Currituck Sound. The bay's subaerial drainage area is extremely small, and has historically provided even less sediment, although construction activity may be beginning to change this pattern (personal communication, Yates Barber, North Carolina fish and wildlife service).

X-ray radiographs from cores of Back Bay reveal heavily bioturbated bottom sediment. Cores are structureless, or, near the sandy ocean side, weakly laminated. Studies by Lane and Dauer (1991) indicate that in terms of biomass, the dominant macrobenthic species (71.1 %) in the muddy facies is the larval stage of the insect *Chironomus riparius*, distantly followed by the spionid polychaete *Scolecolepides viridis* (8.5%) and several oligochaete species. No information is available concerning the bioturbation efficiency of *Chironomus riparius*, but it is apparently high enough to erase stratification induced by resuspension events

In the Silty facies (Lane and Dauer's 'mixed group'), *Chironomus riparius*, and *Scolecolepides viridis* are subequal contributors to biomass, and in the sandy facies, the abundances by biomass are the reverse of those of the muddy facies.; *Scolecolepides viridis* constitutes 69.9 percent of the biomass, while *Chironomus riparius* constitutes 6.8 percent. *Scolecolepides viridis* is reported by Rhoads (1967) from Barnstaple Harbor, MA, as being a weak bioturbator; the extensive bioturbation observed in the X-ray radiographs is due to the large numbers of individuals present. Myers (1977) reports that the related *Scoloplos robustus* burrows to 13 cm in Narragansett Bay.

Storm Resuspension of Bottom Sediment

The bottom sediment of Back Bay is easily resuspended. In July 1987, total suspended solids ranged from 27 to 64 mg 1^{-1}, with 30 to 80% of the suspended material consisting of organic matter. Chlorophyll-a concentrations ranged from 43 to 71 g 1^{-1} (Carter and Rybicki,1991). In April, 1988 during a period of strong winds, total suspended solids increased to 78 to 214 mg 1^{-1} versus 20 to 30 % organic carbon and 34 to 88 mg 1^{-1} Chlorophyll-a (Carter and Rybicki,1991).

Winds in the region are most commonly from the northeast in the winter, and from the south in the summer (Fig. 5, Table I). Strongest winds are north and southeast winds associated with winter frontal passages (personal communication, National Weather Service, Norfolk, VA). The intensity of wave resuspension of the bottom in response to a given wind strength at a point on the Bay floor is controlled by the maximum value, u_{max}, of wave orbital velocity on the bottom. Wave orbital velocity on the bottom is directly proportional to fetch, and inversely proportional to water depth.

In order to understand wave resuspension on the Bay, it is necessary to determine which of these two controls is the most important. As wave height reaches 78 percent of water depth, waves break. The issue therefore becomes: as wind speed increases, does wave height increase until the entire Bay is a breaker zone? A further increase in wind speed would then have no further effect on wave orbital velocity, and waves on the Bay would be depth-limited. Or does the limited fetch prevent such saturation of the Bay surface by wind waves from occurring? The Bay would then be fetch-limited.

The Bay is very shallow (1-2 m deep), but fetches are short. Even a north wind, aligned with the Bay axis, has a maximum unbroken fetch of only 10 km. Wave tables (U.S. Army Corps of Engineers, 1984) indicate that for an average north wind (11 knots or 5 m s^{-1}), waves can build to heights of half a meter near the south end of the Bay. However, they will not break until their height is approximately 78 percent of their depth, so for average north winds, waves on the the Bay is fetch-limited, not depth-limited. For a moderate north wind, breaking occurs only a narrow nearshore surf zone, along the southern sides and south end of the Bay.

This pattern continues for north winds of increasing strength. Figs. 6a and 6b present the fetch lanes, wave heights and surf zone widths for a north wind of 15 ms^{-1} (30 knots) and 26 ms^{-1} (50 knots). The computations show that the Bay is fetch-limited for north winds up to about 50 knots. Beyond 50 knots, the breaker zone (stippled area, Fig. 6b) expands rapidly. For such intense north winds, the Bay surface is saturated with wave energy before hurricane conditions are reached, and the waves become depth-limited.

The wind direction, intensity, and frequency data of Table I can be applied to stations in Back Bay, in order to estimate wave height frequencies. Note that frequencies in Table I and all subsequent tables are presented as percentages. As a first step, wave heights can be determined for each wind speed class, for each of the 16 compass directions of Fig. 5 by means of the shallow water wave tables (U.S. Army Corps of Engineers, 1984). They can then be associated with the appropriate frequency (Table II).

The frequencies of Table II form an irregular band across the middle of the page, with blank zones above and below. For many directions in Table II, no frequencies are reported for the lower wave height classes (upper side of the band). These are cases of longer fetch, where the lowest wind class can produce higher wave heights.

The lower blank zone is present for a different reason. In each wind direction of Table II, the array of decreasing probabilities terminates at the wave height produced by the strongest wind class for which a frequency is available. The values range from .21 to .25 meters. Stronger winds and higher waves occur but for most of the directions, the binning of Table 1 is too coarse to catch these less frequent events.

The wave height frequency data of Table II can in turn be used to compute into the frequency with which the bottom is resuspended to a given depth, by means of the algorithm described by Niedoroda et al.(1989). The algorithm is based on the complex behavior of the near-bottom fluid boundary layer (zone of flow retarded by frictional interaction with the bottom) during wind events. During such events, wave orbital currents stir the bottom. At the same time, wind stress sets the entire water mass into motion, so the Bay floor is subjected to a velocity field that includes both a high-frequency wave component and a mean flow component. The mean flow boundary layer grows slowly as the mean flow develops, to an eventual thickness of a meter or more. However, as waves pass over the bottom, a wave boundary layer must form at the base of the mean flow boundary layer every few seconds. Since it forms then decays rapidly, it can never be more than a few centimeters thick.

Sediment entrainment in such a flow field is directly proportional to the shear stress exerted by the flow on the Bay floor. The wave and mean flow components of the stress, however, are not additive, but rather are multiplicative The mean flow boundary layer sees the the wave boundary layer at its base as an added roughness element (Grant and Madsen, 1979), As a result, the bottom shear stress exerted on the bottom by the combined-flow boundary layer is markedly greater than the sum of the wave stress and mean flow stresses that would occur if each existed in isolation. Shear stresses exerted by a combined flow boundary layer were computed by the Niedoroda algorithm to determine to resuspension depths presented in Table III.

If sufficient wind frequency data is available, it is possible to codify it as an extreme event distribution (Gumbel distribution, Ward et al., 1978). It would be then possible to prepare a plot of resuspension depth versus frequency for Back Bay. However, as noted, the data in Table I does not have the necessary resolution of low frequency events. In order to prepare a Gumbel distribution, it would be necessary to examine the 24 year data set of wind observations on which Fig. 7 is based. The data would have to be reprocessed in such a way as to recapture the 'lost' low frequency data.

Such an analysis is beyond the scope of this paper. It is possible, however, use the data of Table I to place limits of the frequency and intensity of sediment resuspension. In Table III, Some resuspension depths have been computed for a 6 km fetch at station BBI (see Fig. 1 for location). Resuspension appears as the wind speed exceeds 6.01 m s^{-1} (13.5 knots). The resuspension depth changes little as the wind increases through moderates speeds, but increases abruptly above 30 knots. Winds of 64 and 78 knot resuspend 2 to 3 cm of sediment. Above these speeds, the Bay becomes depth-limited, hence greater resuspension depths will not occur.

Table I indicates that the resuspension threshold for this particular data set, 13.5 knots, is exceeded 35.7 percent of the time, or 3127 hours per year. Wind events at Back Bay are associated with the passage of mid-latitude low pressure systems. They are also associated with the much less frequent hurricanes. These more intense storms can have no greater effect, since, as noted, the Bay surface becomes saturated with breaking waves before the peak winds occur.

If a typical wind event is assumed to last 72 hours, then our calculations show that 43 such events can occur per year, or about 4 per month. In fact, weather systems cross Back Bay more frequently (every 4 to 7 days) in the winter, and less frequently in the summer, when the Bermuda high sets in.

Radiogeochemical Measurements of Sediment Accumulation Rates

Radionuclides such as ^{210}Pb and ^{137}Cs are useful for determining sediment mixing and accumulation rates because their input function may be precisely defined. ^{210}Pb has a half life of 22,3 years. It is a naturally occurring radionuclide that has been used extensively for reconstructing the history of shallow marine deposits at 100 year time scales (Koide et al., 1972). It is a daughter product of the ^{238}U decay series, generated by cosmic rays. Its precursor, ^{222}Rn is a short lived noble gas with a half life of 3.8 days, that is continuously released to the atmosphere from the lithosphere. Atmospheric ^{222}Rn decays to ^{210}Pb, which is removed from the atmosphere primarily by wet deposition. This atmospheric source is the dominant source of ^{210}Pb in shallow coastal lagoons (Benninger, 1978). Once ^{210}Pb enters the water column, it tends to associate with the particulate phase, and thus becomes a tracer with which to define sedimentary processes.

^{137}Cs, on the other hand, is an artificial radionuclide with a half life of 34.1 years. It enters the aquatic environment primarily via global fallout as a product of atmospheric tests of nuclear weapons. although it may locally be released from nuclear reactors. In fresh and brackish water, ^{137}Cs also tends to associate with the particulate phase and also serves as a tracer for sedimentary processes. ^{137}Cs was first introduced to the environment in significant quantities in 1954.

The depositional rate peaked in 1964, then tapered off in response to an international moratorium on atmospheric bomb tests. These dates provide valuable time lines in the sedimentary column for establishing recent accumulation rates (Krishnaswamy et al., 1971; Santschi, 1986).

The distribution of tracers such as ^{210}Pb and ^{137}Cs in the sedimentary column is the result of a combination of all of the sedimentary processes. Two major processes are accumulation and mixing. When the distribution of more than one tracer is known it is possible to deconvolve the distributions , and to separate accumulation and mixing rates.

In order to apply these concepts to Back Bay, we collected a core in 1980,and measured the concentration profiles for ^{210}Pb and ^{137}Cs. Two further cores were collected in 1990, and analyzed for ^{210}Pb only. The ^{210}Pb concentration was determined by measuring the activity of its short-lived daughter, ^{210}Po, which is assumed to be in secular equilibrium with its parent. The ^{210}Po activity was measured by isotope dilution alpha spectrometry (Oertel et al., 1989). The activity of ^{137}Cs was determined by gamma spectrometry, using a NaI-T1 detector (Wong and Moy, 1984).

In the 1980 core, (BB1, Fig. 7), 90 percent of the core by weight is less that 63 m in diameter (is mud). The concentration of ^{210}Pb is uniform in the top 4 cm (mixed layer). Below this depth, it decreases exponentially to a depth of 18 cm, at which the concentration of both ^{210}Pb and ^{137}Cs drops abruptly to background level. If the 18 cm level is taken to be the 1954 horizon, when ^{137}Cs was first introduced into the global environment in measurable quantities, then the mean accumulation rate for the overlying layer can be estimated as 6.9 mm yr^{-1}.

It can also be assumed that the concentration of ^{210}Pb below 18 cm is the 'supported' level, consisting of ^{210}Pb released by the decay of radioisotopes brought to the depositional site within the lattices of clay minerals. This assumption permits an estimate of the accumulation rate, based on the ^{210}Pb gradient in the overlying layer, as 6.0 mm yr^{-1}. The two rates are indistinguishable from each other within their experimental uncertainties.

The inventory of excess ^{210}Pb in the core corresponds to a depositional flux of 1 dpm $cm^{-2}yr^{-1}$. Todd et al. (1989) report an atmospheric depositional flux of ^{210}Pb of 0.8 dpm $cm^{-2}yr^{-1}$. Such total retention of ^{210}Pb is characteristic of fine-grained sediments, and suggests that in the period preceding 1980, at least this part of Back Bay was an efficient fine sediment trap.

The two cores collected in 1990 present rather a different picture (BB3, BB9, Fig. 8a, b). Excess ^{210}Pb was found only in the top 8 cm of BB-3, and in the top 6 cm of BB-9. The accumulation rate for both cores, estimated from the concentration gradients of ^{210}Pb, is about 0.6 mm yr^{-1}. Thus the accumulation rate as estimated from the ^{210}Pb distribution is an order of magnitude lower in 1990, with respect to the 1980 value. The inventory of excess ^{210}Pb in 1990 corresponds to depositional fluxes of 0.3 and 0.2 dpm cm^{-2} yr^{-1}, at B-3 and BB-9 respectively.

These depositional fluxes can account for only 25 to 40 percent of the atmospheric depositional flux. They suggest that these areas were *not* efficient fine-sediment accumulating areas in the 1980-1990 period. If they are representative of the bay as a whole, then a significant fraction of fine grained sediment was not being retained in the Bay during this period. The grain size of sediment in the 1990 cores is less uniform than that observed in the 1980 core. In core BB-3, the fine-grained (< 63 μ) fraction varies from 56 to 89 percent. A lens of coarser sediment with less than 70 percent by weight of fine-grained sediment is found between 8 and 20 cm. In core BB-9, the percentage of fine grained sediment varies between 84 and 97 percent. Sediments with less than 90 percent fine-grained sediment occur in a lense between 4 and 120 cm.

Discussion and Conclusions

Given these rates of resuspension and accumulation, it is possible to put some bounds on the recent depositional history of the Bay. Joseph Barrell, in 1917, was the first person to to notice that the depth of coastal lagoon is a function of its fetch. The relationship occurs because lagoonal floors are graded, or equilibrium, surfaces. Coastal lagoons are typically such efficient sediment traps that their depths are wind-maintained. They are serviced by tidal circulation, which brings sediment in, and takes the excess away. In the presence of an abundant sediment supply, they aggrade (become shallow). As the water column decreases, wave orbital currents near the bottom become more intense, and more sediment is resuspended. Finally, sediment introduction is balanced by sediment loss, and the lagoon floor is stabilized. Depth remains constant until sea level, the sediment supply, or the wave climate changes, whereupon the lagoon can either shoal again or deepen, depending on the new settings of of the depositional variables. Sea level, steadily rising through the post glacial period, has generally been the controlling variable for coastal lagoons such as Back Bay (Nichols, 1989). Should the Bay aggrade more rapidly than sea level rise, then storm wave resuspension from the shallow Bay floor would be so intense that more sediment would be lost than gained. Should it lag behind, wave resuspension would lose efficiency in the deeper water, and sediment trapping by the Bay floor would increase.

With some 40 events a year capable of eroding the bottom (see above), the response time of Back Bay to changes of equilibrium is clearly short. However, Back Bay has no significant tides, hence the model must be modified. Circulation in Back Bay occurs instead as a result of 'wind pumping' (Fig. 9). During winter storms, strong southerly winds set down the southern part of Back Bay, and drive turbid water from Currituck Sound through the Knotts Island Passage. As the storm progresses, the wind shifts to the north and northwest, sets up the southern part of Back Bay against Knotts island, and flushes sediment and water back into Currituck Sound. As a consequence of its role as conduit, the Knotts Island channel has been overdeepened by storm erosion. Its maximum depths (2.5 m) exceed any values to the north (Back Bay) or south (upper Currituck Sound).

The radioisotope concentration profiles appear to record a recent shift in the values of these process variables. Profiles of ^{210}Pb and ^{137}Cs in 1984 indicated a short term (30 year) sedimentation rate twice that of sea level rise. The period of record corresponds with Eurasian Milfoil invasion. The historically dense growth of this plant would have modified the equilibrium by damping bottom wave currents, accelerating the sedimentation rate, and shifting the Bay floor to a shallower equilibrium depth. At present, The Bay floor appears to be reverting to the previous regime. Concentration profiles of ^{210}Pb at 2 stations indicate accumulation rates less that sea level rise. Sandy layers at or near the sea floor suggest recent winnowing, and anecdotal accounts suggest that much of the Bay floor may be 'sandier'

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Table 1. Resuspension Depths in Back Bay

Fetch=6 km, Grain Size=.062 mm (4 Phi) Depth=1.5 m

Wind Speed knots	Wind Speed m/s	Wave Ht. meters	Wave Period seconds	Current cm/s	Resus. Depth cm
13.50	6.01	0.24	1.80	7	0.60
19.50	8.68	0.30	2.00	7	0.60
19.50	8.68	0.34	2.30	10	0.60
24.50	10.90	0.38	2.20	10	0.60
31.80	15.00	0.53	2/80	10	0.60
63.60	30.00	0.81	3.40	13	2.70
78.20	37.00	1.05	3.96	15	2.80

Table 2. Wind Direction and Frequency Versus Speed
From National Weather Service, Norfolk, VA

Wind Dir.	0-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	>40	Total Freq.
N	0.2	1.2	3.4	4.4	1.1	0.2	0.1			10.6
NNE	0.1	1.0	2.7	2.6	0.5	0.1	0			6.9
NE	0.2	1.6	3.5	3	0.4	0.1				8.7
ENE	0.2	1.6	1.8	1.1	0.1					4.8
E	0.4	1.8	1.8	0.7						4.9
ESE	0.3	1.2	1.1	0.4						3.1
SE	0.3	1.6	1.9	0.7						4.4
SSE	0.3	1.6	1.5	0.5						4
S	0.5	3.8	5.4	2.9	0.3					13.6
SSW	0.3	2	3.3	3.2	0.4	0.1				9.3
SW	0.3	1.6	2.7	2.9	0.6	0.1				8.1
WSW	0.2	0.9	1.4	1.6	0.3	0.1				4.6
W	0.2	1	1.9	1.9	0.3		0.1			5.4
WNW	0.1	0.7	1.1	1	0.2					3.2
NW	0.1	0.6	1.4	1.5	0.3					3
NNW	0.1	0.5	1	1.7	0.3					3.6
Calm	0.7									1.7
Total F1	**55.6**	**22.8**	**35.9**	**30.1**	**4.8**	**0.7**	**0.1**	**0**	**0**	**100**

Table 3. Wave Height Frequencies, Station BB1

Wave Height Cm	N (2)	NNE (2)	NE (3)	ENE (2.5)	E (2.5)	ESE (4)	SE (5)	SSE (6)	S (4.5)	SSW (3)	SW (6)	WSW (4)	W (4.5)	WNW (5)	NW (5.5)	NNW (6.5)	Total Freq.
	Direction and Fetch in km																
Calm																	1.7
17	0.2	0.1															0.3
18	1.2	1			0.4												2.6
19	3.4	2.7	0.2	0.2	1.8				0.5				0.2				9
20	4.4	2.6	1.6	1.6	1.8	0.3	0.3		3.8	0.3		0.2	0.9	0.1	0.1		18.1
21				1.8	0.7	1.2	1.6	0.3	5.4	2	0.3	0.9	1.4	0.7	0.6	0.1	17.5
22	1.1	0.5	3.5	1.1		1.1	1.9	1.6	2.9	3.3	1.6	1.4	1.6	1.1	1.4	0.5	24.9
23	0.2	0.1	3			0.4	0.7	1.5		3.2	2.7	1.6		1	1.5	1	16.9
24			0.4	0.1				0.5	0.3		2.9		0.3			1.7	5.2
25	0.1		0.1							0.4		0.3					0.9
26										0.1							0.1
27																	
28														0.2			0.2
29											0.6						0.6
30																	
31																0.3	0.3
32																	
33																	
34															0.3		0.3
35																	
36													0.1				0.1
37												0.1					0.1
38											0.1						0.1
Total Freq.	10.6	6.9	8.7	4.8	4.9	3.1	4.4	4	13.6	9.3	8.1	4.6	5.4	3.2	3	3.6	100

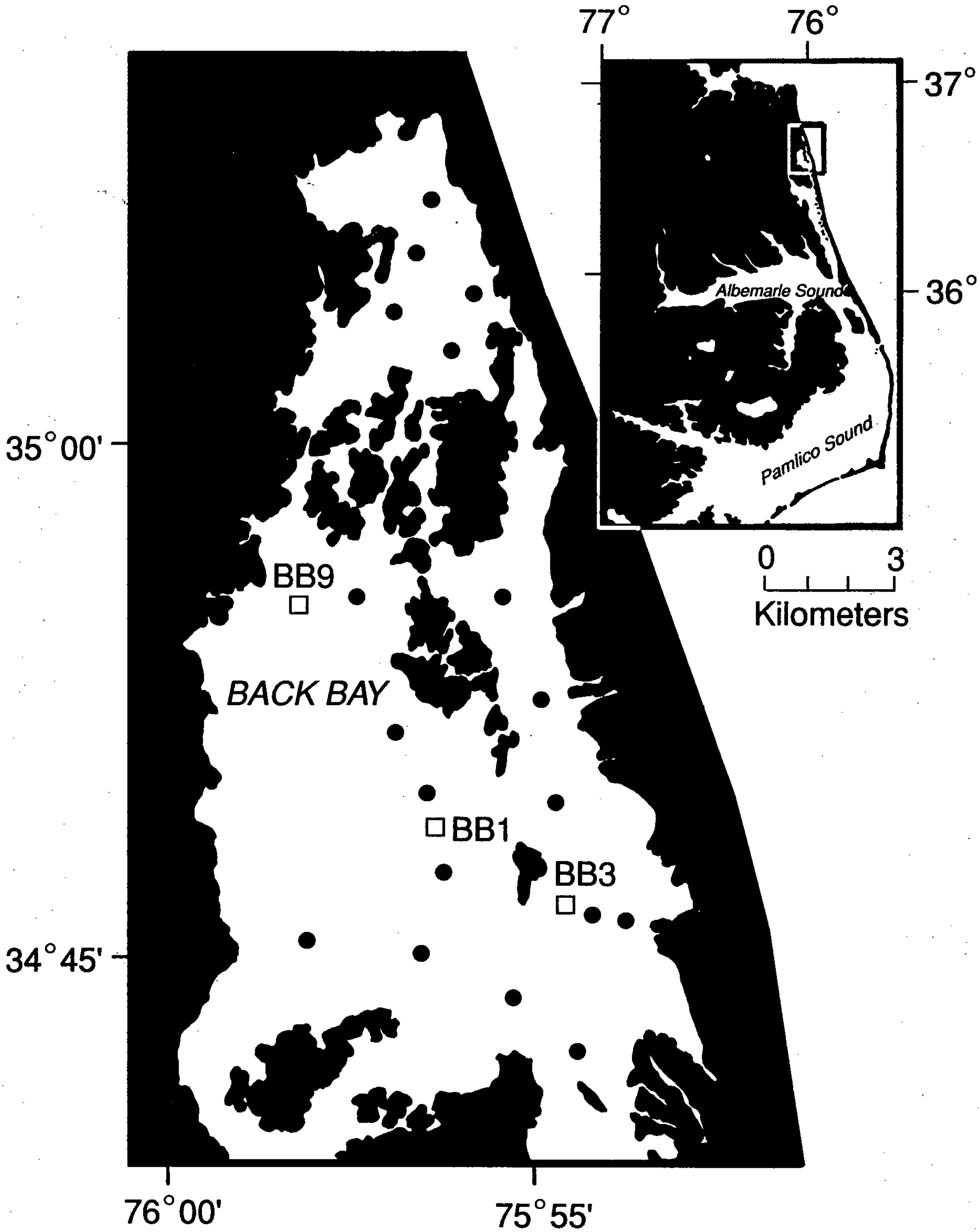

Figure 1. Back Bay showing location of stations, and relation to Albemarle-Pamlico lagoon-estuary system.

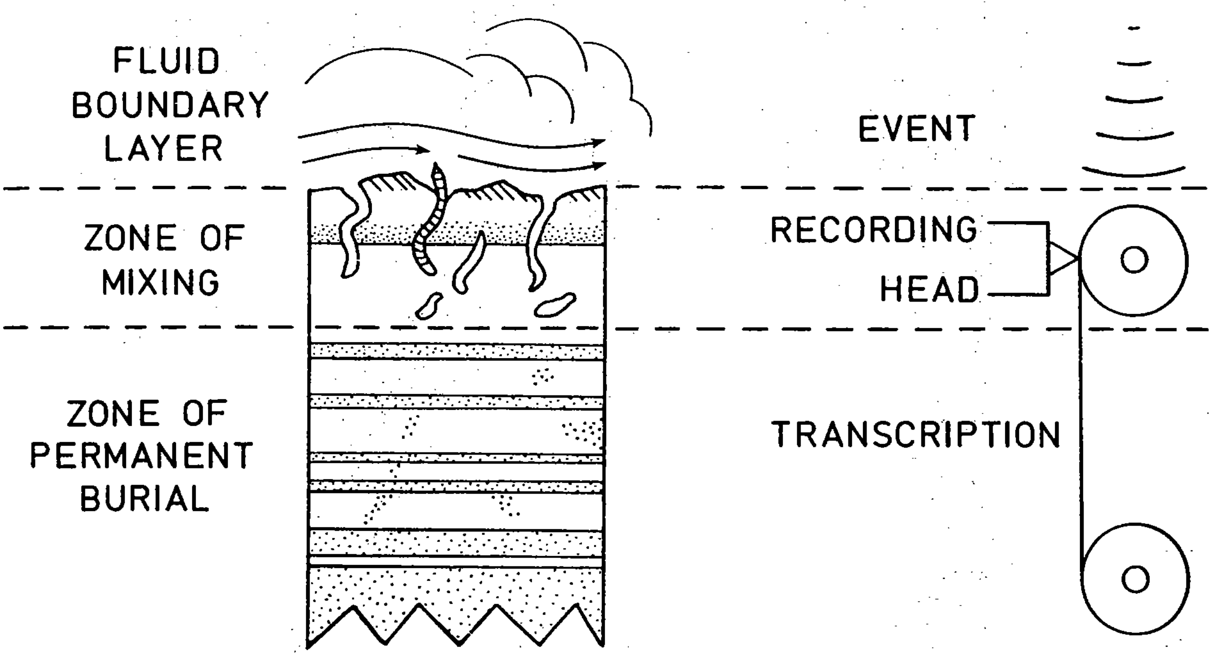

Figure 2. Dynamics of the mixed layer. Strata are formed by storm events, and are wholly or partially resuspended by later events. Strata are erased and sediment mixed by burrowing infauna. Signal formed by resuspension and bioturbation in the zone of mixing passes downward into of the zone of permanent burial as the "unreeling tape" of the stratigraphic record.

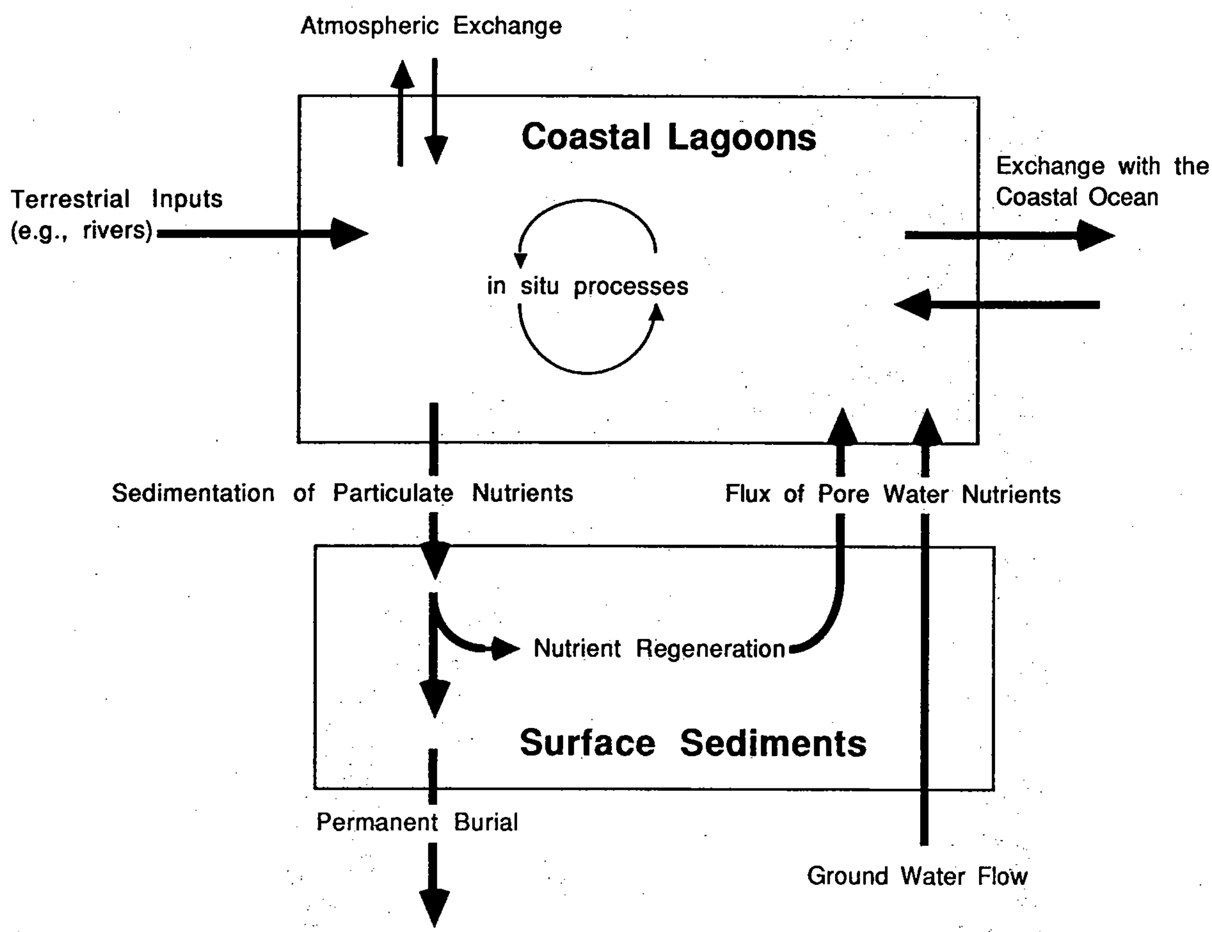

Figure 3. Model of nutrient cycle in a middle Atlantic lagoon (David Burdige, personal communication).

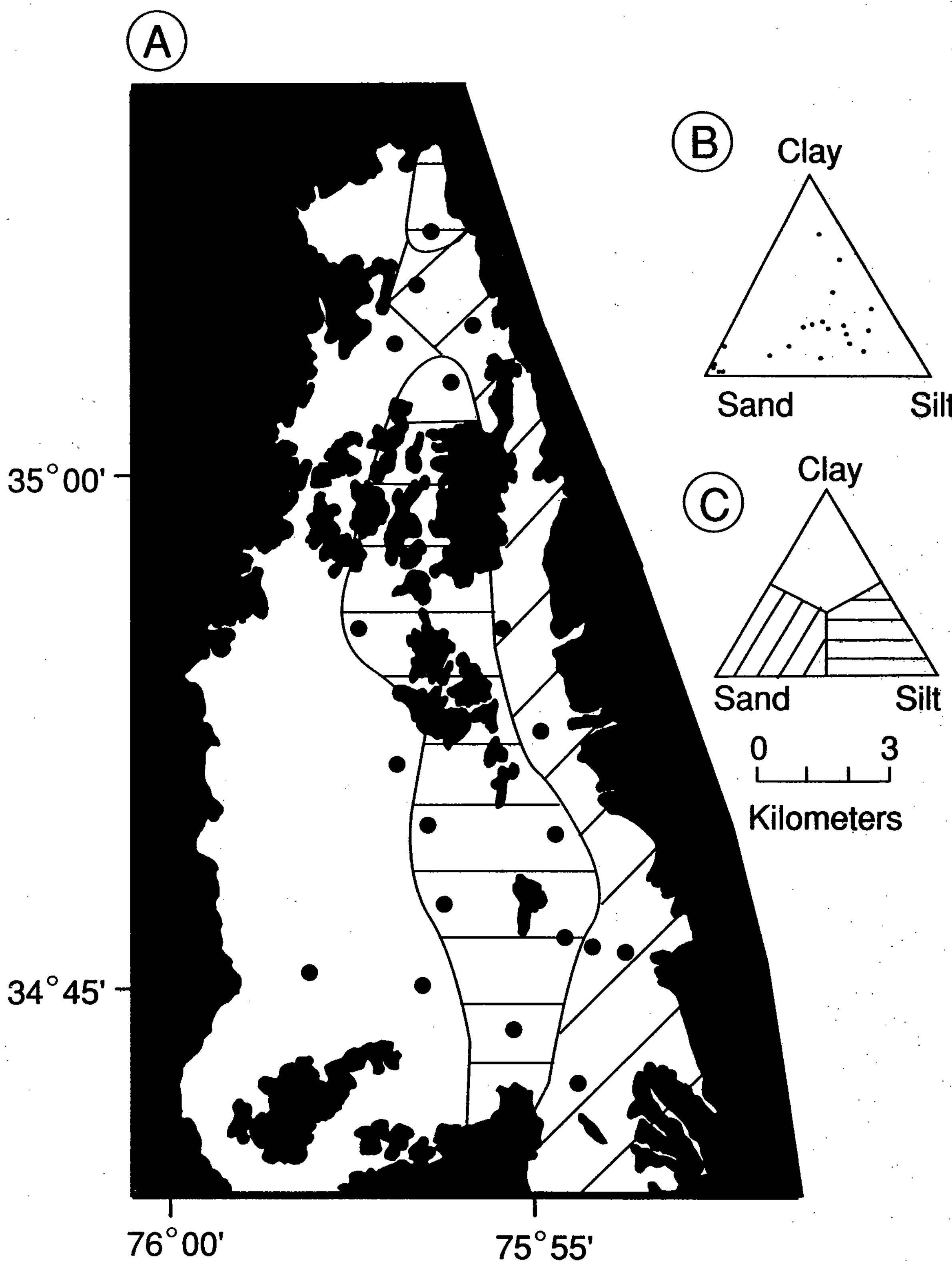

Figure 4. Sediment types of the Bay floor. A) distribution map. B) Sand silt clay diagram. C) Key to sediment types on map.

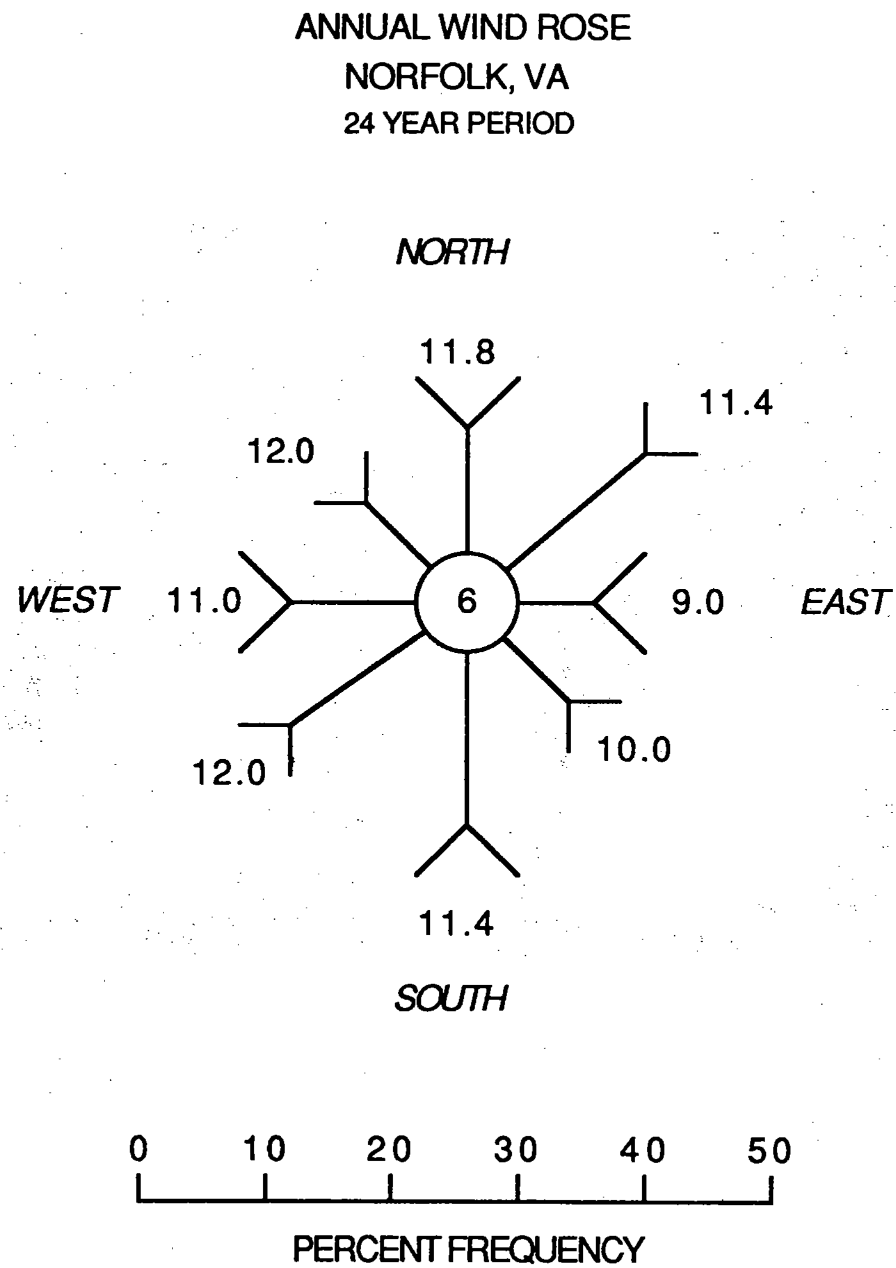

Figure 5. Annual wind rose for Norfolk, VA. Arrows point in the wind direction. Numbers by the tails of the arrows are average velocities in nautical miles per hr. Lengths of shafts, as measured on scale, indicate percent frequency. Personal communication National weather service, Norfolk, VA.

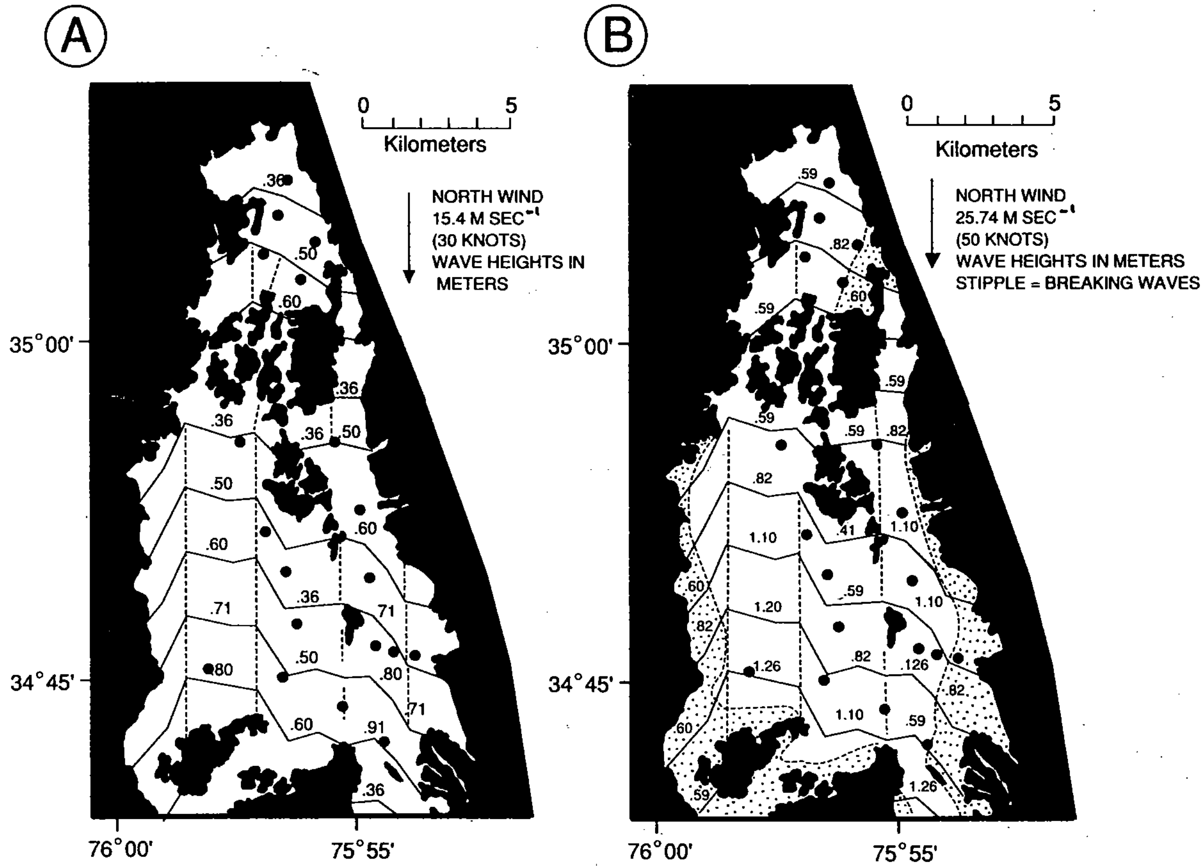

Figure 6. Wave heights in Bay for A) 15 m Sec^{-1} (30 knot) north wind and B) a 38 m sec^{-1} (75 knot) north wind. Dashed lines separate fetch lanes. Stippled area is zone of breaking waves. Bay is fetch-limited rather than depth-limited for winds of less than hurricane strength.

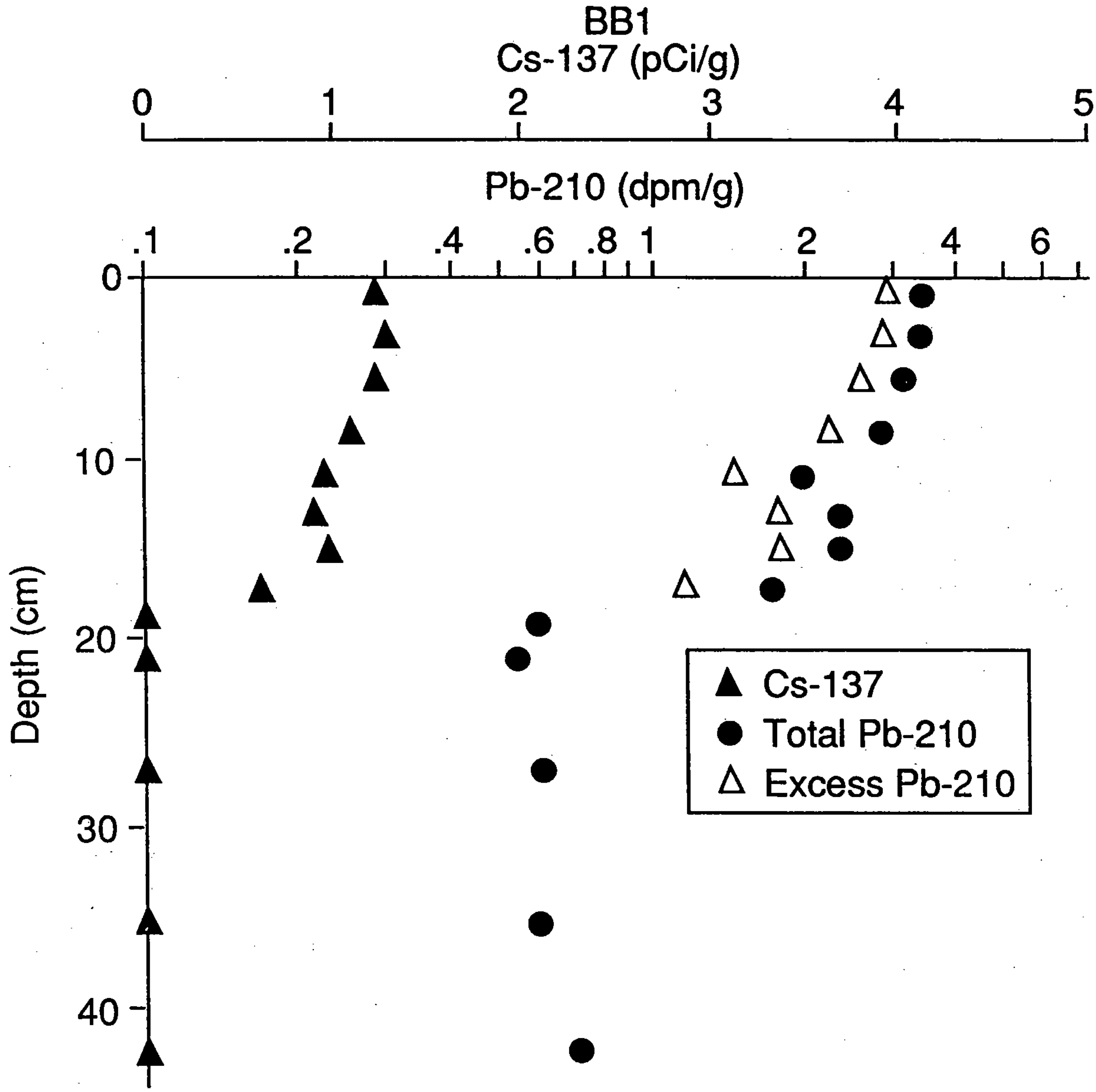

Figure 7. Depth profiles of ^{210}Pb activity (total and excess), and of ^{137}Cs at a station in the bay center. Core collected and data analyzed in 1984. See Fig. 1 for location.

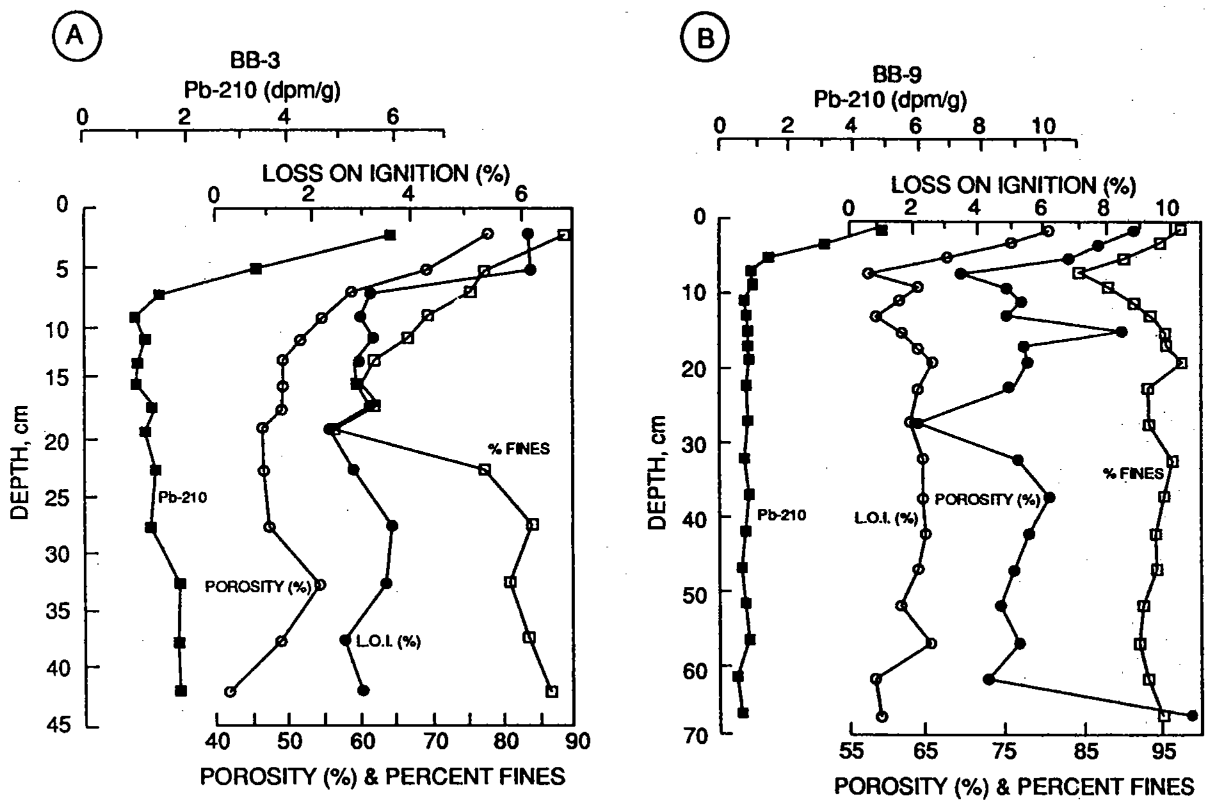

Figure 8. ^{210}Pb profiles from 2 cores collected in 1990, plotted against loss on ignition, porosity, and percent fines.

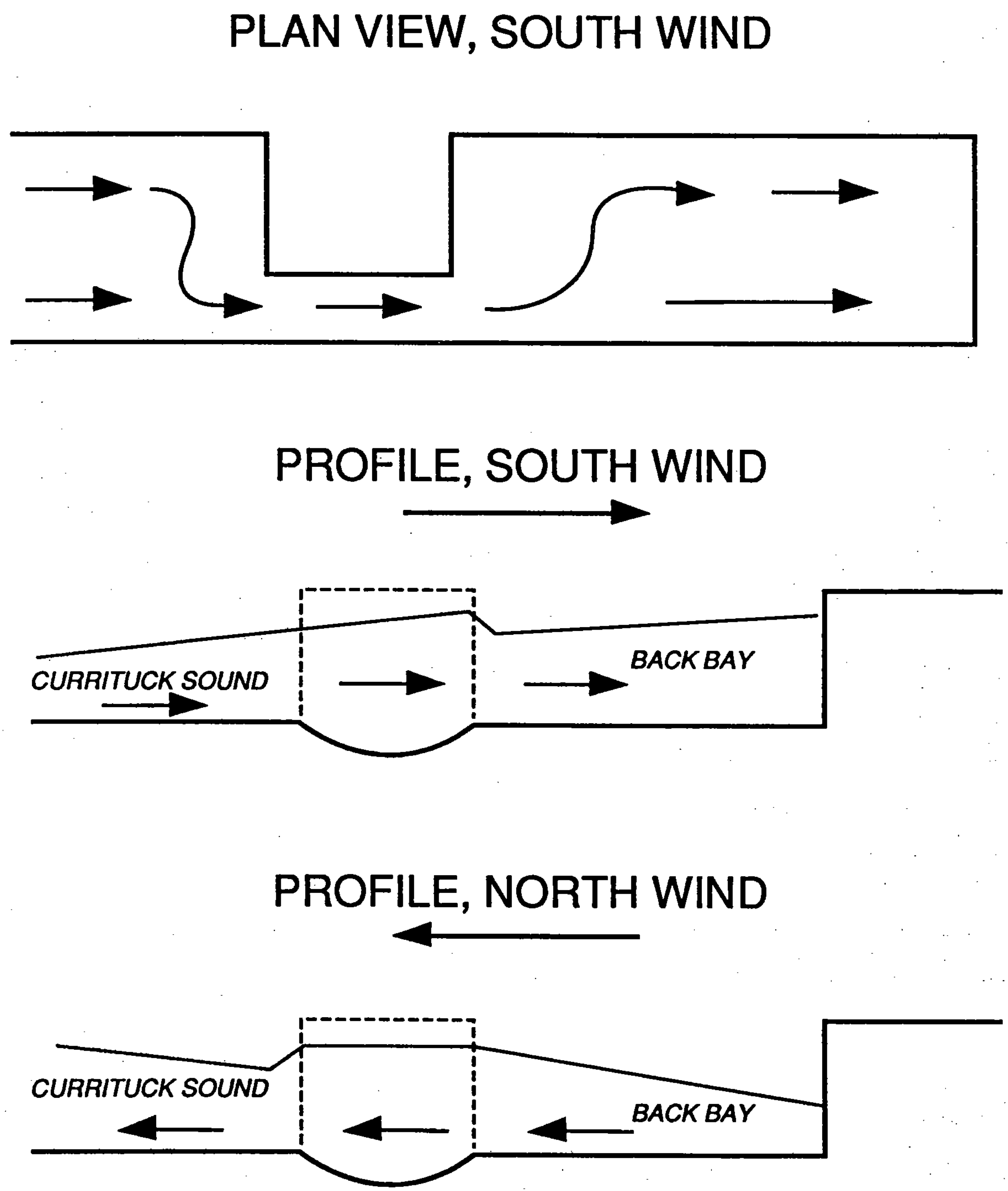

Figure 9. Model of wind pumping mechanism for sediment supply. A) At onset of storm, south wind resuspends sediment in Currituck Sound and sets up Currituck sound against Knotts Island, forcing suspended sediment and water through Knotts Island passage. B). After passage of front, north wind sets Back Bay up against Knotts Island; water and excess sediment is returned through Knotts Island Passage. Dashed line in figure is outline of Knotts island, located behind the plane of the paper. Knotts Island Passage is overdeepened by scour.

Multivariate Analyses of Spatiotemporal Water Quality Patterns of Back Bay, Virginia

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Abstract: An investigation employing multivariate statistical techniques was conducted to determine major spatiotemporal patterns in water quality in Back Bay, Virginia. Water quality data collected by the Virginia Water Control Board (VWCB) over the past two decades and recent data collected by the Department of Game and Inland Fisheries and the Back Bay Restoration Foundation were consolidated for statistical analysis. Unfortunately, lack of continuity in sampling regimes prevented the use of many of the site/date/variable combinations in the statistical analyses. Nonetheless, a number of water quality patterns were characterized.

Long-term trends could be evaluated for a relatively few parameters (NO_2, NH_3, TKN, conductivity, DO, and pH) for which an adequate data base existed. Trend analysis of a 16-year data base for Hell Point Creek indicated a significant decrease in ammonia concentrations (-0.011 mg l^{-1} yr^{-1}), possibly related to changes in land use activities in the region.

The TKN concentrations in the Bay almost doubled between the 1970's and 1980's (from 1.14 mg/1 to 1.97 mg/1). Indicators of eutrophication such as high daytime dissolved oxygen and pH measurements qualitatively appeared to decrease between 1970's and 1980's throughout the Bay, but lack of spatial and/or temporal continuity in the data sets prevented direct statistical comparisons.

Distinct seasonal patterns were characterized: "summer" conditions were characterized by high temperatures but lower suspended solids load and nutrient concentrations, while the converse was true for "winter" months. "Spring" and "fall" collection periods were intermediate in these characteristics but displayed elevated volatile suspended solids and depressed phosphorus concentrations, possibly due to seasonal phytoplankton blooms.

Overall spatial patterns indicated the tributary creeks appeared to be "source areas" for elevated nitrogen and phosphorus based nutrients, while the main Bay was characterized by a high organic-rich suspended solids load. The tributary of greatest concern was Nawney Creek, which displayed elevated nutrient concentrations and appeared to influence water quality in the proximate Bay region. In summary, two major problems appear to be associated with water quality conditions in Back Bay: elevated levels of nitrogen and phosphorus based nutrient in the tributary creeks and a high suspended solids load of organic-rich particles in the Bay. The full ecological significance of these conditions cannot be determined by the present study. However, consistent and comprehensive monitoring of water quality conditions, such as has been implemented in recent years, should permit observation of long-term trends in environmental conditions in various portions of the Bay. Only in this way can the success of any management or restoration actions be judged.

Introduction

Over the past two decades, there has been concern over the apparent degradation of the Back Bay ecosystem in Virginia Beach, Virginia. A variety of environmental studies have been conducted at Back Bay, including a number of water quality investigations. The Virginia State Water Control Board (VWCB) has monitored a varying number of stations in Back Bay over the last two decades. Also, since 1986 the Department of Game and Inland Fisheries and the Back Bay Restoration Foundation have been collecting monthly water quality samples from Back Bay and its tributary streams, respectively. Although the results of most of these investigations are archived in the STORET system through the Tidewater Regional Office of the Virginia State Water Control Board, no attempts have been made to perform multivariate statistical analyses to explore major spatial and temporal patterns in the water quality of the Back Bay ecosystem since the collections began. The purpose of the present study is to evaluate the spatiotemporal coverage and compatibility of the various water quality data sets and to utilize multivariate statistical techniques to delineate any "big picture" patterns in water quality conditions.

Objectives

The following objectives were identified for the present study:

1. To screen all water quality data for spatio-temporal continuity and compatibility for use in subsequent statistical analyses;
2. To determine whether there have been any long term trends in water quality at sites for which data have been collected from the early 1970's to the late 1980's;
3. To characterize large scale temporal patterns, once spatial patterns have been taken into account:
   a) to compare water quality conditions from the 1970's to those observed in the 1980's;
   b) to delineate temporal patterns of similar water quality conditions during the periods of collections;
4. To characterize large scale spatial patterns, once temporal patterns have been taken into account:
   a) to delineate spatial patterns in water quality for the entire period of collections (1970's and 1980's);
   b) to delineate spatial patterns in water quality conditions for the more comprehensive studies conducted during the late 1980's.

Technical Approach

For simplicity of presentation, the technical approach section is organized by "tasks" that correspond directly to the objectives.

Task 1. Screening of Water Quality Data for Continuity and Statistical Compatibility

The water quality data received from STORET had to be screened in a number of ways prior to the development of multivariate statistical models. In all multivariate statistical techniques, continuity of variables measured at each of the stations over the collection period is of primary concern, since "missing values" or combinations that do not quite "match up" cause entire sample sets to be discarded by the analysis. Therefore, the data had to be visually screened through a number of plotting protocols. Plots of observation periods for each station, and water quality variables versus date by sites, as well as tables of unique listings of collection dates for each site were examined for continuity. Ultimately, a matrix was produced to display the degree of temporal continuity for the various site-variable combinations. Decisions concerning which data could be used for subsequent analyses were based upon this matrix.

For cases where exact collection dates did not "match up", a computer routine matching month by month correspondence had to be utilized. Site-variable combination not displaying sufficient continuity over time were eliminated from subsequent analyses. Additional spatiotemporal analyses were conducted on data from the more comprehensive 1980's water quality study in order to include the more extensive set of variables being collected.

Task 2. Determination of Long Term Trends in Water Quality

Environmental trend analysis over a time series represents a rather new, complex and often controversial field of study. In order to meet the assumptions of most time series based trend analyses, data must be normally distributed, be collected over an extensive time period (often a minimum of 10 years) and contain no "missing values". Since most environmental data sets generally do not fit these criteria, several new, nonparametric approaches have been recommended for water quality trend analyses (Gilbert, 1987).

In the present study, two nonparametric trend analyses were utilized. The first approach called the "Seasonal Kendall test" was developed by Hirsch et al. (1982). A more recent approach described by Hirsch and Slack (1984) takes into account autocorrelation (or serial correlation), a typical characteristic of time series data which influences the power and robustness of statistical analyses. Unfortunately, this approach can only be used for data sets containing more than 10 years of monthly observations. Therefore, for site-variable combinations with sufficient numbers of observations, both analyses were conducted.

Task 3. Characterization of Overall Temporal Patterns

In order to examine temporal patterns in Back Bay, major spatial patterns must first be taken into account statistically. Therefore, a series of complementary multivariate spatial and temporal analyses were conducted which paralleled those being used for the Chesapeake Bay Program (Alden et al., 1988; Birdsong et al., 1988). The first procedure, based upon the methods described by Williams and Stephenson (1973), allowed the calculation of classification coefficients which were used in complementary cluster analyses: 1) to cluster sites according to similarities in water quality patterns, once temporal patterns have been taken into account; and 2) to classify temporal groups displaying similar water quality patterns, once spatial patterns have been taken into account. The evaluation of dendograms produced by these analyses allowed the determination of "site groups" (sites displaying similar water quality patterns through time) and "date groups" (time periods displaying similar water quality patterns over all sites).

Prior to the analyses of the specific water quality conditions associated with the temporal patterns, any spatial effects were "removed" by subjecting the data to a multivariate analysis of variance (MANOVA) of site groups defined by the Williams and Stephenson cluster analysis. Residuals from the MANOVA were analyzed by three alternate models: 1) an *a priori* comparison of the 1970's to the 1980's water quality conditions; 2) a comparison of "date groups" defined by the cluster analysis of the 1970's and 1980's data; and 3) a comparison of "date groups" defined by the cluster analysis of the 1980's data alone. The models each involved a MANOVA and a discriminant analysis of the water quality "residuals". The discriminant analyses were used for data presentation purposes. The discriminant functions produced by these analyses can be related to the water quality variables most responsible for differences between the temporal groups. Since the MANOVA is a far more conservative test of group differences than discriminant analysis, the variable list used to "name" the discriminant axes included only variables shown to be statistically significant (a=0.01) by this analysis.

Task 4. Characterization of Overall Spatial Patterns

The spatial patterns were analyzed in an analogous manner. Two models were employed to explore major spatial patterns in water quality in Back Bay: 1) a comparison of "site groups" defined by the cluster analysis of the combined 1970's and 1980's data sets; and 2) a comparison of "site groups" defined by the cluster analysis of the more extensive 1980's data set. Prior to the analyses, MANOVAs were conducted to "correct" for date groups defined by the cluster analysis. The residuals from this step were analyzed by the MANOVA/discriminant analysis procedures to compare site groups.

Results

Task 1. Screening of Water Quality Data for Continuity and Statistical Compatibility

A total of 19 water quality variables were sampled at 17 stations throughout the Back Bay ecosystem. Only 12 of the stations were sampled into the 1980's. Unfortunately, many of the site-variable combinations were not very consistent over time (Table 1). In fact, less than 5% of all possible site-variable combinations displayed year round continuity throughout the study period from the 1970's through the 1980's. These combinations (NO_2, NH_3, TKN, DO, conductivity, and pH at station HPC001.46) were used for time series trend analysis (Task 2).

Other subsets of data were screened and assembled for the other spatiotemporal analyses (Tasks 3-4). For each analysis, data sets had to be established which had spatial and temporal continuity and few missing values. For the temporal and spatial analyses involving data from 1970's and 1980's, only three variables (TKN, NH_3, and NO_2) from eight stations were available for analysis. For the temporal and spatial analyses of the 1980's data, ten variables (temperature, TKN, NH_3, NO_2, NO_3, OPO_4, TP, volatile suspended solids, and fixed suspended solids) at 12 stations were available for analysis.

The data also had to be screened for inconsistencies in designation of "below detection limit" (BDL) values. The STORET coded many values which were BDL with a code of "K" beside a number which varied from one sample to another. In order to standardize these values for statistical analyses, the Virginia Division of Consolidated Laboratory Services was contacted to determine a standardized detection limit for each variable. All values coded with the BDL coding were converted to the appropriate standardized detection limits.

Task 2. Determination of Long Term Trends in Water Quality

The results of the long term trend analysis of water quality at station HPC001.46 are presented in Table 2. Of the water quality variables, only ammonia had a significant trend, decreasing approximately 0.011 mg/1 per year. This trend represents an approximate decline of 7.4% of the median value per year (Fig. 1). In the early 1970's, ammonia values were sporadically quite high (>1.00 mg/1). By the late 1970's, the ammonia values were consistently found at low levels, often below detection limits. None of the other water quality parameters displayed significant trends. Nitrates were not monitored consistently at this station in the 1970's, so it cannot be established whether the lower ammonia concentrations translated to reduced nitrate levels.

Task 3. Characterization of Overall Temporal Patterns

The results of the cluster analyses that simultaneously classified dates into date groups and sites into site groups according to similarities in water quality patterns from the 1970's to the 1980's (NO_2, NH_3, TKN only) are presented in Figures 2 and 3, respectively.

The results of the cluster analyses of the 1980's water quality data (temperature, TKN, NH_3, NO_2, NO_3, OPO_4, TP, TOC, volatile suspended solids, and fixed suspended solids) are presented in Figures 4 and 5. For interpretation purposes, mean values and standard errors for each site group-date group combination are presented in Figures 6 to 8 for the 1970's/1980's data set, and Figures 9 to 16 for the 1980's data set. Details concerning the composition and water quality characteristics of the date groups and site groups will be discussed in this section and in the following section.

The Williams and Stephenson (1973) method produces information concerning the relative importance of temporal and spatial factors. Table 3 presents values that Williams and Stephenson (1973) term the "mean variances per comparison". These values are somewhat analogous to eigenvalues and represent the relative amount of the variance in each data set that can be attributed to temporal effects, spatial effects or the spatial-temporal interaction. In the 1970's/1980's data analysis, the temporal and spatial effects appeared to be quite important to the overall patterns in the data, representing 30% and 61% of the variance, respectively. The interaction value, which Williams and Stephenson (1973) term "noise" when the magnitude is small, accounted for less than 10% of the variance. The analyses of the 1980's water quality data produced similar results. Temporal effects accounted for 35% of the variance, while 58% of the variance was attributable to spatial effects. The spatiotemporal interaction accounted for only 7% of the variance, Thus, it appears that spatial effects account for nearly twice as much of the variance as temporal effects, regardless of whether the 1970's and 1980's data sets were analyzed together or the 1980's data were analyzed alone.

The first analysis of temporal patterns involved a comparison of the 1970's water quality conditions with those from the 1980's, once the spatial patterns had been taken into account. The residuals of a MANOVA of site groups defined by the cluster analysis for selected water quality variables (TKN, NH_3, NO_2) were analyzed for the MANOVA/discriminant analysis protocol comparing these conditions for the two decades. Only TKN concentrations significantly differed between the two decades, increasing from an average of 1.14 ± 0.30 mg/1 in the 1970's to an average of 1.97 ± 0.41 mg/1 in the 1980's.

The temporal patterns were further explored through an analysis of the date groups of similar water quality conditions indicated by the cluster analysis. The dendogram for the temporal effects for the 1970's/1980's data set indicated four major date groups, once site effects were taken into account (Fig. 2). Date group 1 (DG-1) encompassed the majority of the sampling dates (a total of nearly 70 collection periods). Date group 2 (DG-2) represented a few winter/spring collection dates in 1975, 1976, 1987, and 1988. Date group 3 (DG-3) was composed of most of the collection periods in 1986 and 1987, as well as a few summer/fall collections from 1988. The MANOVA/discriminant analyses indicated that, across all sites, DG-3 tended to have higher TKN values, while DG-2 tended to exhibit higher NH3 concentrations (Fig. 17). The two periods composing DG-4 displayed elevated but highly variable NO_2 concentrations and low NH_3 concentrations. These patterns can be confirmed in Figures 6 to 8, if one looks at overall concentration patterns along the x-axes and mentally "averages" the values across the site groups.

The dendogram of the temporal groups of the 1980's data alone indicated three major date groups (Fig. 4). Date group 1 (DG-1) was a "summer" group, consisting of collections made during the late spring and summer of 1986 and the summers of 1987 and 1988. Date group 2 (DG-2) was a group that contained mostly fall and spring collection dates. Date group 3 (DG-3) consisted of collection periods from the winter of 1987, February of 1988 and March and April of 1989.

The results of the MANOVA/discriminant analyses of site- corrected temporal effects are presented in Figure 18. Each of the date groups were characterized by certain water quality conditions. The "summer" data group (DG-1) had higher temperatures; and lower fixed suspended solids (indicative of sediment particles), NH_3 concentrations and NO_3 concentrations. On the other hand, the "winter" group (DG-3) displayed lower temperatures, a higher sediment load (higher fixed suspended solids concentrations), and higher NH_3 and NO_3 concentrations. The "spring-fall" group (DG-2) was intermediate in these water quality conditions. It was distinct from the other groups in displaying slightly higher volatile suspended solids (indicative of carbon-rich particles such as phytoplankton cells, detritus particles, humus particles, etc.), and lower total phosphorus concentrations.

Task 4. Characterization of Overall Spatial Patterns

As noted in the previous section, spatial patterns (i.e. between-site variation) accounted for approximately twice the "explained" variance in the water quality data as the temporal patterns. Figure 3 displays the dendogram for spatial effects in the 1970's/1980's data set. There were three site groups formed by the eight sites for which common variables (TKN, NH_3, NO_2) were collected. Site group I (SG-I) consisted of a single site (WNC003.65) in West Neck Creek (Fig. 19). Site group II (SG-II) represented sites in the mouths of Muddy Creek (MDY000.00) and Hell Point Creek (HPC000.00), as well as two sites in the eastern portion of Back Bay (Sand Bay-BKY006.48; and Shipps Bay- SHB000.57). The third site group (SG-III) consisted of sites located in three tributary creeks along the northern and western borders of Back Bay: Hell Point Creek (HPC001.46), Beggars Bridge Creek (BBC000.76), and Nawney Creek (NWN000.00).

The results of the MANOVA/discriminant analyses of the site groups are presented in Figure 20. Site group II tended to display elevated levels of TKN relative to SG-I, with SG-III being intermediate and somewhat more variable in TKN concentrations (see Fig. 6). Site group III tended to display higher NH_3 levels relative to the other site groups, particularly during the winter/early spring date group (DG-2) which may have been subject to increased storm activity (see Fig. 7).

The three site groups defined by the cluster analysis of the more comprehensive water quality data set collected in the 1980's are presented in the dendogram in Figure 5. In this analysis, the first site group (SG-I) consisted of most of the tributary creek sites: West Neck Creek (WNC003.65), a tributary of the North Landing River, Beggars Bridge Creek (BBC000.76), Muddy Creek (MDY000.00), Hell Point Creek (HPC001.46), and a site described as "Drum Point", off the mouth of Nawney Creek (BKY006.37) (Fig. 21). The two sites located at Nawney Creek formed the second site group (SG-II). The sites forming SG-III were for the most part, located in Back Bay: Hell Point Creek (HPC000.00), Shipps Bay (SHB000.57), Sand Bay (BKY006.48), "Off Pellitory Point" (BKY003.17), and "North of Buckle Island" (BKY000.99). Despite the fairly large geographic spread of the "main-Bay" sites, the similarities in overall water quality conditions were quite high and the separation from the other two site groups quite evident.

The results of the MANOVA/discriminant analyses characterizing significant differences in water quality conditions between the site groups are presented in Figure 22. As with the date group patterns, the reader may visually confirm these spatial patterns in Figures 9 to 16, which display mean values for each of the variables found to be significant by the analyses of the various site group/date group combinations. The major separation between the groups was between SG-II and SG-III: SG-II had higher concentrations of nutrients such as phosphorus (both TP and OPO_4), and nitrogen (NO_3 and NH_3); while SG-III had lower levels of these nutrients but higher levels of suspended solids (both volatile and fixed suspended solids, particularly during the "winter" date group when storm activities probably tended to stir the sediments). Site group I had intermediate levels of the nutrients, but tended to have somewhat lower concentrations of TKN than the other site groups.

Discussion

The success of multivariate statistical techniques in analyzing environmental data is highly dependent upon the continuity of the collection regime. On the other hand, programs such as the environmental monitoring that has occurred in Back Bay over the past two decades often depend upon the opportunistic acquisition of data of various sorts from many different sources. Such data sets require much screening to eliminate site-time-variable combinations that are not compatible with the remaining data. Subjective decisions often must be made to determine which sites or collection periods are "close enough" to have the appropriate degree of continuity. Variables, sites, dates, or even entire data sets must often be discarded because they do not meet even these subjective criteria. All of these circumstances were encountered to some degree in the assessment of the Back Bay water quality data. Nonetheless, a number of patterns have emerged from the multivariate analyses. These patterns will be discussed along with more qualitative evaluations of some of the data which could not be used in the analyses. A positive observation that emerged from the screening phase of the assessment was that the water quality data sets collected in the late 1980's have far greater continuity over the site-time- variable combinations than those collected earlier. If the data collection can be maintained over the long term, comprehensive trend analyses similar to those being targeted for the Chesapeake Bay Monitoring Program could become a reality for Back Bay.

The major long-term trend at the single Hell Point Creek site with a sufficient data base for time series trend analysis was a decrease in ammonia concentrations. The trend represented an average decrease of 7.4% (0.01 mg/1/1) of the median concentration (0.15 mg/1) per year. It is believed that discharges from an animal feed lot and a small sewage treatment plant may have produced sporadically high (>1.00 mg/1) levels of ammonia. These were brought under control by the late 1970's, leading to a decrease in ammonia levels. The watershed has since been converted from agricultural and woodland to large residential subdivisions.

The Williams and Stephenson cluster analyses of both the 1970's/1980's data sets combined and the 1980's data set alone indicated that spatial effects (i.e. site to site patterns) accounted for twice as much of the "explained" variance in the water quality as temporal effects. The spatial-temporal interaction term proved to represent only a small portion of the variance, indicating that site groups did not tend to exhibit opposite patterns within the date groups (i.e. there appeared to be a continuity of temporal patterns for the site groups).

In comparing water quality for the 1970's with that of the 1980's, only TKN displayed a significant difference, increasing in the 1980's. However, it should be emphasized that only TKN, NH_3 and NO_2 could be included in the analysis, due to lack of continuity in the remaining parameters. The elevation of TKN concentration in the 1980's was more or less confirmed in the MANOVA/discriminant analyses of date groups formed by cluster analysis of the same data set. The date groups representing much of the 1980's (particularly 1986 and 1987) displayed significantly higher TKN concentrations than the other groups. An examination of the raw data strongly suggests that the TKN concentrations have increased in the main Bay (Fig. 23a) but that the pattern in the tributary (creeks) data set was less distinct, due to sporadically high TKN concentrations in the 1970's at the Hell Point Creek site which moderated during the late 1970's (Fig. 23b). The concentrations of TKN in the 1980's average between 1.5 mg/1 and 2.5 mg/1 for most of the site group-date group combinations. These concentrations are quite high. As a point of comparison, the Virginia Water Control Board (VWCB) at one time used a concentration of 0.9 mg/1 TKN as a "reference level" against which to compare the quality of Virginian's waters in the 305b Water Quality Inventory reports (VWCB, 1976). This level was selected to act as a "reference" to determine whether an ecosystem was over-enriched in nitrogen as a potential long term nutrient load. Although no water quality criteria have been established for TKN, and even the use of a "reference level" was dropped from 305b reports in the late 1970's (VWCB, 1978), the TKN concentrations in Back Bay appear to be quite high. However, ammonia (NH_3),which often constitutes the major component of TKN, did not appear to be elevated (usually, <0.5 mg/1) for most site group-date group combinations displaying high TKN levels (Figs. 6, 7, 10, and 11). Therefore, it is believed that the observed TKN concentrations represent organically bound nitrogen, probably in the form of detritus particles, organic-rich suspended sediments, or phytoplankton biomass.

Marshall (1988) has reported that the phytoplankton communities have become less eutrophic since the 1970's, so phytoplankton blooms would not appear to be responsible for the persistently elevated TKN concentrations in the 1980's. More likely explanations revolve around other changes pointed out by Marshall (1988): changing land use patterns including increasing agricultural activities and housing developments; increasing turbidities in Back Bay; and loss of submerged aquatic vegetation. Suspended solids concentrations were not measured in the 1970's, but the TKN trends may reflect the increased suspended solid load of organic-rich sediments and detritus due to the changing land use activities in the Back Bay watershed during the two decades.

Ammonia concentrations tended to be highest during the winter/early spring months, reaching high concentrations (>1 mg/1) in some of the tributary creeks (HPC001.46 in the 1970's NWN000.00 in the 1980's, see Fig. 24). The concentrations of ammonia in the main Bay, while exhibiting the same seasonal patterns, never exceeded 1.0 mg/1. The water quality criteria for ammonia are dependent on specific pH and temperature conditions, so it is impossible to make definitive statements concerning the potential for ammonia toxicity in the tributaries without much more detailed case by case assessments. However, the 1976 305b Report (VWCB, 1976) indicated that only a small percentage ($<$ 10%) of all water quality observations in the major river basins in Virginia exceeded the "reference level" of 0.89 mg/1. Perhaps levels above 1 mg/1 should be considered to be "elevated" as a potential nutrient source, with toxicity becoming an issue when concentrations greatly exceed that level, particularly under conditions of high pH and temperature. During the 1980's, the ammonia concentrations generally exceeded 1 mg/1 during the winter/early spring months *only* at Nawney Creek sites, probably due to agricultural runoff (Fig. 24).

The analyses of the short-term temporal (seasonal) patterns of water quality in the 1980's indicated three date groups. The "summer" date group tended to have higher temperatures, but lower suspended solids and nutrients. The "winter" date group had lower temperatures, but higher suspended sediment and nutrient loads. The "spring/fall" date groups displayed elevated volatile solids and depressed phosphorus concentrations relative to the other groups, possibly due to seasonal blooms of various phytoplankton species (Marshall, 1988).

The spatial patterns in water quality dominated the "explained variance" in the multivariate analyses. In other words, geographic patterns in water quality in Back Bay and its tributaries overshadowed short-term or even long-term temporal trends by a margin of 2 to 1. The overall spatial pattern that appears to emerge is that the main Bay sites tend to have higher suspended solid and organic nitrogen (TKN) loads than the tributaries, but the tributary waters tend to be enriched in nutrients, both nitrogen (NH_3 and NO_3) and phosphorus (TP and OPO_4). Thus, it appears that the tributary creeks, particularly Nawney Creek act as source areas for nutrients, probably due to agricultural and residential runoff, while the main Bay waters tend to be enriched in organic-rich suspended particles, probably plant detritus, sediments, or both. The portion of the suspended solid load that appears to be associated with inorganic suspended sediment particles (fixed suspended solids) tend to reach maximum concentrations during the winter months when wind and storm activities probably keep the shallow Bay waters stirred up. However, the organically-rich suspended solids (i.e. fine humus particles and detritus) tend to be relatively elevated (generally >20 mg/1; see Fig. 15) throughout all seasons. Whether the turbid waters of the Bay are due to its action as a "sink" or reservoir for sediments carried by runoff from land being developed for agricultural and residential use in the watershed, or due to the loss of sediment stabilization by the dwindling submerged aquatic vegetation in the Bay cannot be determined from monitoring data. In fact, it cannot be stated with complete certainty that the natural condition for a shallow, wind-driven system such as Back Bay is not to exhibit the suspended solid load observed in the 1980's. Measurements of suspended solids and turbidity in the main Bay were not started until the 1980's, so it is difficult to substantiate the suspected trend of increasing suspended solid loads in the system. However, the observed increase in organically bound nitrogen (TKN) in the Bay does indirectly suggest that organic-rich suspended solids concentrations have increased over the past two decades.

It may prove useful to classify the levels of various water quality parameters measured in the Bay during the 1980's relative to 305b "reference levels" (VWCB, 1976), as has already been done for TKN and ammonia. Among the nutrients, average nitrate concentrations for Nawney Creek sites (SG-II) for winter months (DG-3) exceeded the reference level of 0.9 mg/1 (Fig. 12). In fact, this reference level was exceeded by factors of 2-3 during certain collection periods at sites in Nawney Creek (Fig. 25b). The other creeks had somewhat elevated levels of nitrates, but "peak" concentrations observed during the 1970's tended to moderate during the 1980's, particularly in Hell Point Creek and Beggars Bridge Creek (Fig. 25b). Nitrate concentrations at the main Bay sites did not exceed the reference level, although sites BKY006.37 and BKY003.47 did display the most elevated nitrate concentrations during this period, possibly reflecting their proximity to the Nawney Creek "source" area (Fig. 25a).

Average concentrations of OPO_4 exceeded the "reference level" of 0.1 mg/1 at Nawney Creek sites (SG-II) during all seasons (Fig. 13). The OPO4 concentrations at these sites often exceeded the reference level by factors of 2-3 or more (Fig. 26b). The reference level was exceeded occasionally at other creek sites (Fig. A26b), as well as the two main Bay sites (BKY006.37 and BKY003.47) in closest proximity to Nawney Creek (Fig. 26a).

Total suspended solids (fixed plus volatile suspended solids) exceeded the reference level of 80 mg/1 at the main Bay sites (SG-III) during the winter months (DG-3) and much of the spring/fall collections (DG-2) (see Figs. 15, 16, 27a, and 27b). Peak concentrations of suspended sediments at sites BKY003.47 and BKY006.37 exceeded this level by factors of 2-3, presumably during winter "storm" events (Fig. 27a).

The pH readings which were quite elevated in the main Bay waters (often measuring 9-10 pH units, exceeding the reference level of 9) during the 1970's appeared to moderate (readings of 7-8 units) during the 1980's (Fig. 28a). This trend could be due to a decrease in primary production, either of submerged aquatic vegetation, or phytoplankton, or both. Although dissolved oxygen readings were not taken in the 1980's, high (probably supersaturated) oxygen concentrations were observed during the 1970's, tending to substantiate the speculation that elevated pH readings during that decade were due to high levels of primary productivity. Neither pH nor dissolved oxygen measurements were taken consistently at all of the tributary creek sites during the 1980's, so no speculation can be made concerning the patterns of these parameters in these areas.

Finally, salinity measurements in Back Bay have been taken for the STORET data set only since mid-1987. Since seawater pumping operations have ceased, it has been speculated (Marshall, 1988) that salinities in Back Bay should decrease over time. Although it is difficult to detect a significant long-term trend with only two years of data, the patterns may suggest that salinities may be decreasing (i.e. spring lows for 1987 were lower than 1988; see Fig. 28b). Of course, the spring of 1989 was quite wet, so only a more extended data base will confirm whether a long-term trend for decreasing salinities is, in fact, in progress.

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Acknowlegements

This study has been supported by a grant from the Back Bay Restoration Foundation through funds provided by the Virginia Environmental Endowment. We would like to acknowledge the substantial technical efforts of John Seibel and the staff of the Applied Marine Research Laboratory Computer Section: John Kressel, Cheryl Hess, and Michael Ehret. The study would not have been possible without their dedicated efforts in the areas of data acquisition, reduction and management; multivariate statistical analyses; and computer graphics. We also would like to express appreciation to Rita Hidalgo who provided the technical support required for the preparation of this report.

We would also like to acknowledge the efforts of Mitchell Norman and Ron Southwick of the Department of Game and Inland Fisheries and Bill Scott and Sean Priest of the Back Bay Restoration Foundation who collected the samples that provided much of the data analyzed in this report and Walter Priest who was the project manager for the Foundation.

The efforts of Robert F. Jackson and his staff of the Virginia State Water Control Board in organizing the sampling program and providing interim data reports are greatly appreciated.

Table 1. Matrix displaying qualitative degree of continuity in water quality data sets from Back Bay.

Station	TEMP	TOTAL RE SID	SSVOL	SSFIX	AMMONIA	NITRITE	NITRATE	TKN	TP	ORTHO	TOC	SALIN	pH	TURBY	COND	DO	FECCOL	BOD_5	SECCHI
WNC003.65	A	A	A	A	A	A	A	A	A	A	B	NS	F	C	D	F	A	F	NS
	A	F	F	F	A	A	B	A	F	F	F	NS	A	F	F	A	F	E	NS
SHB000.57	A	A	A	A	A	A	A	A	A	A	B	B	A	B	B	F	F	NS	B
	G	F	F	F	G	G	H	G	F	F	F	F	G	F	F	G	G	NS	F
NWN001.84	A	A	A	A	A	A	A	A	A	A	B	NS	NS	C	D	NS	NS	NS	NS
	F	F	F	F	F	F	F	F	F	F	F	NS	NS	F	F	NS	NS	NS	NS
NWN000.00	A	A	A	A	A	A	A	A	A	A	B	NS	F	C	B	F	F	NS	NS
	G	F	F	F	G	G	H	G	F	F	F	NS	G	F	F	G	G	NS	NS
MDY000.00	A	A	A	A	A	A	A	A	A	A	B	NS	F	D	B	F	F	F	NS
	G	F	F	F	G	G	H	G	F	F	F	NS	G	F	F	G	G	D	NS
HPC001.46	A	A	A	A	A	A	A	A	A	A	B	B	A	D	A	A	A	A	NS
	A	D	F	F	A	A	B	A	F	F	F	F	A	F	F	A	A	E	NS
HPC000.00	A	A	A	A	A	A	A	A	A	A	B	B	A	B	B	F	F	F	B
	G	F	F	F	G	G	H	G	F	F	F	F	G	F	F	G	G	D	F
BKY006.48	A	A	A	A	A	A	A	A	A	A	B	B	A	B	B	F	F	NS	B
	F	F	F	F	G	G	H	G	F	F	F	F	G	F	F	G	G	NS	F
BKY006.37	A	A	A	A	A	A	A	A	A	A	B	B	A	B	B	NS	NS	NS	B
	F	F	F	F	F	F	F	F	F	F	F	F	F	F	G	MS	MS	MS	F
BKY003.47	A	A	A	A	A	A	A	A	A	A	B	B	A	B	B	NS	NS	NS	B
	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	NS	NS	NS	F
BKY000.99	A	A	A	A	A	A	A	A	A	A	B	B	A	B	B	NS	NS	NS	B
	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	NS	NS	NS	F
BBC000.76	A	A	A	A	A	A	A	A	A	A	B	NS	F	C	B	F	F	F	NS
	A	F	F	F	A	A	B	A	F	F	F	NS	A	F	F	A	A	E	NS

Legend (top half of box = sampled in 1980; bottom half of box = sampled in 1970):

A = sampled regularly
B = sampled regularly, but with 1 large gap
C = sampled once
D = sampled a few times
E = sampled many times with significant gaps
F = not sampled during time period
G = sampled during summer only
H = sampled during summer only, but with 1 large gap
NS = never sampled

Table 2. Results of the long term trend analysis of water quality at station HPC001.46. The probability (p) values for the overall trends are shown for nonparametric models unadjusted and adjusted into units.

Variable	Median Value	Trend Slope (Units/Year)	P-Value		Significant "Seasonal" Trend Slopes (Units/Year)	Month	P-Value
			Unadjusted	Adjusted			
TKN	1.500 mg/1	0.018	0.058	0.292	-0.100	Jan.	0.021
					0.108	Sep.	<0.001
NH3	0.150 mg/1	0.011	<0.001	0.008	-0.108	Jan.	0.001
					-0.041	Mar.	0.031
					-0.022	Apr.	0.043
					-0.010	May	0.026
					-0.024	Jun.	0.026
NO_2	0.010 mg/1		0.096	0.100	—	—	—
DO	8.9 mg/1		0.12	0.10	—	—	—
Temp	18°C		0.065	0.143	—	—	—
Cond	3023 mohms		0.385	0.581	—	—	—
pH	7.1		0.972	0.976	—	—	—

Table 3. Mean variance per comparison values for the 1970 and 1980 water quality data sets. Values in parentheses represent the percentage that each represents of the total "explained" variance.

Nature of Comparison	Variance Attributable To:		
	Spatial Effects	Temporal Effects	Spatial-Temporal Interaction
1970 & 1980 data	4.50 (61)	2.22 (30)	0.70 (9)
1980 data only	8.82 (58)	5.39 (35)	1.10 (7)

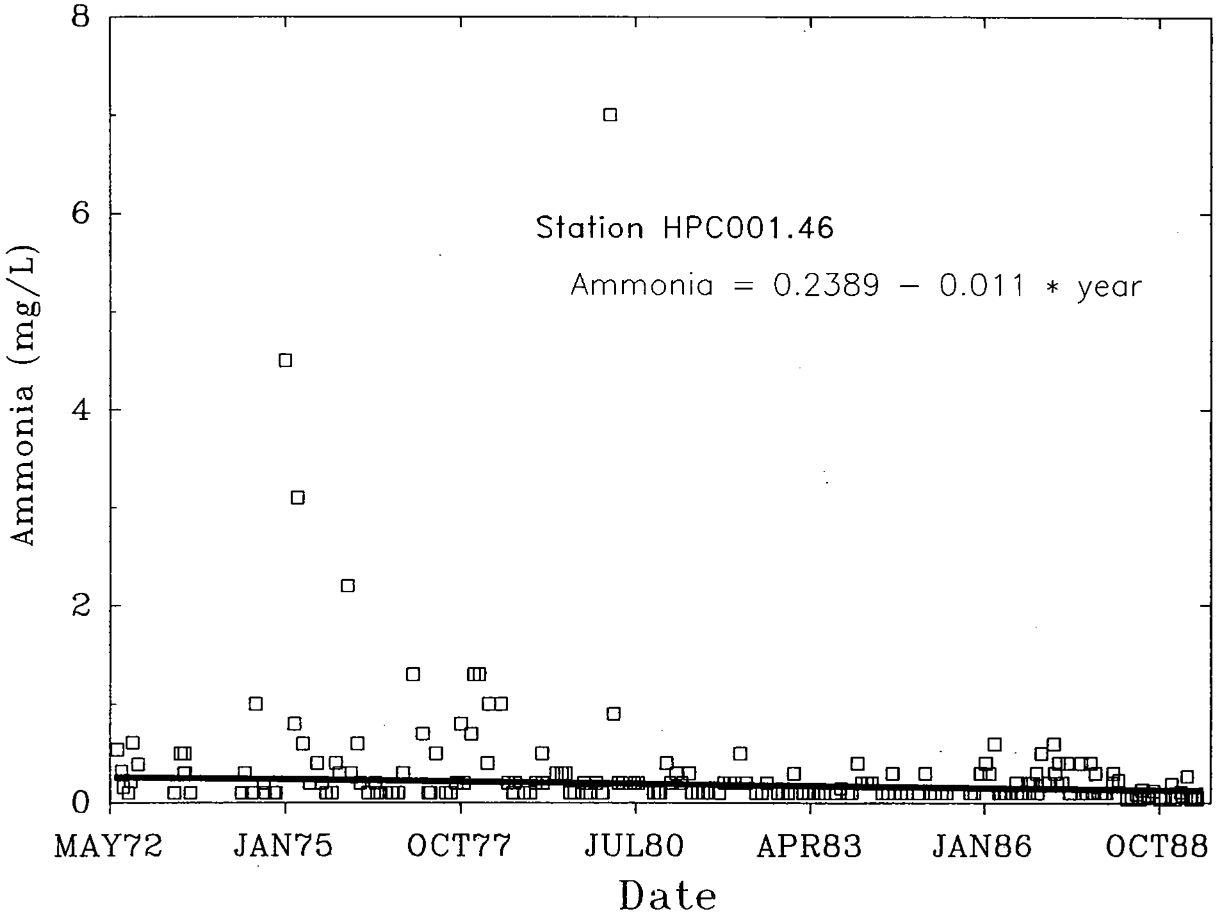


Figure 1. Ammonia concentrations (mg/1) versus date of collection for Hell Point Creek site HPC001.46. The line represents the trend detected by the seasonal Kendall test for serially correlated data.

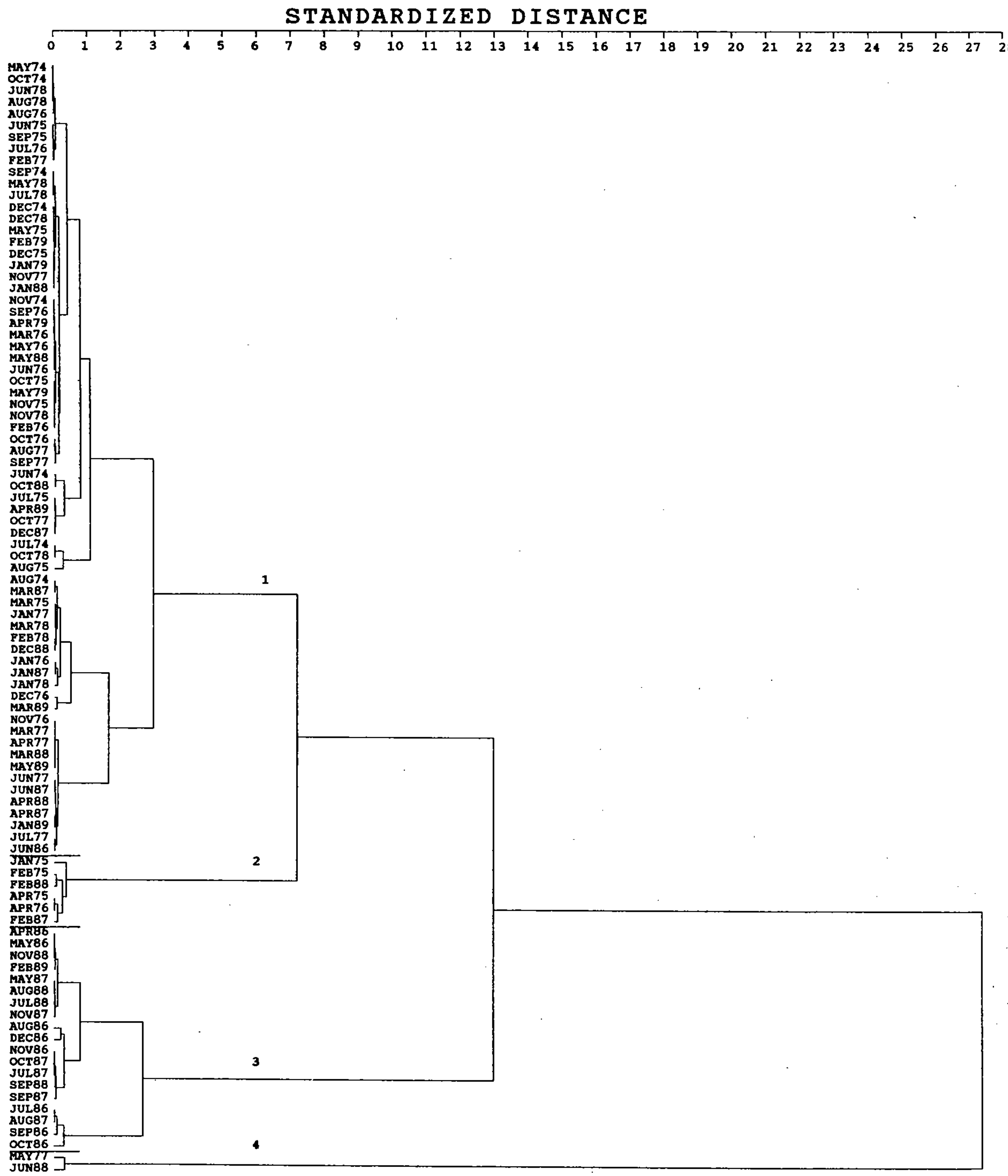


Figure 2. Standardized distance dendogram for classification of temporal patterns with respect to water quality conditions for the 1970's and 1980's (spatial effects removed). The arabic numbers designate date groups.

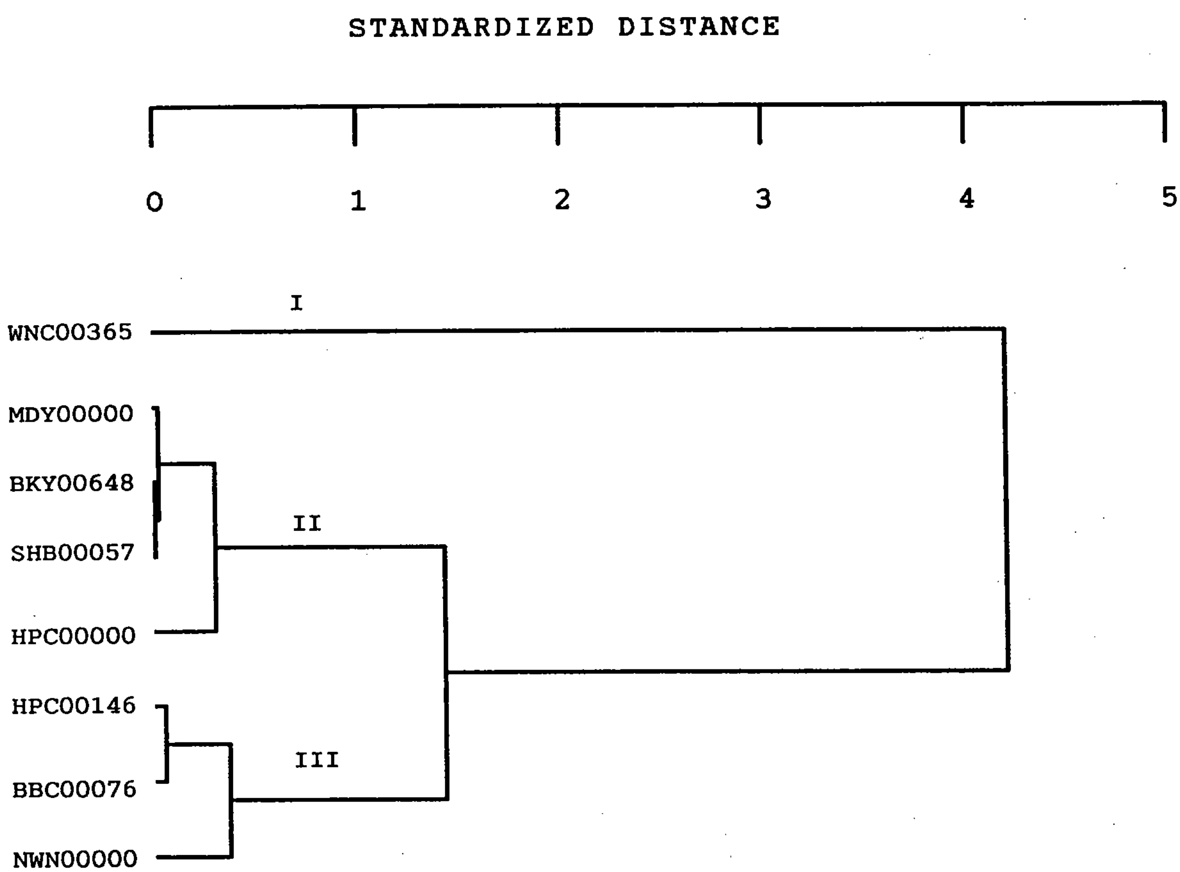


Figure 3. Standardized distance dendogram for classification of spatial patterns with respect to water quality conditions for the 1970's and 1980's (temporal effects removed). The roman numerals designate site groups.

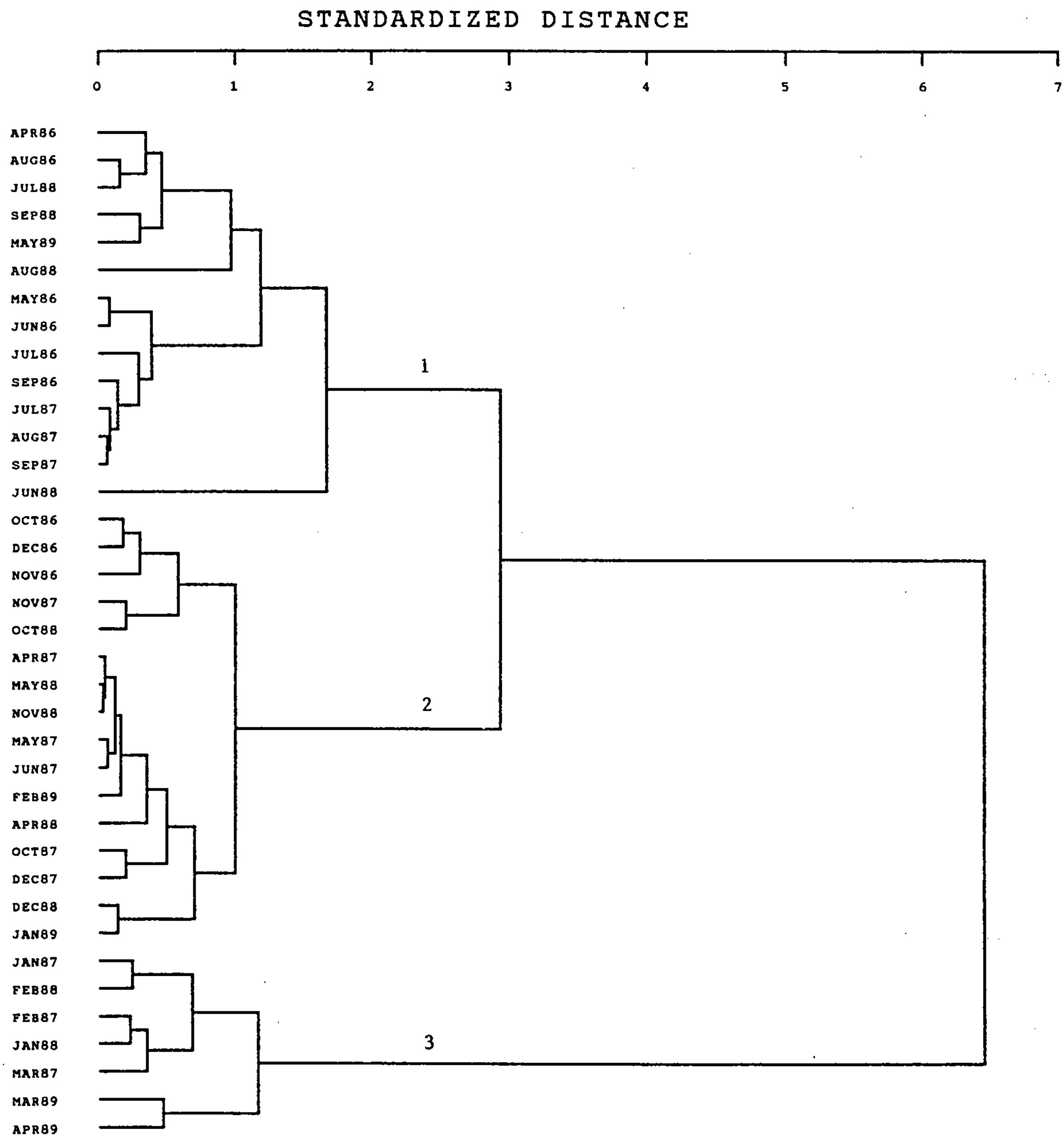


Figure 4. Standardized distance dendogram for classification of temporal patterns with respect to water quality conditions for the 1980's (spatial effects removed). The arabic numbers designate date groups.

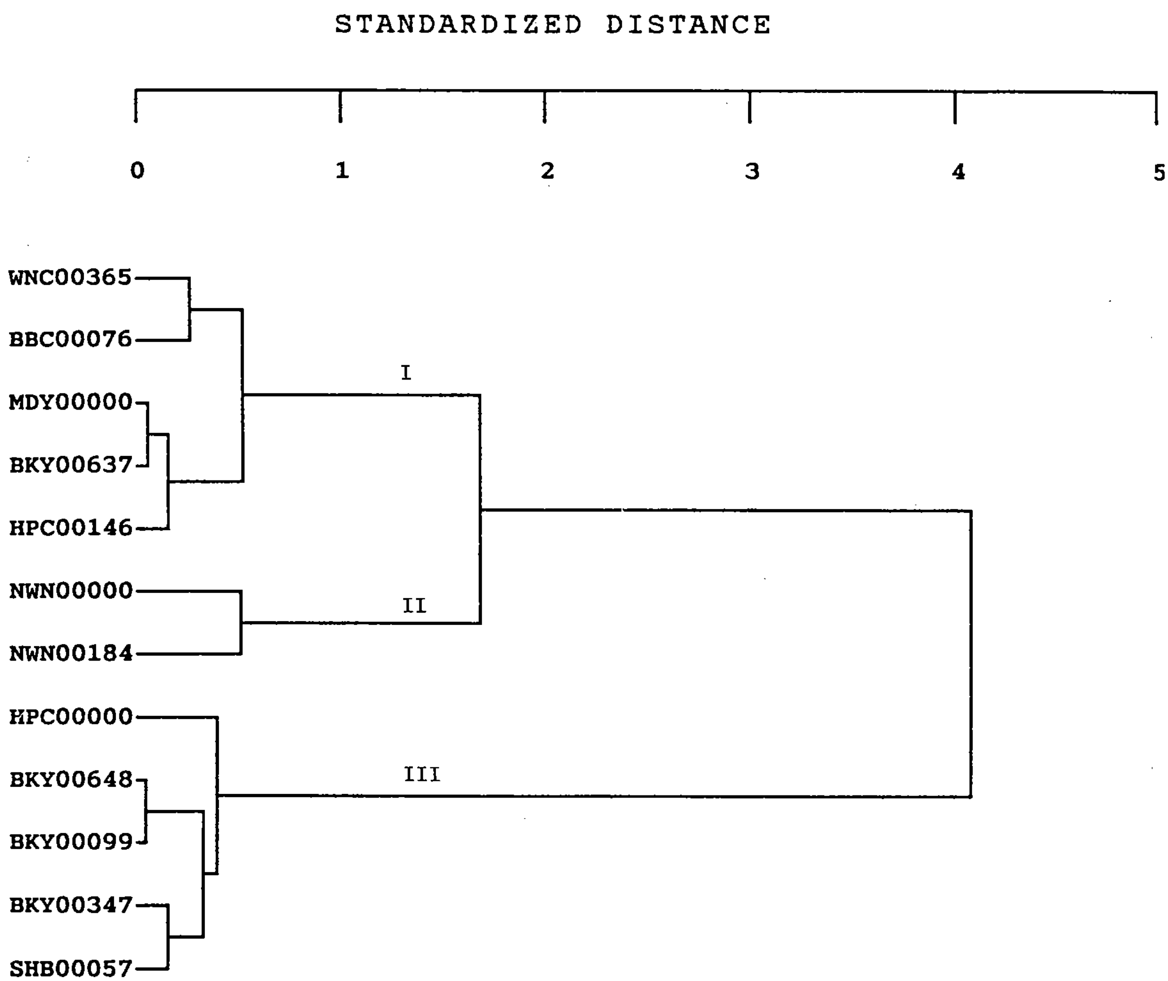


Figure 5. Standardized distance dendogram for classification of spatial patterns with respect to water quality conditions for the 1980's (temporal effects removed). The roman numerals designate site groups.

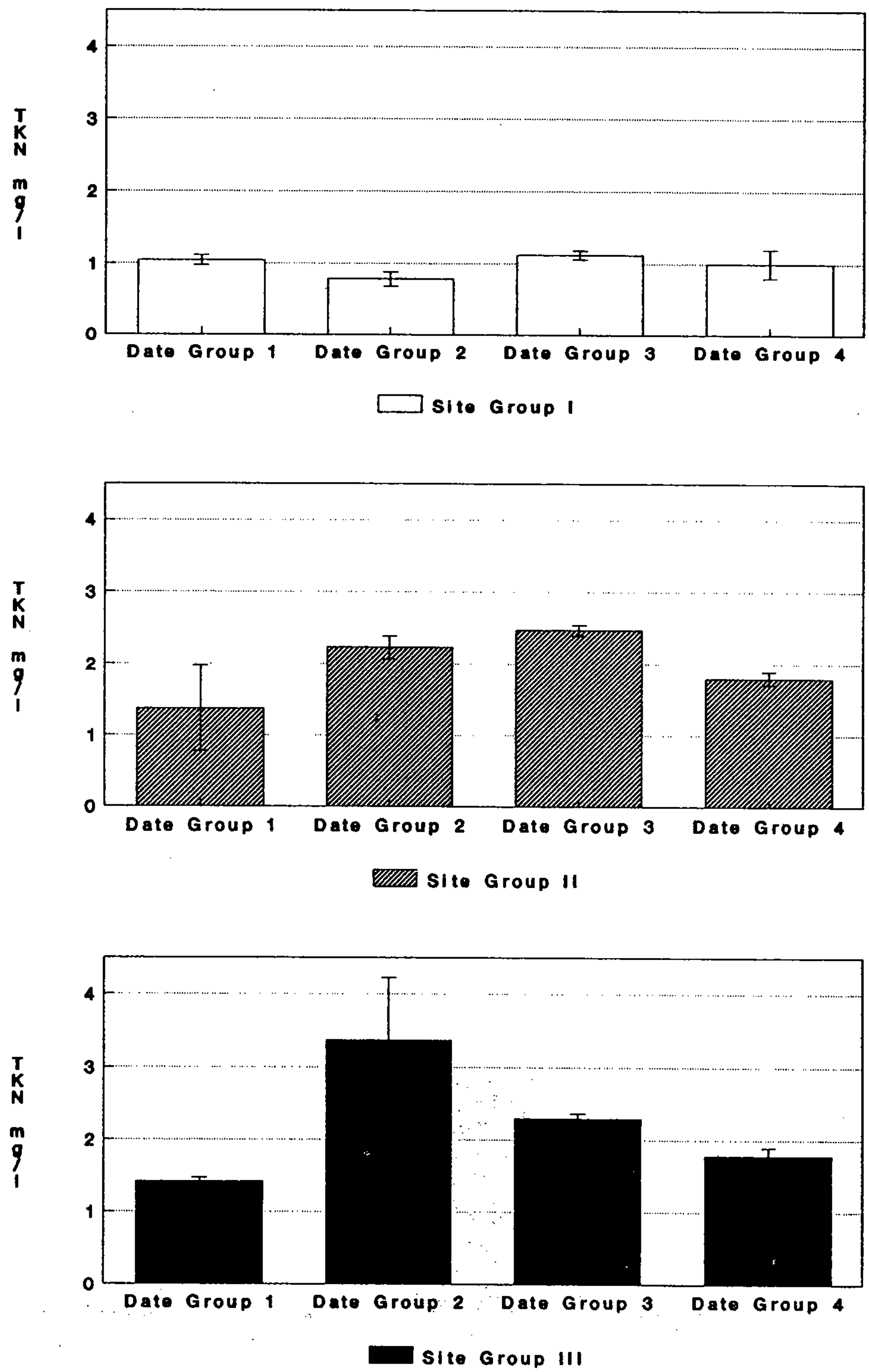


Figure 6. Mean concentrations of total Kjeldahl nitrogen (mg/1) for site group-date group combinations resulting from cluster analysis of the 1970's and 1980's water quality data. The vertical bars represent +/- one standard error of the mean.

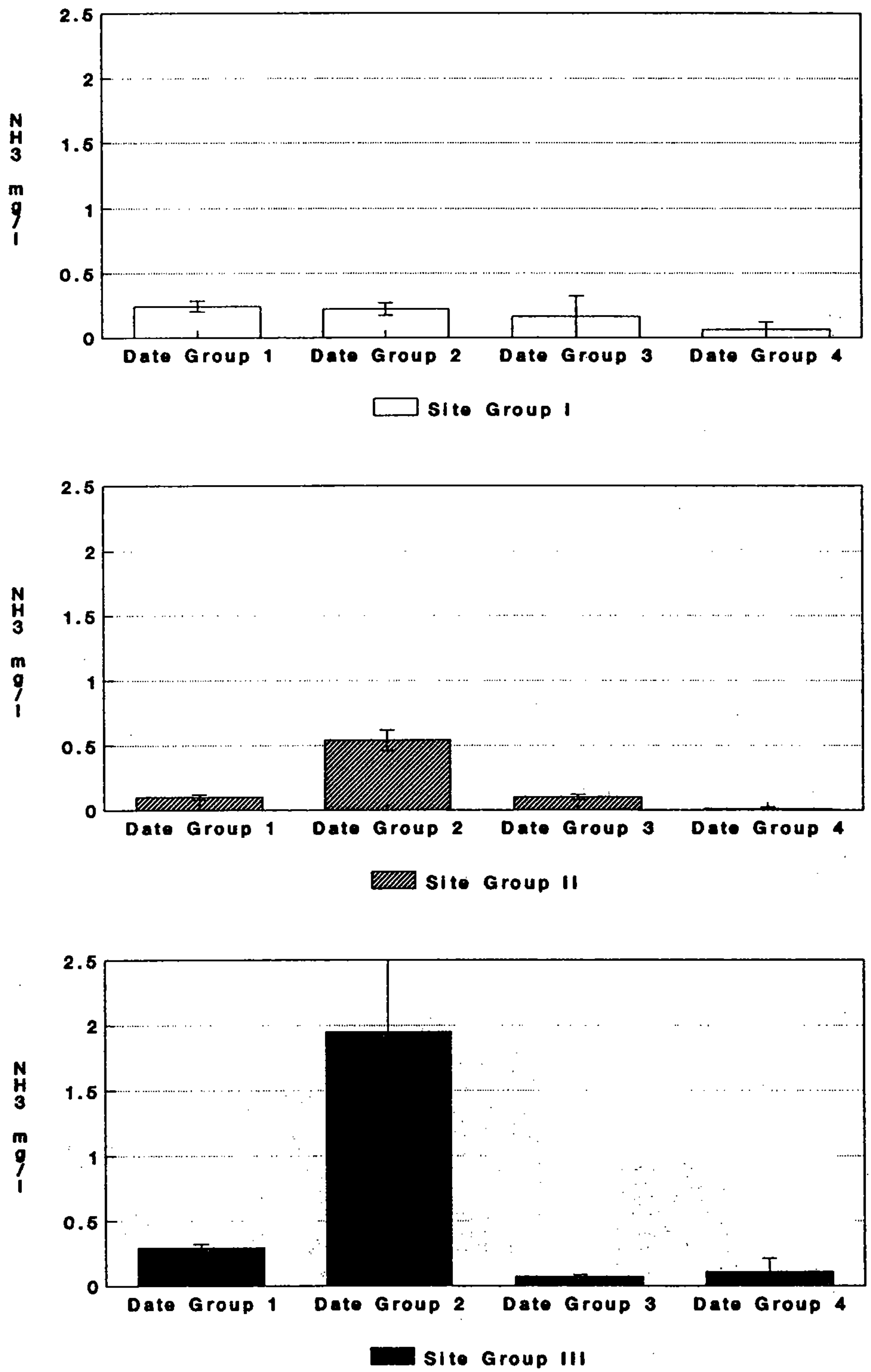


Figure 7. Mean concentrations of ammonia (mg/1) for site group-date group combinations resulting from cluster analysis of the 1970's and 1980's water quality data. The vertical bars represent +/- one standard error of the mean.

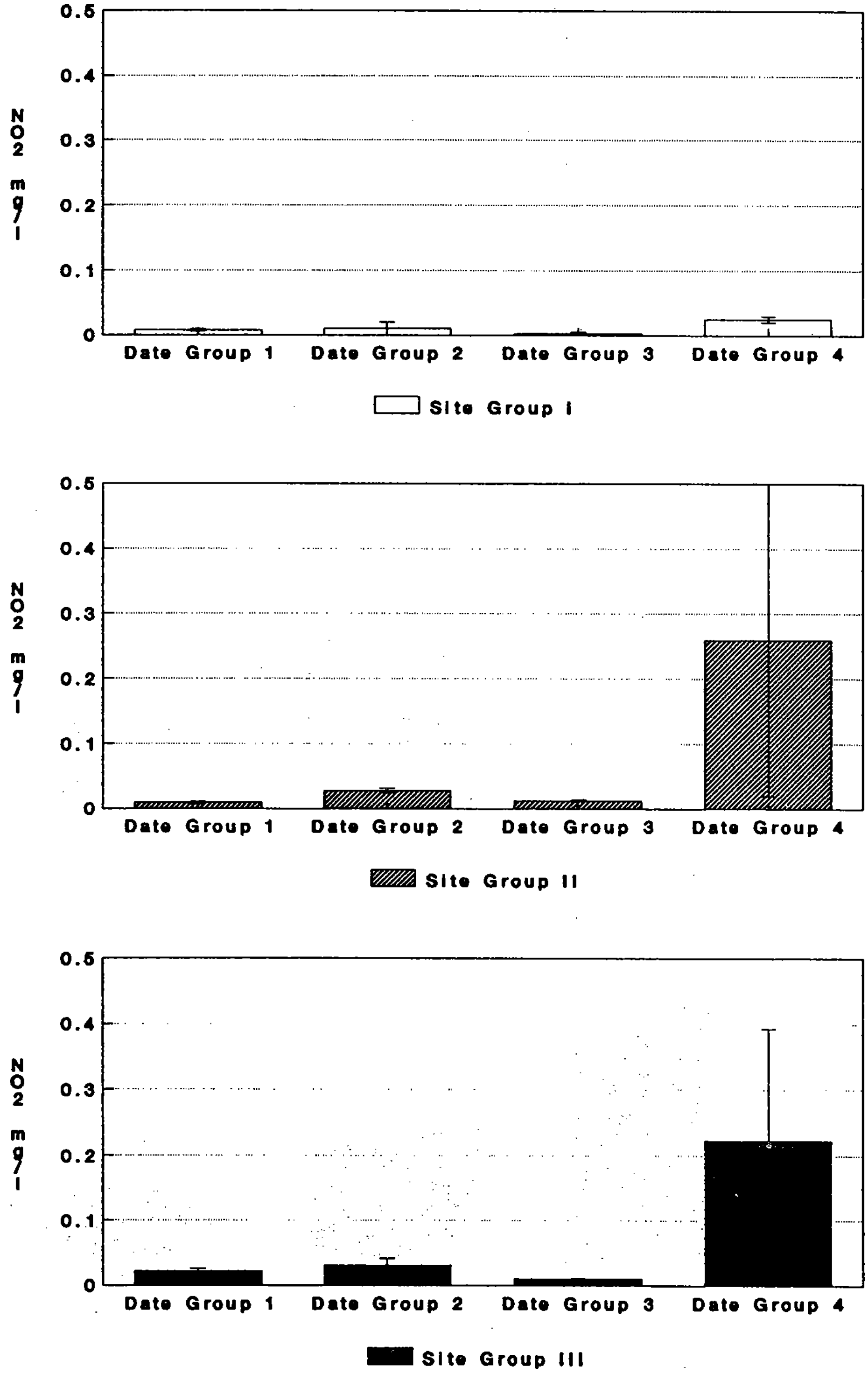


Figure 8. Mean concentrations of nitrite (mg/1) for site group-date group combinations resulting from cluster analysis of the 1970's and 1980's water quality data. The vertical bars represent +/– one standard error of the mean.

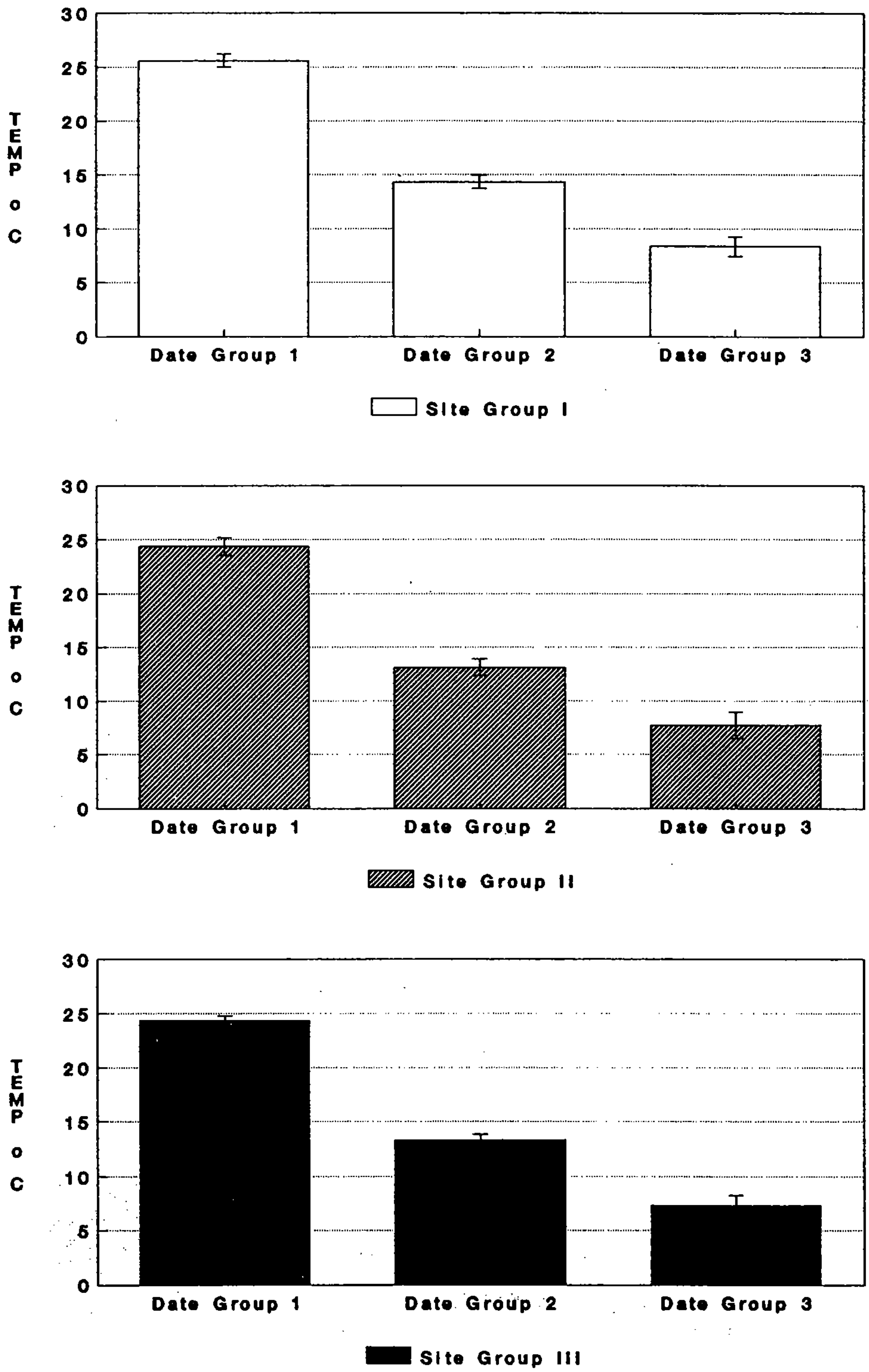


Figure 9. Mean concentrations of temperature (°C) for site group-date group combinations resulting from cluster analysis of the 1980's water quality data. The vertical bars represent +/– one standard error of the mean.

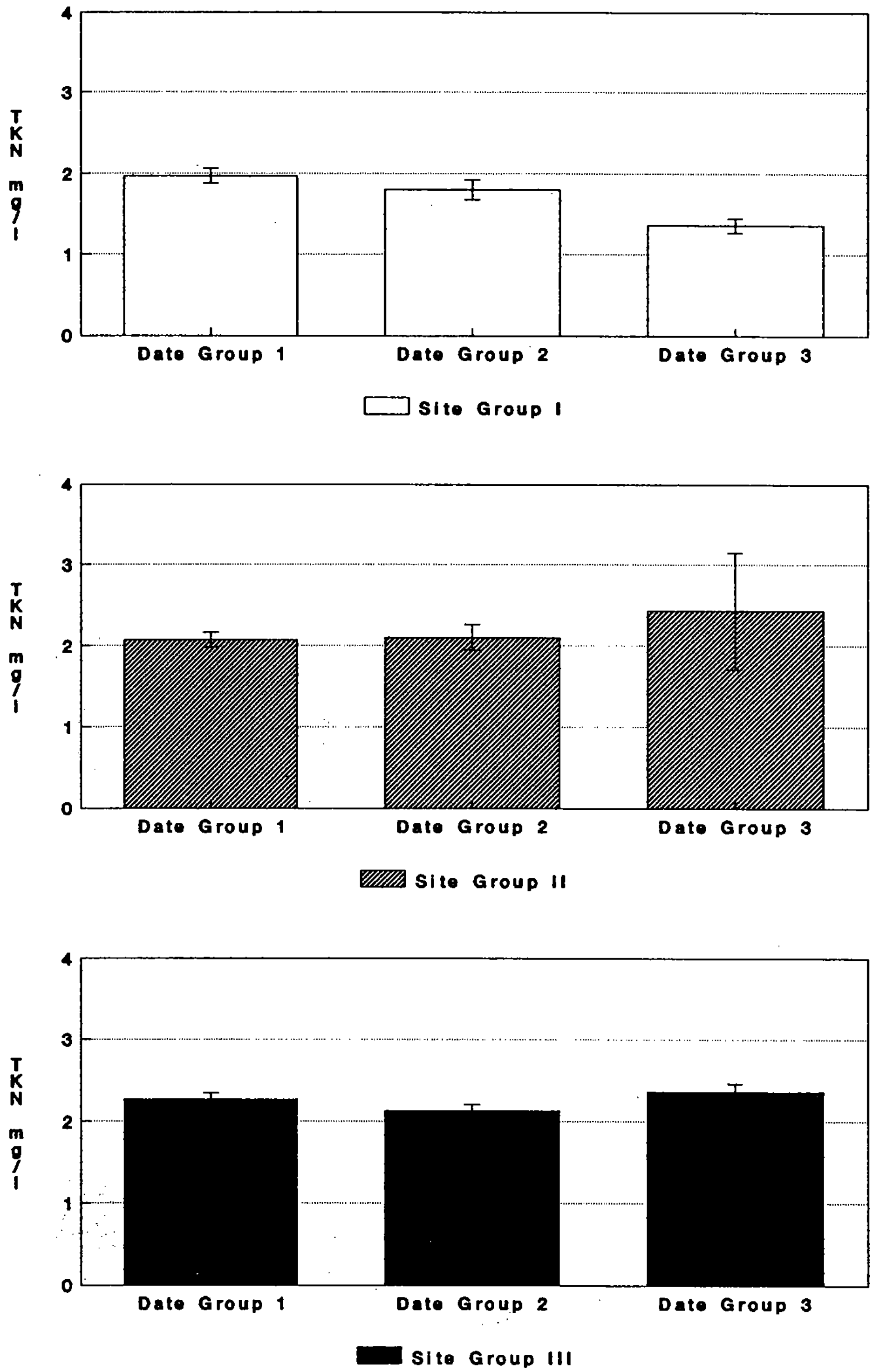


Figure 10. Mean concentrations of total Kjeldahl nitrogen (mg/1) for site group-date group combinations resulting from cluster analysis of the 1980's water quality data. The vertical bars represent +/- one standard error of the mean.

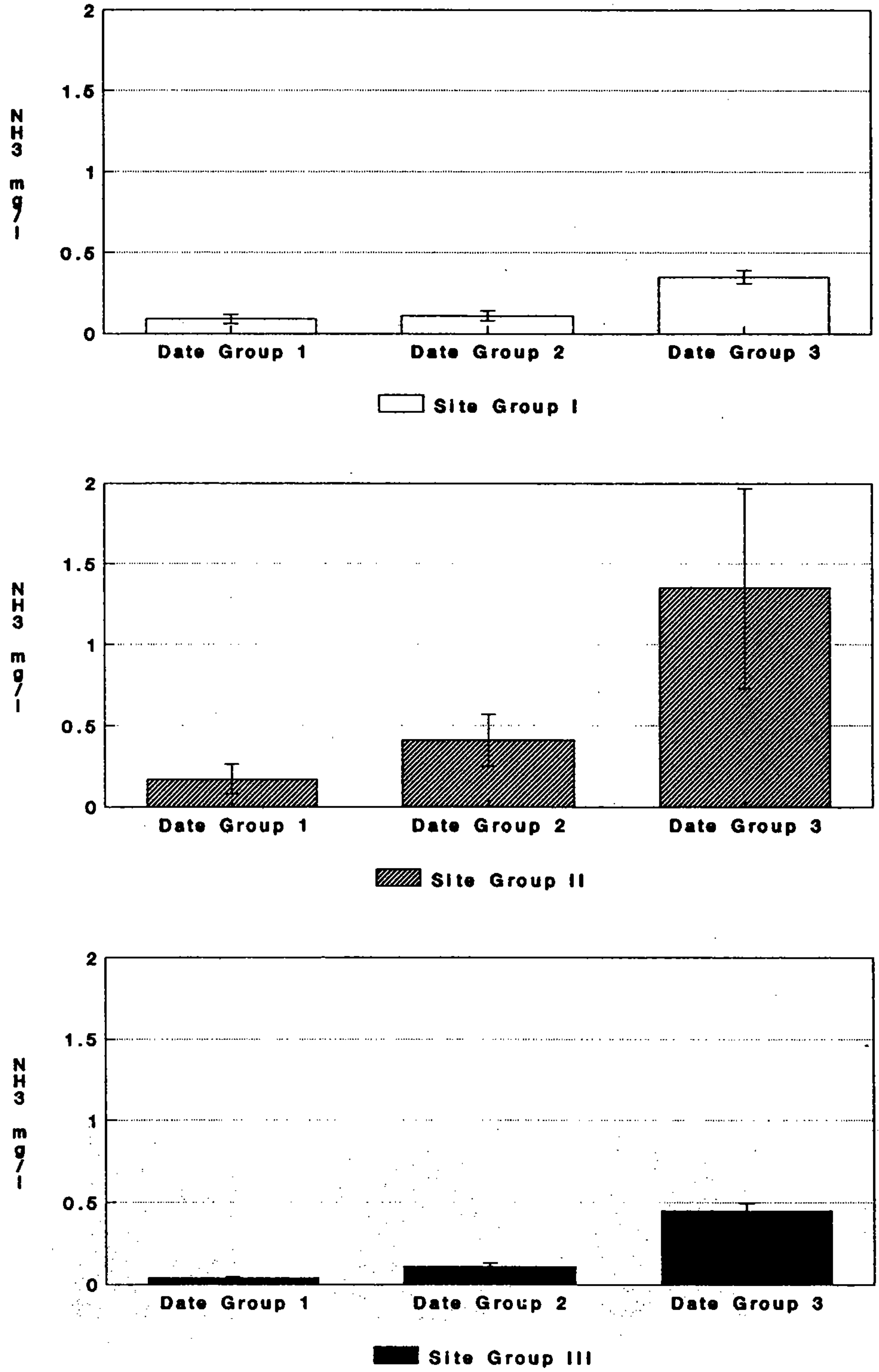


Figure 11. Mean concentrations of ammonia (mg/1) for site group-date group combinations resulting from cluster analysis of the 1980's water quality data. The vertical bars represent +/– one standard error of the mean.

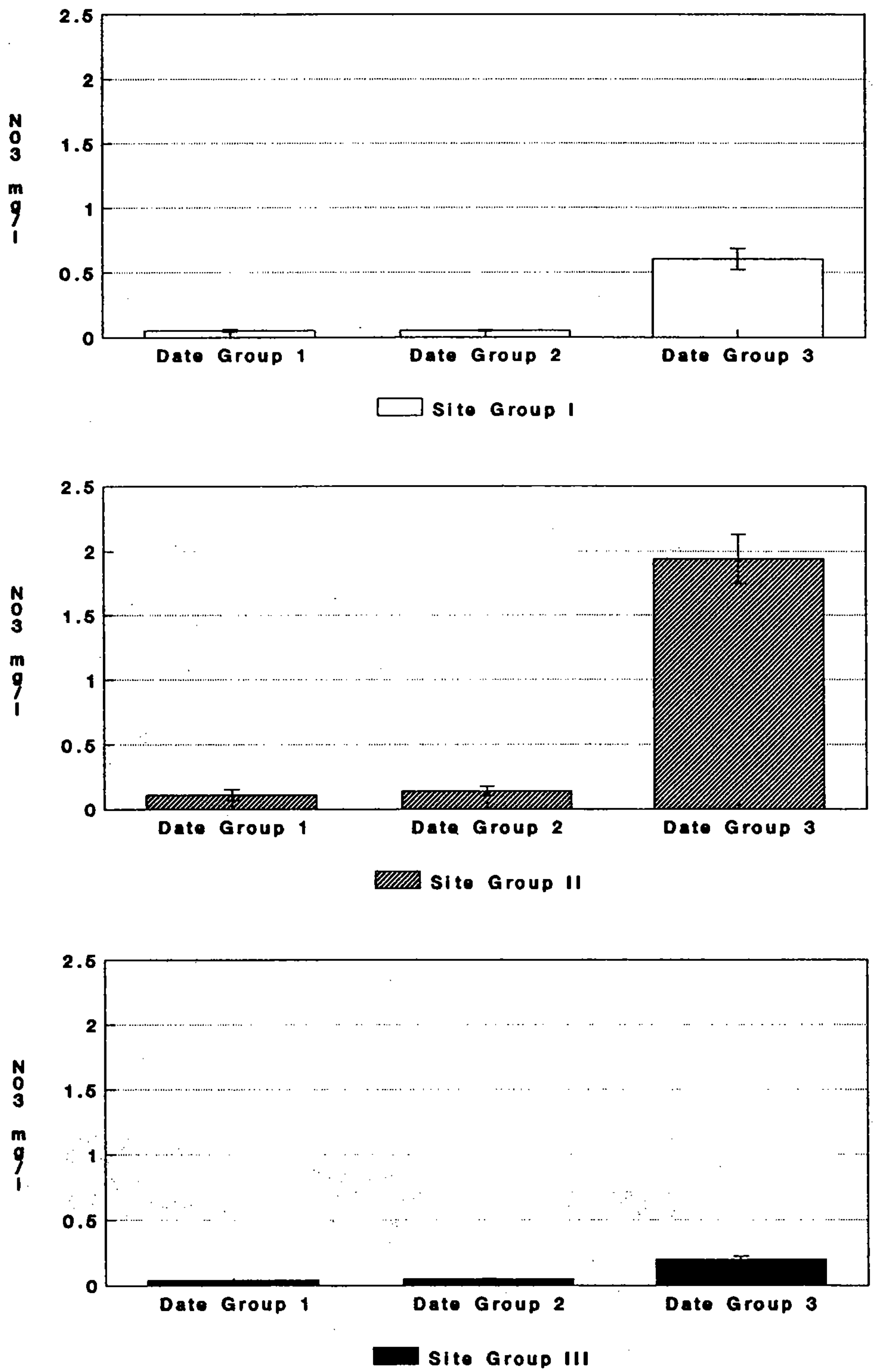


Figure 12. Mean concentrations of nitrate (mg/1) for site group-date group combinations resulting from cluster analysis of the 1980's water quality data. The vertical bars represent +/– one standard error of the mean.

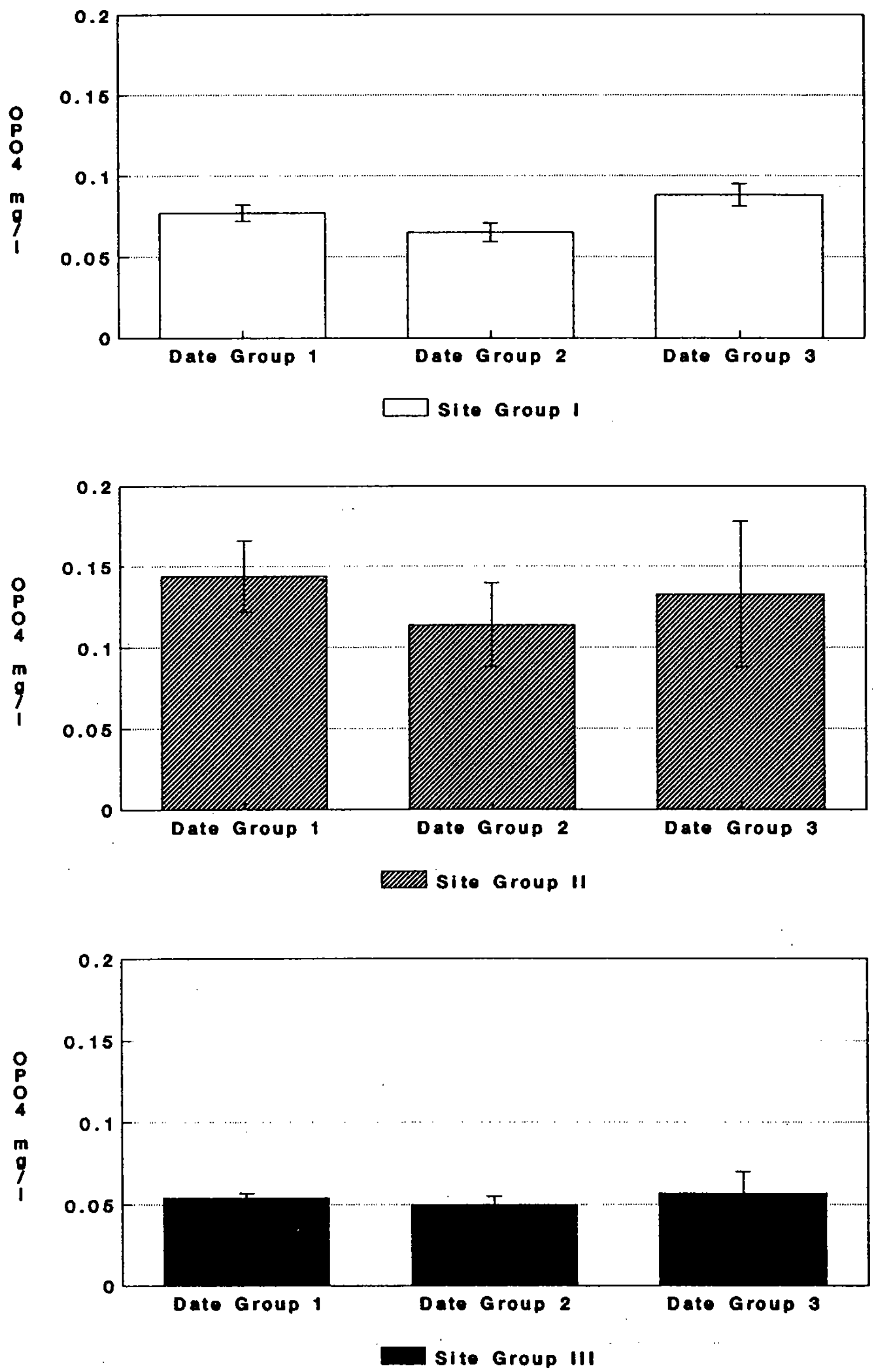


Figure 13. Mean concentrations of orthophosphates (mg/1) for site group-date group combinations resulting from cluster analysis of the 1980's water quality data. The vertical bars represent +/ - one standard error of the mean.

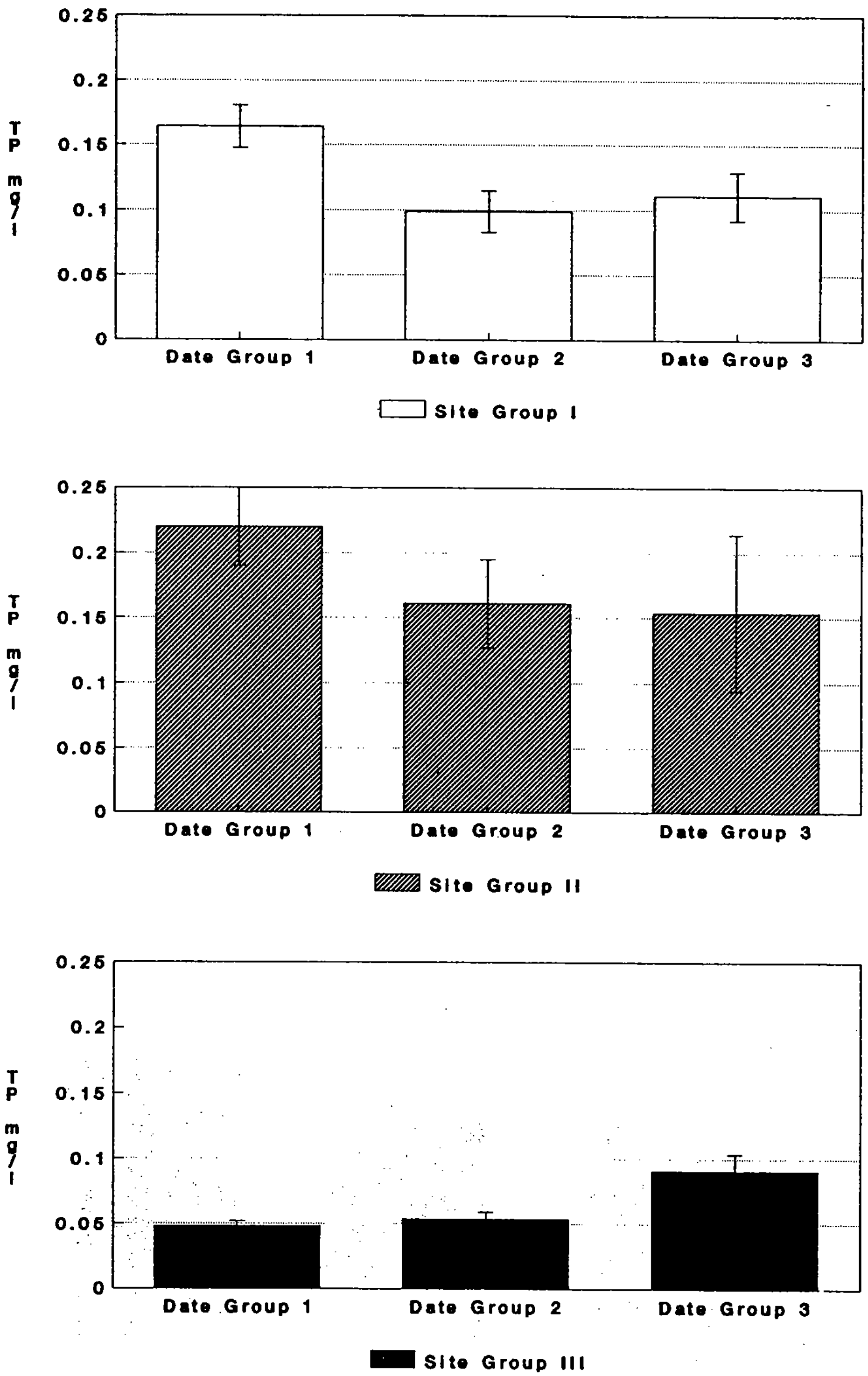


Figure 14. Mean concentrations of total phosphorus (mg/1) for site group-date group combinations resulting from cluster analysis of the 1980's water quality data. The vertical bars represent +/ – one standard error of the mean.

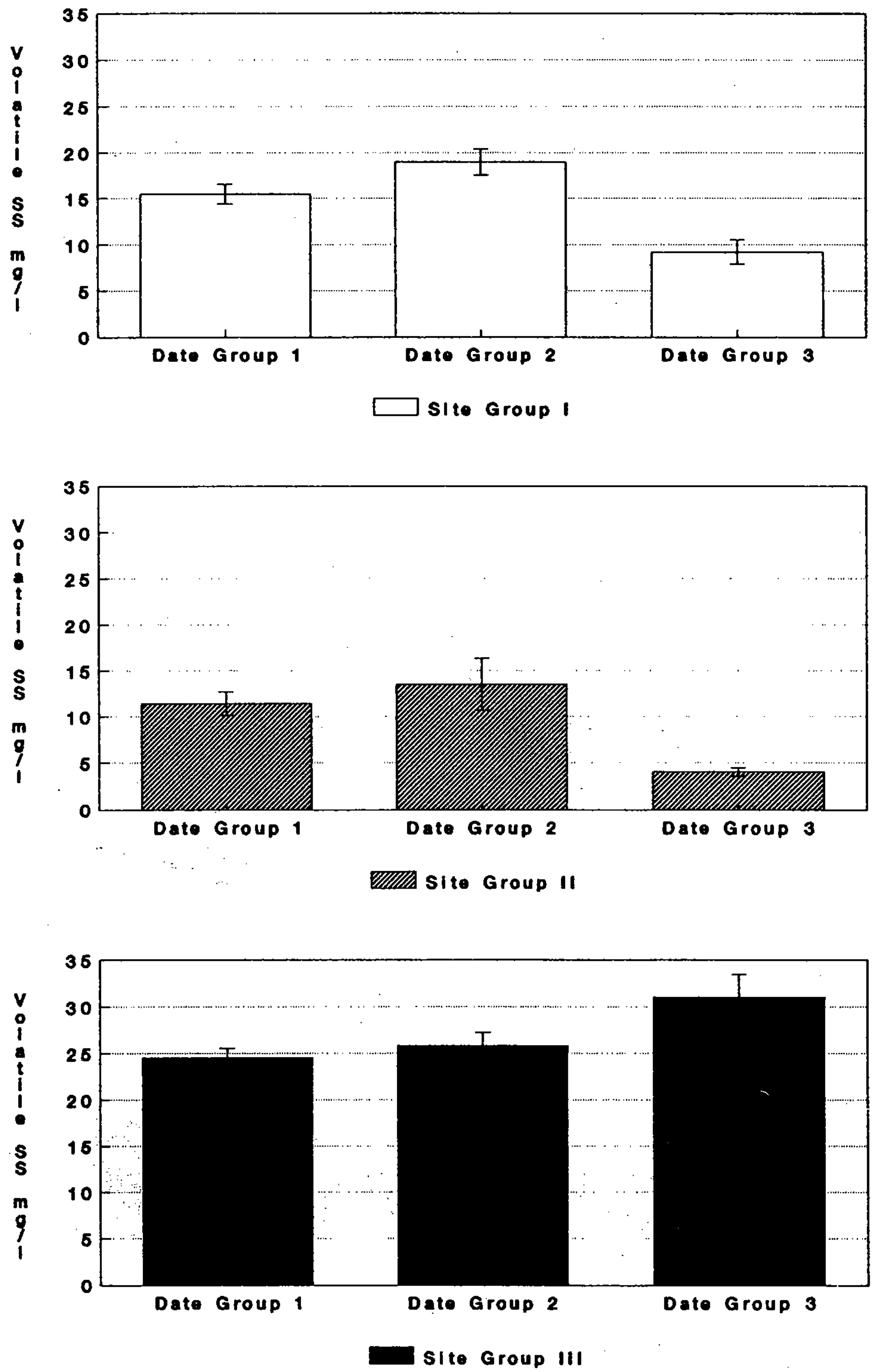


Figure 15. Mean concentrations of volatile suspended solids (mg/1) for site group-date group combinations resulting from cluster analysis of the 1980's water quality data. The vertical bars represent +/– one standard error of the mean.

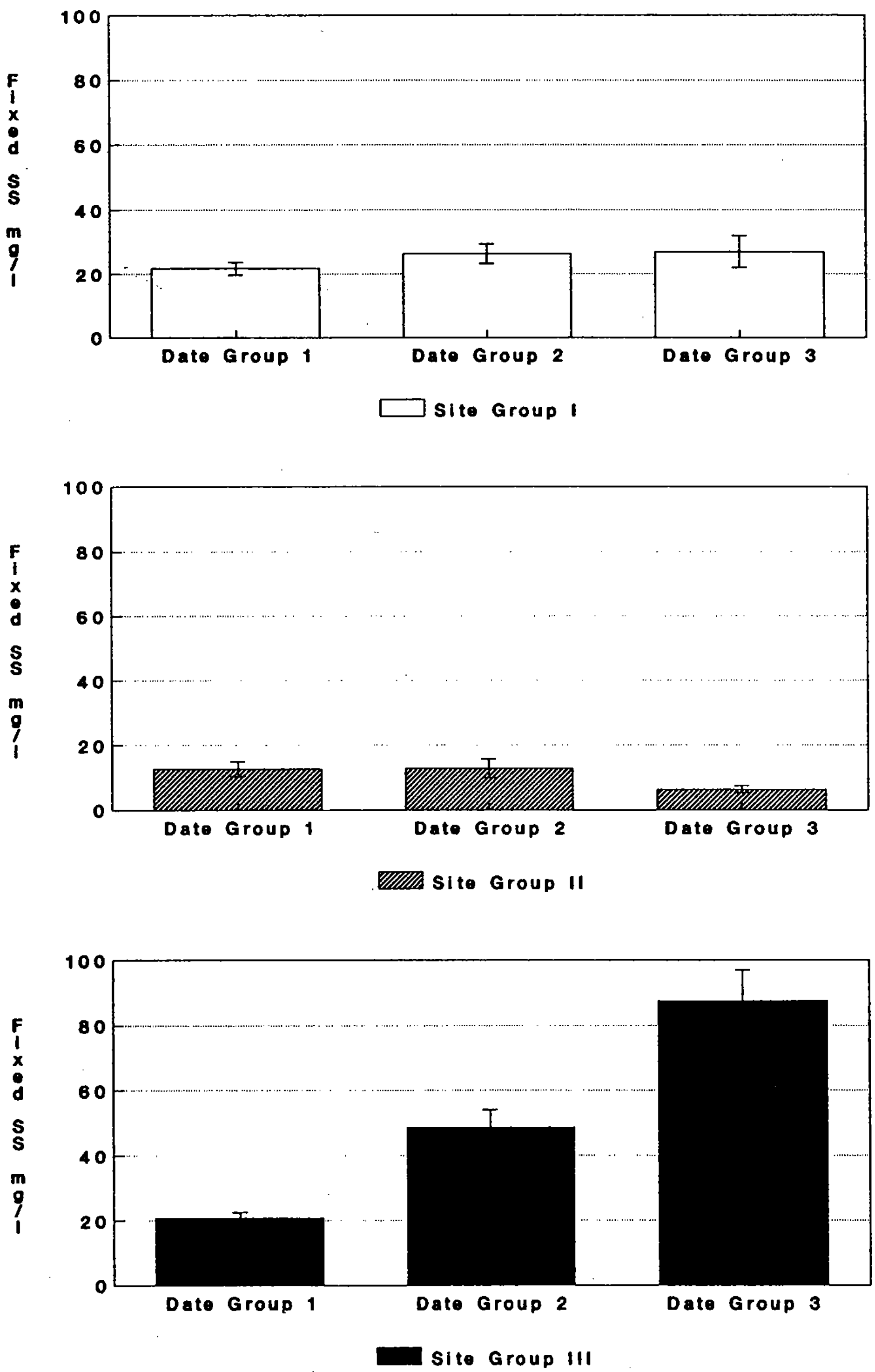


Figure 16. Mean concentrations of fixed suspended solids (mg/1) for site group-date group combinations resulting from cluster analysis of the 1980's water quality data. The vertical bars represent +/– one standard error of the mean.

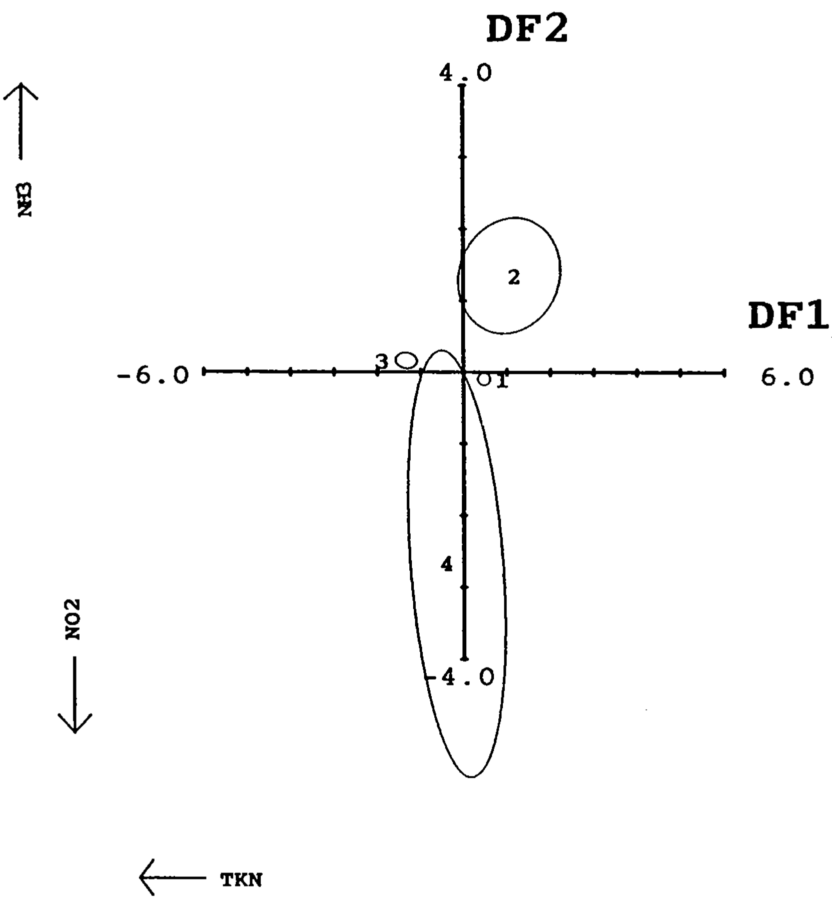


Figure 17. Confidence ellipses (a=0.05) for canonical discriminant scores of functions describing temporal differences in water quality conditions in the 1970's and 1980's. The date groups are those defined in Figure 2.

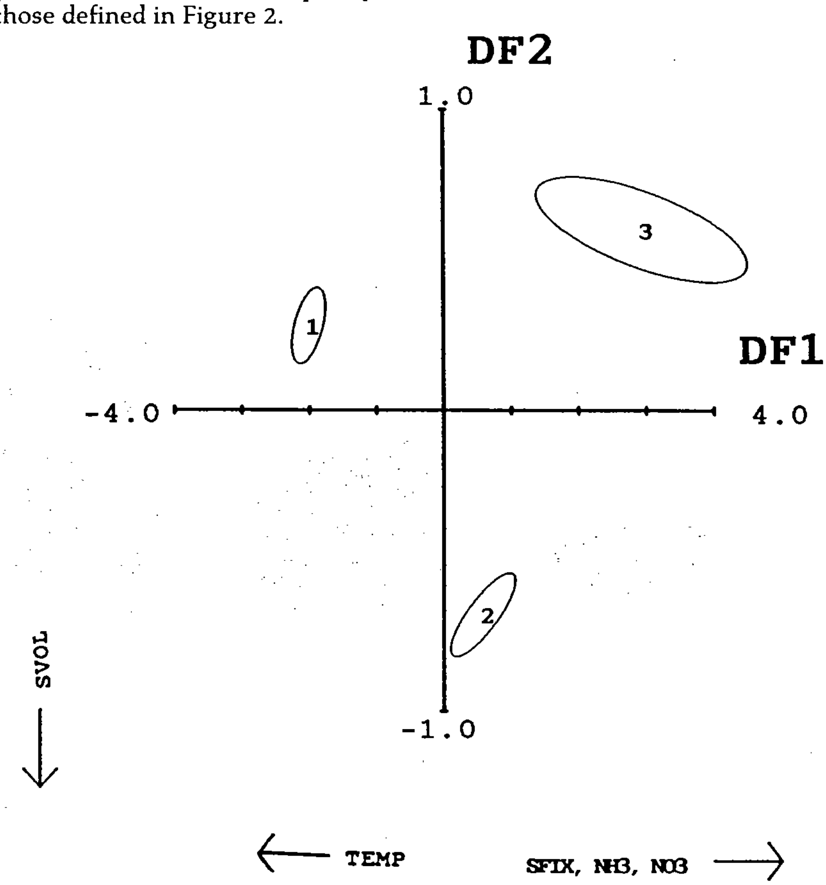


Figure 18. Confidence ellipses (a=0.05) for canonical discriminant functions describing temporal differences in water quality conditions in the 1980's. The date groups are those defined in Figure 4.

#	STATION	DESCRIPTION
1	5BWNC003.65	WEST NECK CREEK
2	5BMDY000.00	MOUTH OF MUDDY CREEK
3	5BHPC001.46	HELL POINT CREEK
4	5BHPC000.00	MOUTH OF HELL POINT CREEK
5	5BBBC000.76	BEGGARS BRIDGE CREEK
6	5BNWN001.84	MAWNEY CREEK ROAD BRIDGE
7	5BNWN000.00	MOUTH OF MAWNEY CREEK
8	5BBKY006.37	SOUTH OF DRUM POINT, OFF MOUTH OF MAWNEY CREEK
9	5BBKY003.47	OFF PELLITORY POINT
10	5BBKY000.99	NORTH OF BUCKLE ISLAND
11	5BBKY003.61	BACK BAY
12	5BBKY006.48	SAND BAY
13	5BBKY008.40	BUCK ISLAND BAY
14	5BSHB000.57	SHIPPS BAY, EAST
15	5BSHB001.15	SHIPPS BAY, WEST
16	5BXAJ001.01	NORTH BAY, LOWER
17	5BXAJ000.53	NORTH BAY, UPPER

NOTE: 'P' Designates Phytoplankton Station
All others are Water Quality Stations

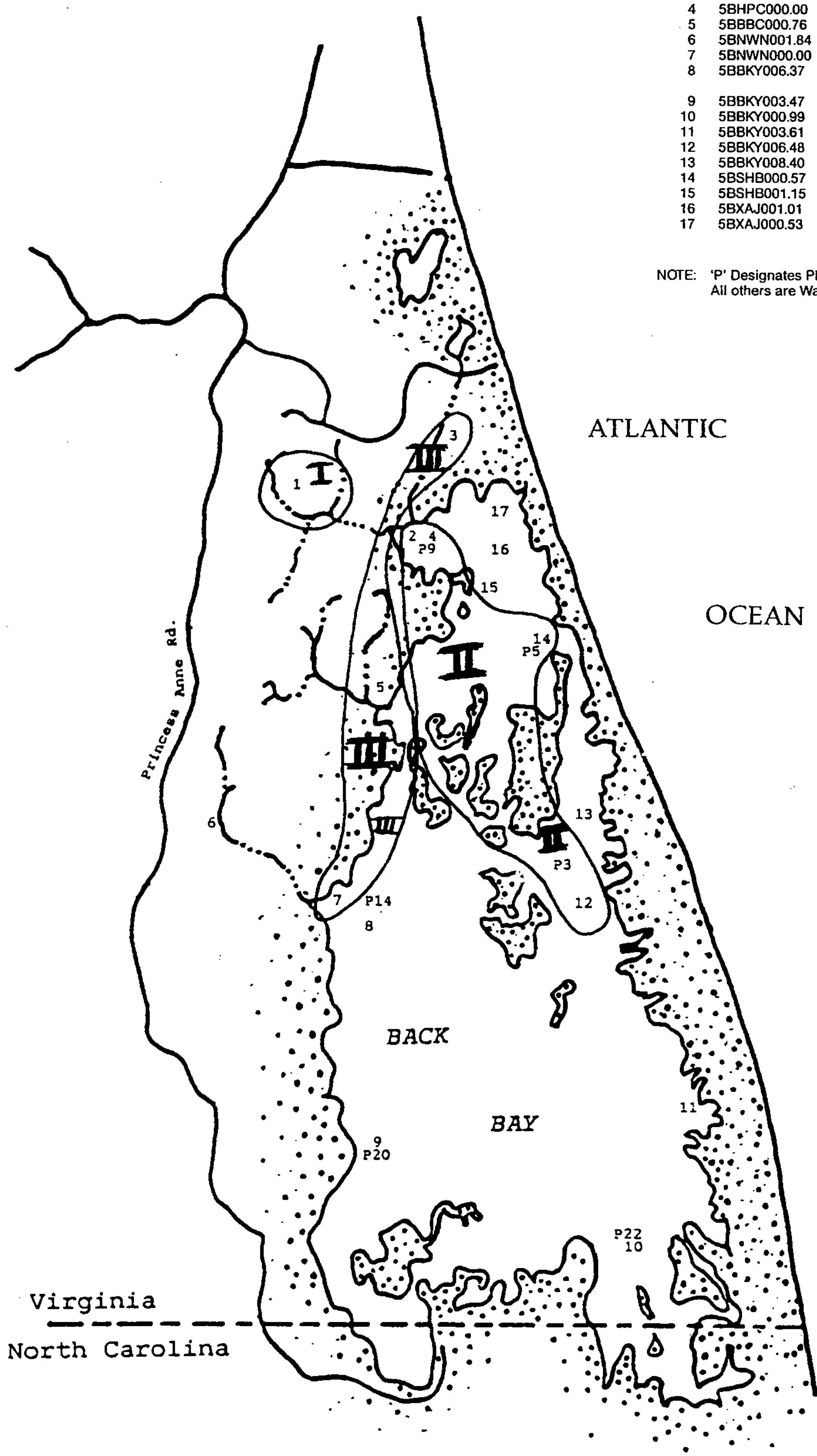


Figure 19. Map of Back Bay study area displaying collection sites and groups of sites displaying similar water quality patterns during the 1970's and 1980's. The site groups are those defined in Figure 3.

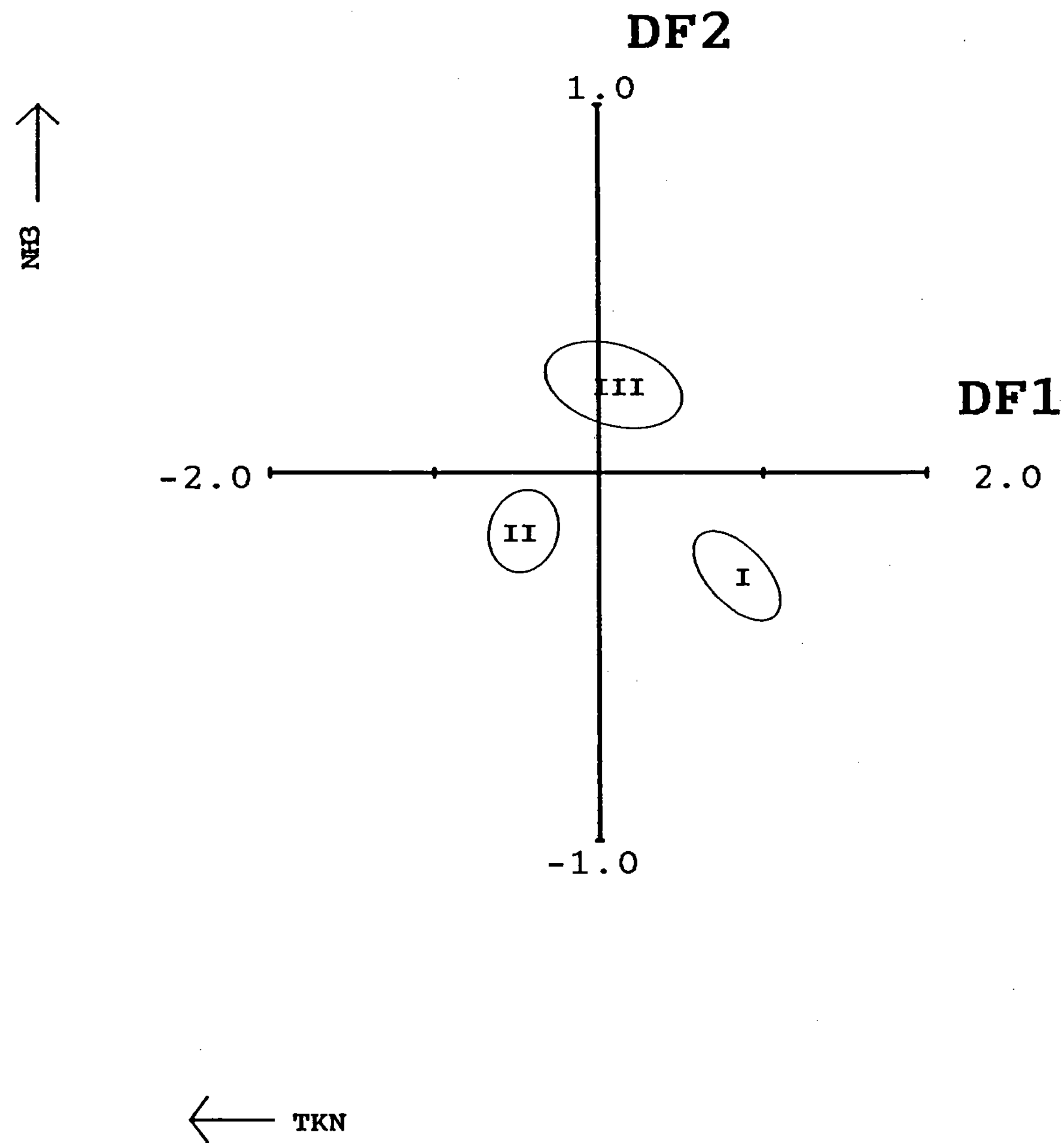


Figure 20. Confidence ellipses (a=0.05) for canonical discriminant scores of functions describing spatial differences in water quality conditions in the 1970's and 1980's. The site groups are those defined in Figure 3.

#	STATION	DESCRIPTION
1	5BWNC003.65	WEST NECK CREEK
2	5BMDY000.00	MOUTH OF MUDDY CREEK
3	5BHPC001.46	HELL POINT CREEK
4	5BHPC000.00	MOUTH OF HELL POINT CREEK
5	5BBBC000.76	BEGGARS BRIDGE CREEK
6	5BNWN001.84	MAWNEY CREEK ROAD BRIDGE
7	5BNWN000.00	MOUTH OF MAWNEY CREEK
8	5BBKY006.37	SOUTH OF DRUM POINT, OFF MOUTH OF MAWNEY CREEK
9	5BBKY003.47	OFF PELLITORY POINT
10	5BBKY000.99	NORTH OF BUCKLE ISLAND
11	5BBKY003.61	BACK BAY
12	5BBKY006.48	SAND BAY
13	5BBKY008.40	BUCK ISLAND BAY
14	5BSHB000.57	SHIPPS BAY, EAST
15	5BSHB001.15	SHIPPS BAY, WEST
16	5BXAJ001.01	NORTH BAY, LOWER
17	5BXAJ000.53	NORTH BAY, UPPER

NOTE: 'P' Designates Phytoplankton Station
All others are Water Quality Stations

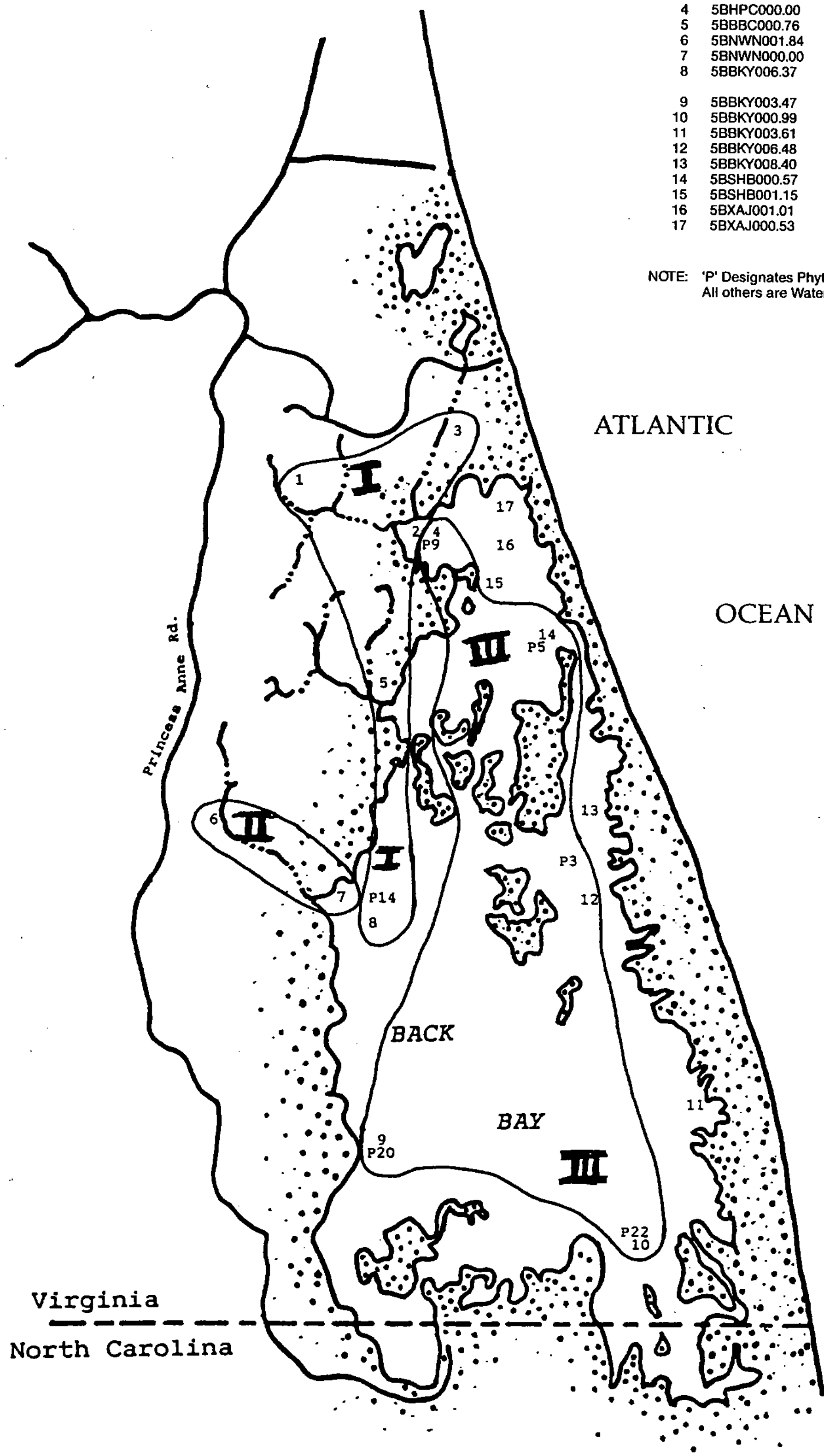


Figure 21. Map of Back Bay study area displaying collection sites and groups of sites displaying similar water quality patterns during the 1980's. The site groups are those defined in Figure 5.

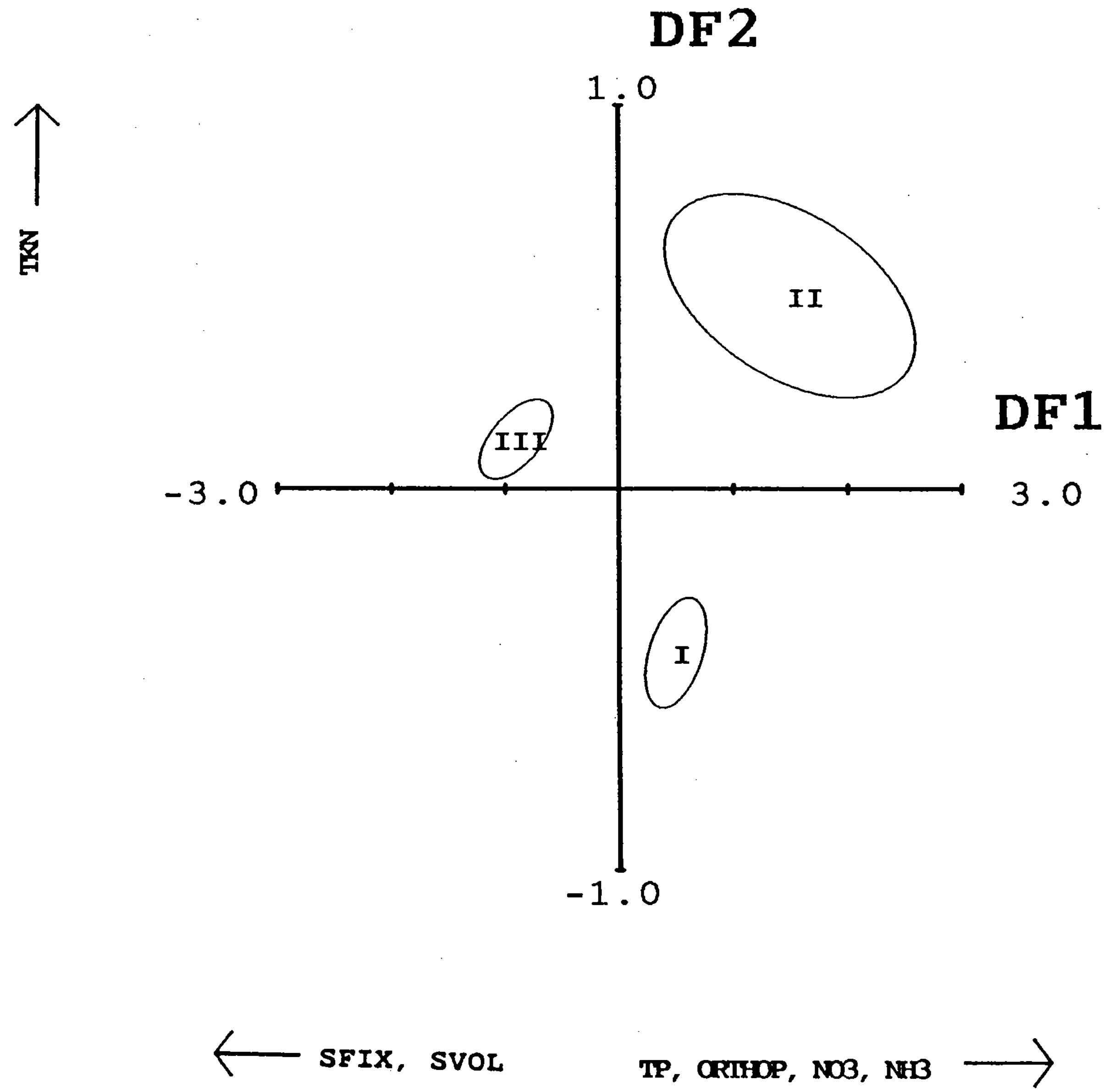
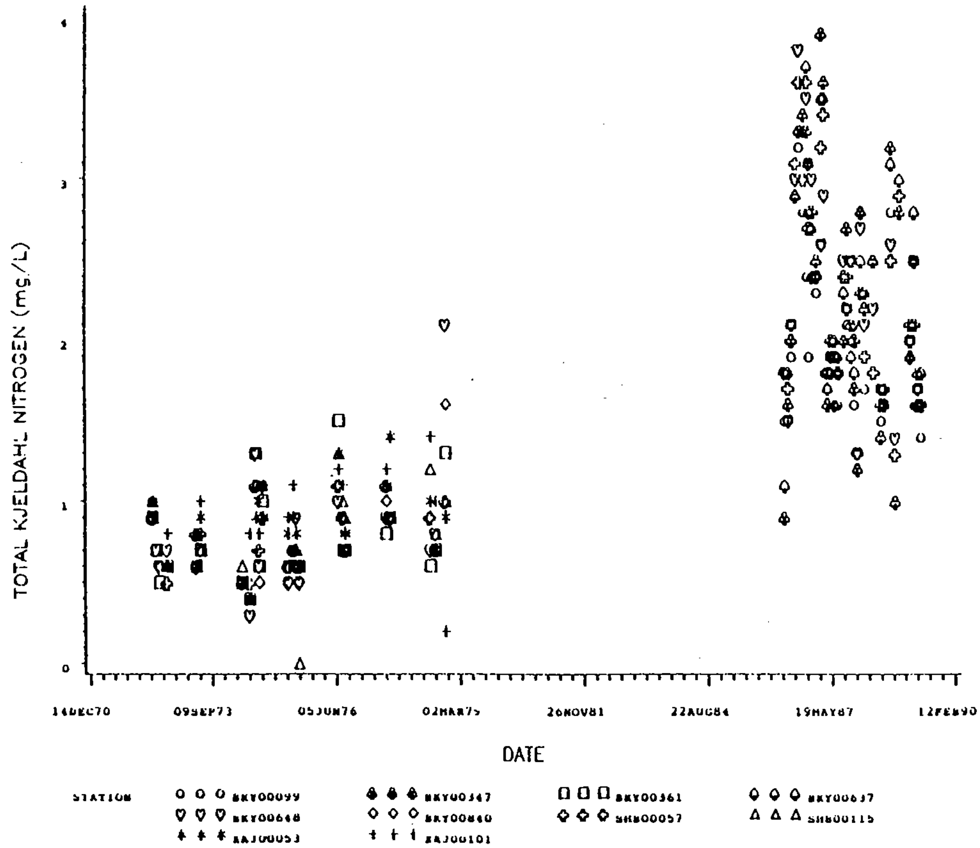


Figure 22. Confidence ellipses (a=0.05) for canonical discriminant scores of functions describing spatial differences in water quality conditions in the 1980's. The site groups are those defined in Figure 5.

a) 

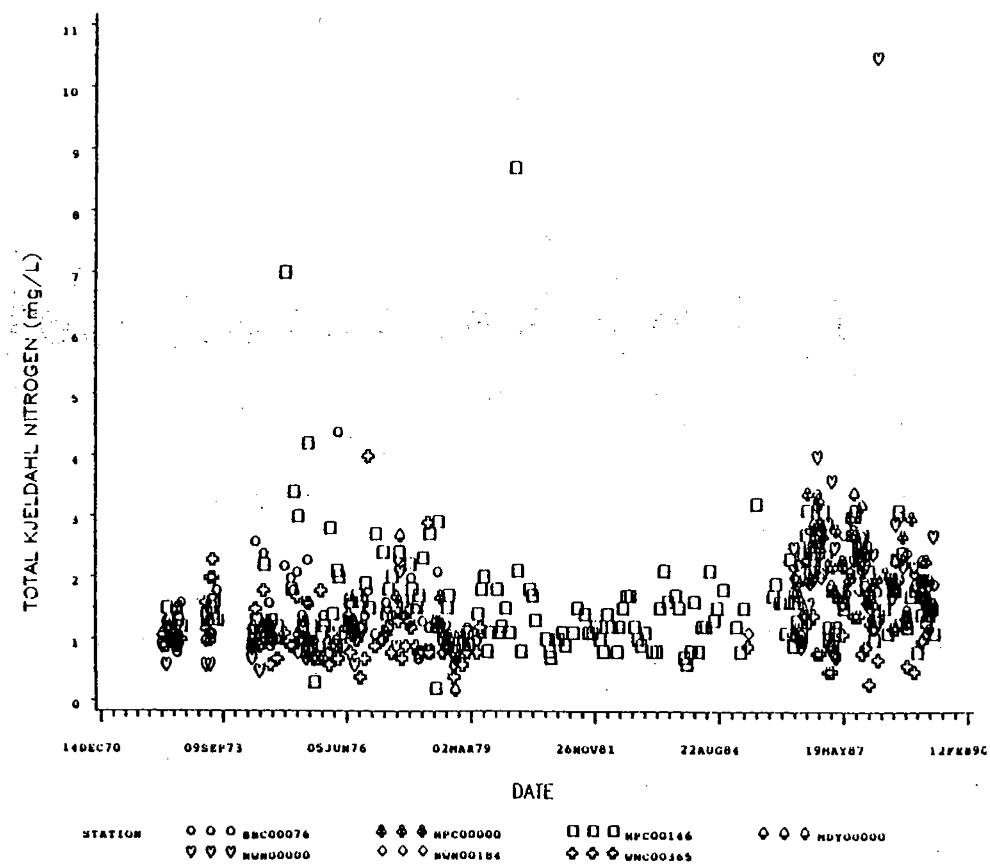
b) 

Figure 23. Scatterplots for Total Kjeldahl Nitrogen concentrations (mg/l) over time: a) main Bay sites; and b) tributary creeks.

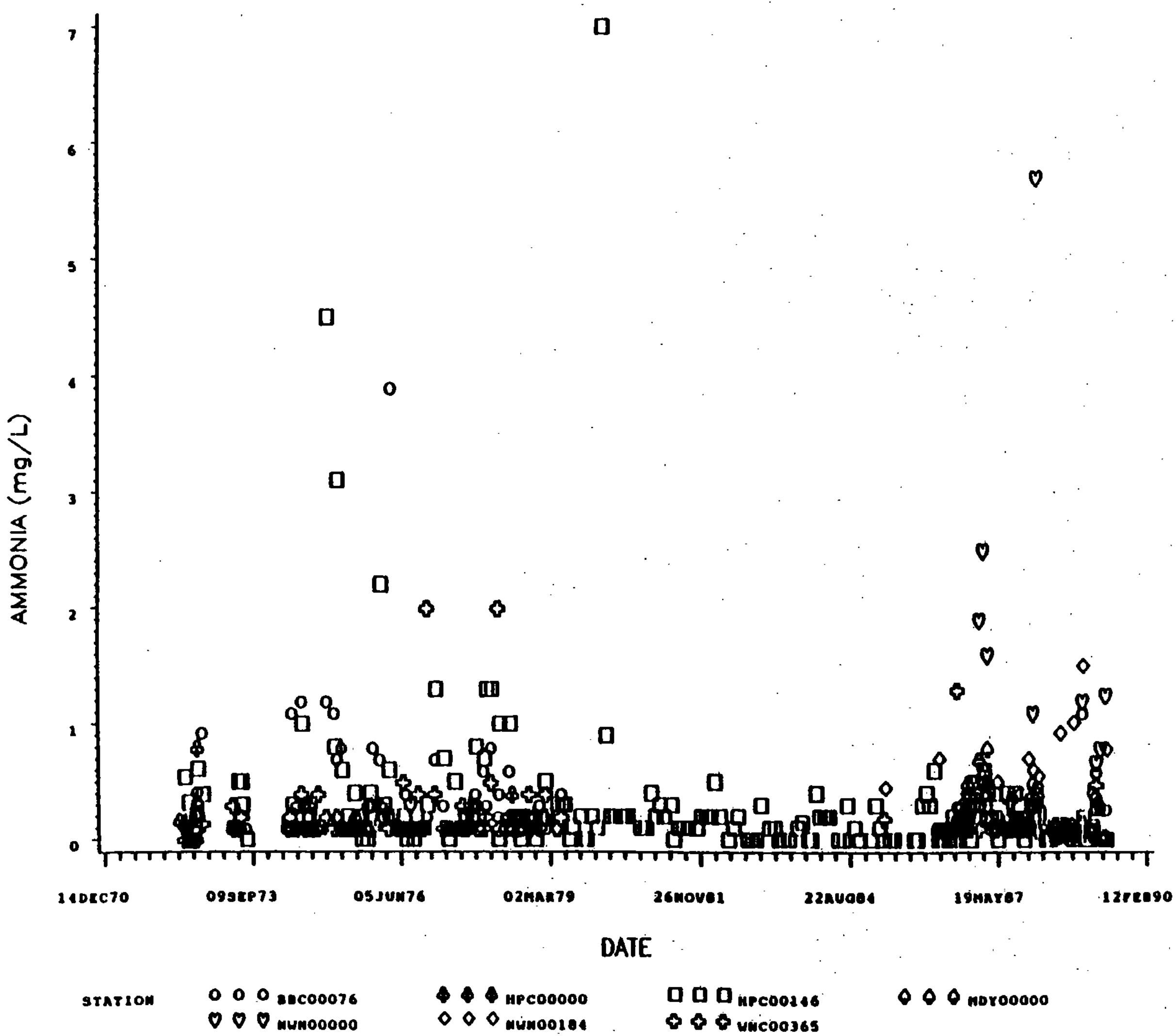
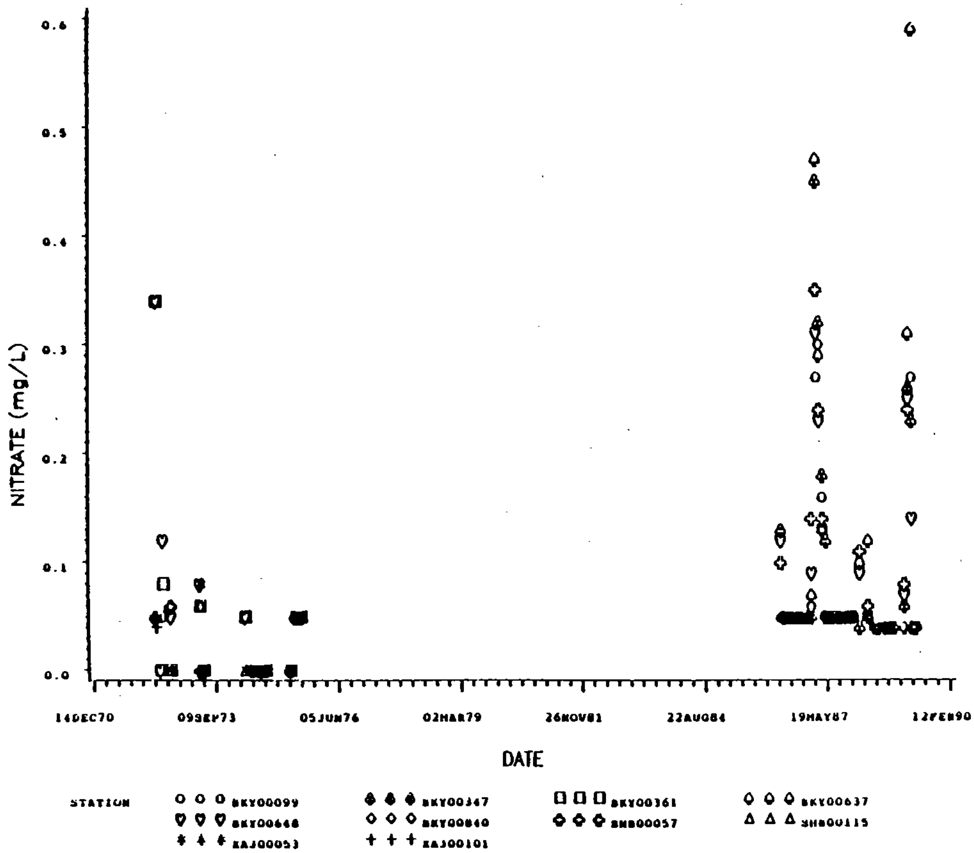


Figure 24. Scatterplot for ammonia concentrations (mg/l) over time for tributary creeks.

a)



b)

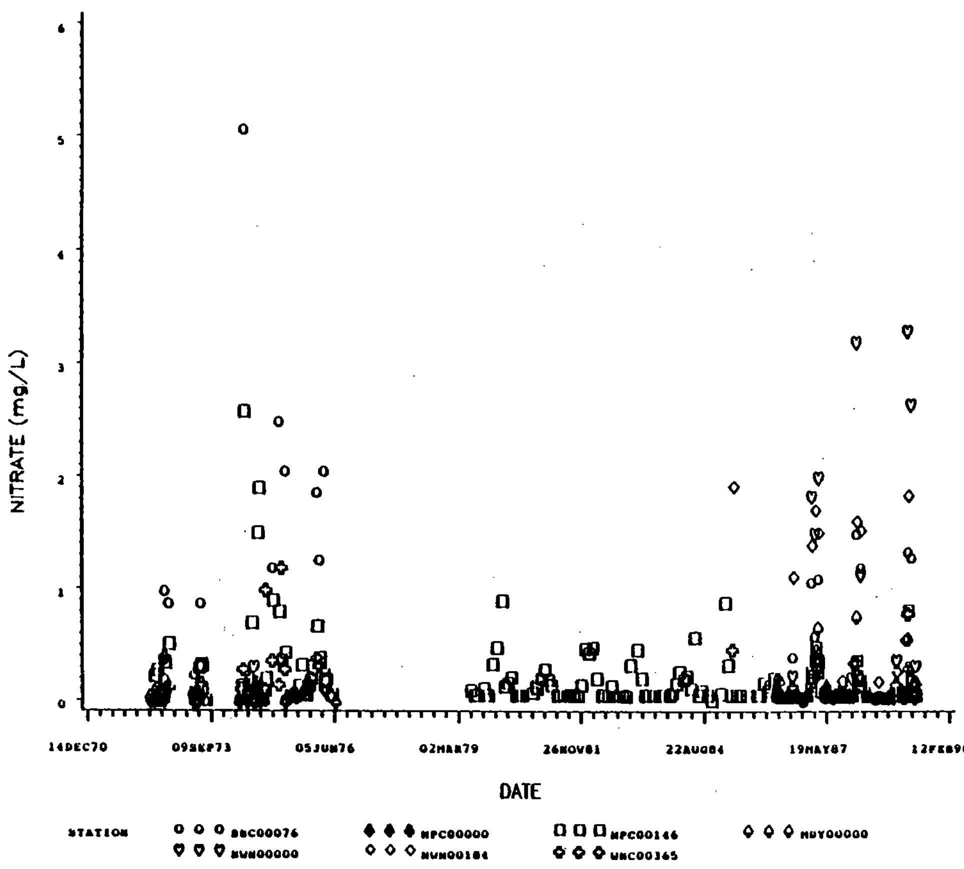


Figure 25. Scatterplots for Nitrate concentrations (mg/l) over time: a) main Bay sites; and b) tributary creeks

a) b)

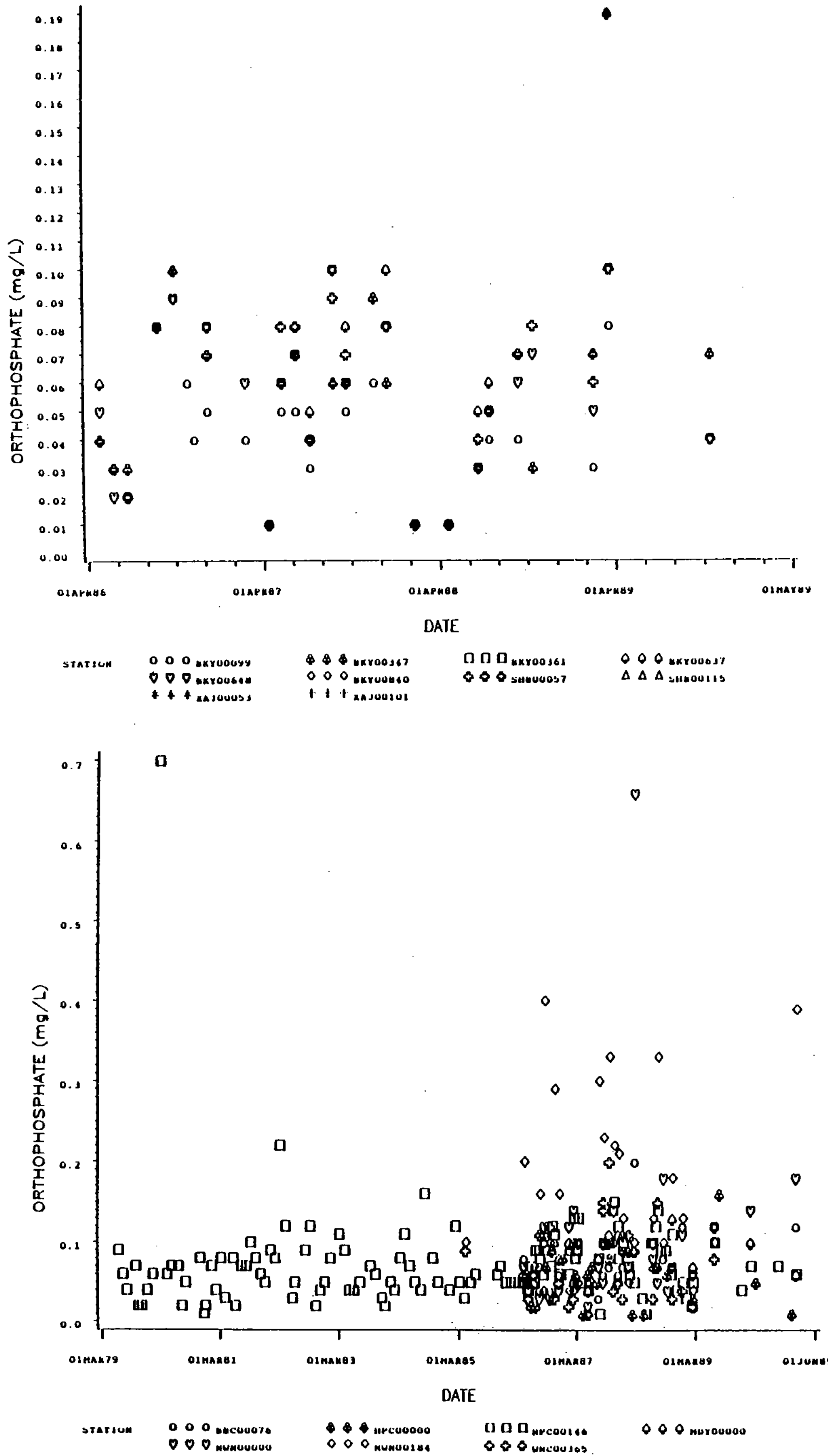


Figure 26. Scatterplots of orthophosphate concentrations (mg/l) over time: a) main Bay sites; and b) tributary creeks.

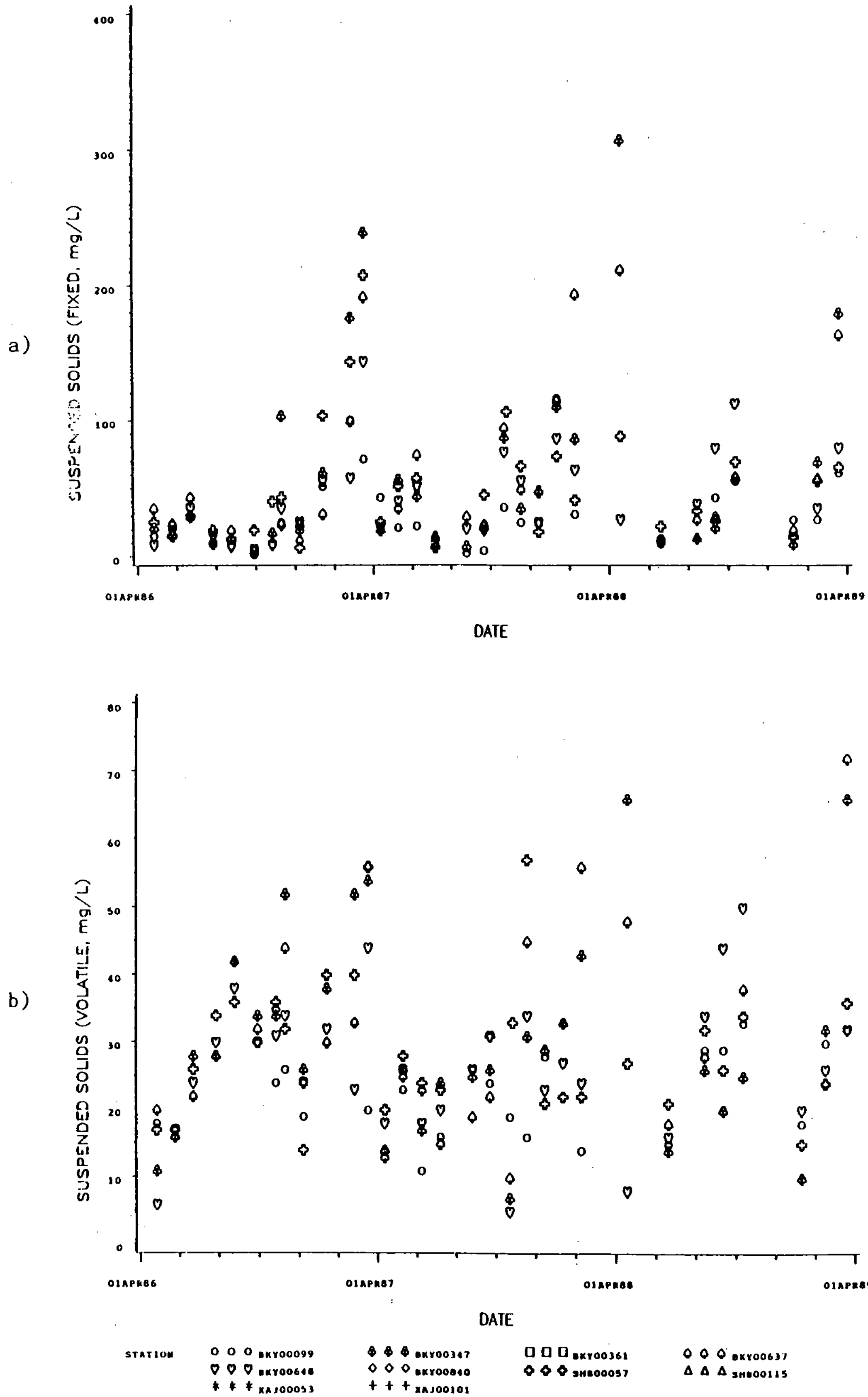
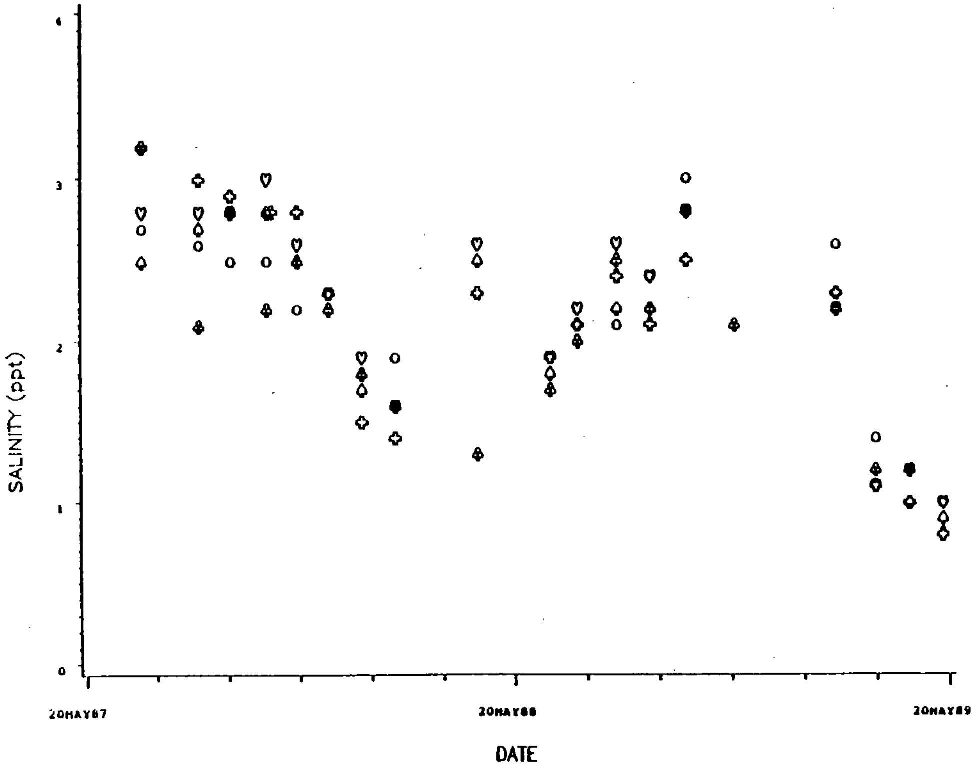


Figure 27. Scatterplots for suspended solids concentrations (mg/l) over time: a) fixed suspended solids; and b) volatile suspended solids.

a)



b)

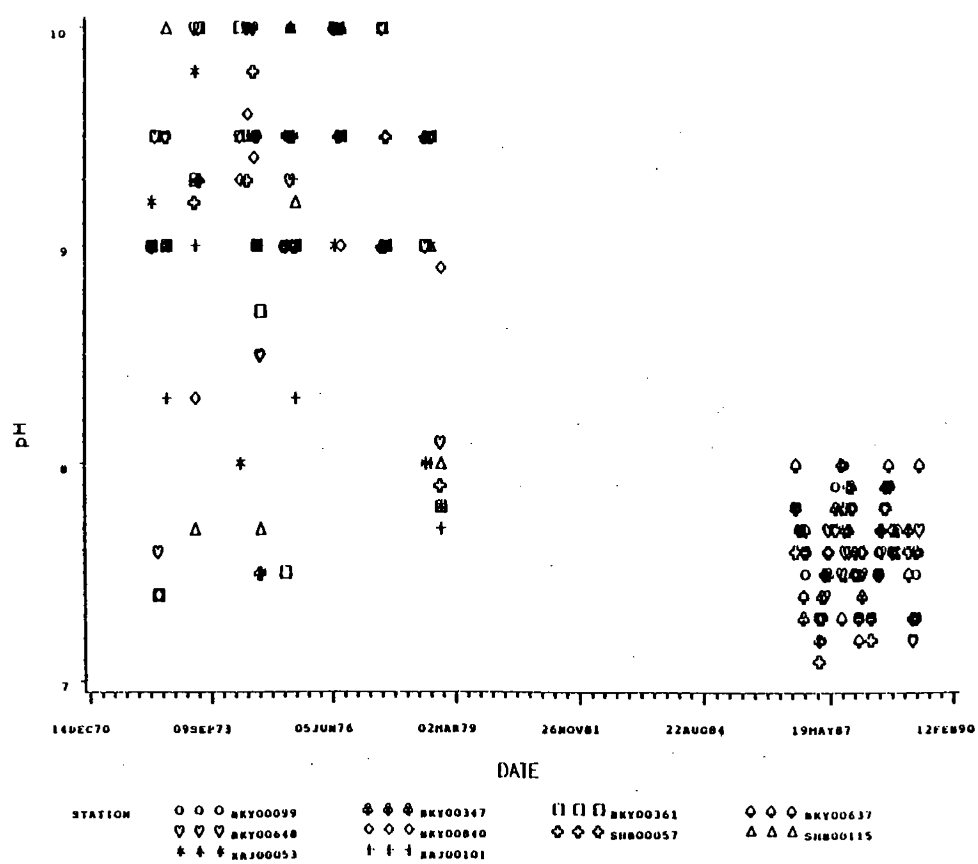


Figure 28. Scatterplots of salinity (a) and pH (b) measurements over time.

II. Fauna

Community Structure of the Macrobenthos in Back Bay, Virginia

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Abstract: A study of the subtidal macrobenthos in Back Bay, Virginia was conducted to examine community structure in relation to sedimentary and water quality characteristics. Samples were collected in August and November of 1987 and February and May of 1988 at ten stations.

From a cluster analysis of ten collection stations, three site groups were identified. Species composition between site groups was relatively homogeneous. Discriminant analysis indicated that eight species accounted for most of the variation between site groups. A comparison of plots of the biological and environmental variables in discriminant space suggested that variation in the biological data between site groups was related in part to silt-clay content, organic content, and particle size of the sediment.

Three temporal groups were identified from a second cluster analysis of data averaged over all collection stations by collection date. Discriminant analysis indicated that six species accounted for most of the variation between temporal groups. Temporal variation in macrobenthic community structure was the result of reproductive and recruitment events of these six species.

Species diversity indices were similar to values obtained in oligohaline regions of the Chesapeake Bay (Dauer 1988; 1989). Community density was higher and community biomass was lower than values found in the Chesapeake Bay oligohaline areas (Dauer, 1988; 1989). Major changes in total community density and biomass were related to spatial and temporal changes in two dominant species: *Chironomus riparius* (Insecta) and *Scolecolepides viridis* (Polychaeta).

Introduction

Benthic macrofauna are an important component of marine and estuarine systems. These organisms are a food source for higher trophic levels (Holland et al. 1980; Dauer et al. 1982; Virstein 1977), affect both the physical and chemical properties of the sediment and the overlying water column (e.g. Aller 1978, 1980; Rhoads 1973; Rhoads and Young 1970) and influence nutrient cycling (Flint and Kamykowski 1984; Rowe et. al 1975; Zeiteschel 1980). These characteristics suggest that monitoring of the benthos should provide important information for making management decisions in marine systems (Bilyard 1987). Also, the life span and sedentary nature of these organisms make them good indicators of water quality and the effects of man-made disturbances on aquatic systems (Bilyard 1987; Reish 1973).

Studies of the macrobenthos in the state of Virginia have focused primarily on the Chesapeake Bay and its tributaries (Boesch 1972, 1973, 1977a, Boesch et al. 1976a, 1976b; Dauer et al. 1984; Dauer et al. 1989; Hawthorne and Dauer 1983; Tourtellote and Dauer 1983). Back Bay an area just south of Chesapeake Bay has received little attention. It is an important commercial and recreational fishery, as well as, a major wetlands area and feeding ground for waterfowl. Only two unpublished studies of the benthos have been conducted in Back Bay (Robinson 1978; Wollitz 1962).

The purpose of this study was to describe the macrobenthic communities in Back Bay and examine possible relationships between macrobenthic community structure and sedimentary characteristics. Temporal patterns in community structure over a one year period were also examined.

Description of Study Area

Back Bay is a large shallow estuary located in the southern sector of the city of Virginia Beach. It is the northernmost body of a chain of similar embayments which are separated from the Atlantic Ocean by the Outer Banks - Cape Hatteras barrier island chain. The Bay extends approximately 17.7 km from Sandbridge to Currituck Sound (Fig. 1). Width of the Bay ranges from 3.2 km at the northern end to 8 km at the southern end.

Back Bay consists of approximately 9950 hectares of open water and has a total drainage basin of approximately 270 km2. Several small creeks drain into Back Bay. Average depth of the bay is 1.3 m with a maximum depth of 3 m. Lunar tidal amplitude is estimated to be 0.7 m; however, wind driven tides virtually eliminate the influence and periodicity of lunar tides (Mann 1983).

Methods and Materials

Sampling procedures

A total of 120 benthic samples were collected at 10 stations during August and November of 1987 and February and May of 1988. The collection dates will be referred to as Summer (August), Fall (November), Winter (February) and Spring (May). Locations of the sampling stations are shown in Figure 1.

Three replicate samples were taken at each station using a hand-held coring device. The core had a length of 22.9 cm, an internal diameter of 7.6 cm, and sampled a total surface area of 45.4 cm^2. During the last three sampling events, an additional core was taken at each station from which an aliquot of sediment was removed for particle size analysis and volatile solids content analysis. Temperature, dissolved oxygen levels, and salinity were recorded at each station using a Hydrolab SVR-2.

Benthic samples were sieved through a 0.5 mm sieve screen and the material retained on the screen was washed into prelabeled cloth bags. Specimens were relaxed in dilute isopropyl alcohol and preserved in a 10% solution of formalin and rose bengal.

Benthic Sample Processing

Benthic samples were sorted in white enamel pans with the aid of fiber optic illuminators. Organisms were counted and identified to the lowest possible taxon. Biomass estimates of the major taxa were recorded as ash-free dry weight (AFDW) biomass. AFDW biomass was determined by drying each major taxon for 24 hours at 60°C and then ashing the sample at 550°C and taking the difference between the dry and ashed weights. AFDW Biomass values less than 1 mg were recorded as 1 mg.

Sediment Analysis

Silt-clay and sand fractions of the sediment were separated by wet sieving the sediment through a 63 um sieve screen. The sand fraction was transferred into culture dishes, placed in a drying oven at 65°C for 24 hours, and divided into whole phi intervals by sieving through a series of Wentworth graded screens. Each fraction was transferred to a pre-tared plastic pan and weighed using a Sartorius analytical balance.

Particle size distribution of the silt-clay fraction was determined using pipette analysis (Folk 1974). The percentage of sand and silt-clay, mean grain size, and sorting coefficients were calculated using a computer program designed by Darby and Wobus (1976). Volatile solids content of the sediment was calculated as the ash-free dry weight (AFDW) of the sediment divided by the dry weight of the sediment expressed as a percentage.

Data Analysis

A one-way ANOVA was used to determine significant differences in log-transformed abundances, biomass and diversity indices between stations, site groups, and temporal groups. Duncan's range test was used to determine specific differences between stations, site groups, and temporal groups (Sokal and Rohlf 1981).

Species diversity was calculated using the Shannon-Weaver index:

$$H' = - \sum_{i=1}^{s} pilog2pi$$

where pi is the proportion of the i-th species and s is the number of species (Pielou 1966). Species richness was calculated using Margelef's index:

$$SR = (S - 1)/lnN$$

where S is the total number of species and N is the total number of individuals collected at the station. Evenness was measured using Pielou's index:

$$J = H'/log2S.$$

Stations and collection times were classified into spatial groups and temporal groups using log transformed abundance data. The variance between sites and times was obtained by calculating the Euclidean distance between sites and times (over all species) after sites and times were centered to their respective means. The variance estimates were then used as a measure of dissimalarity for cluster analyses to determine the spatial and temporal groups (Williams and Stephenson 1973). A flexible sorting strategy was used with a cluster intensity coefficient of -0.25 (Boesch 1977b).

The mean variance between sites (over all times) and between times (over all stations) was determined by calculating the variance attributable to the species over all inter-site and inter-time comparisons, and then finding the mean of these values. The means were examined to determine the relative importance sites and times had on the variation in the data (Williams and Stephenson 1973).

Multivariate analysis of variance (MANOVA) was used to determine if there were significant differences in centroids between spatial and temporal groups. Plots of the site and time groups on the major discriminant functions were used to determine which species provided the best discrimination between groups. Those species with high loadings and significant ANOVAs were used as axis labels for the discriminant functions. Three species (the cumacean *Almyracuma proximoculi*, the isopod *Edotea triloba* and the chironomid *Djalmebatista pulcher*) occurred only once during the entire study and were eliminated from all analyses.

A second discriminant analysis was conducted using the water quality and sedimentary variables. Plots of the site groups and the environmental variables in discriminant space were compared to determine if the separation between site groups was influenced by the environmental parameters (Green 1979).

Results

Water quality data

No significant differences were found in any of the water quality parameters between stations ($p<0.05$). Salinity values were oligohaline with a baywide average of 2.4 ppt. Mean baywide salinity declined from 2.9 ppt in the summer to 1.9 ppt in the spring (Fig. 2A). Temperature showed a typical seasonal pattern with only small variations between stations. Dissolved oxygen values were generally high throughout the bay and were highest during the fall and winter when temperatures were lowest (Fig. 2B). Station means were all above 9.0 mg/l and anoxic conditions were never observed during this study. A minimum dissolved oxygen value of 5.5 mg/l was recorded at Station 2 during the summer.

Sedimentary data

Sediments at Stations 1, 2, 4, and 10 had high percentages of silt-clay and mean grain sizes ranging from medium to coarse silts (Folk 1974). The sediments at these stations were poorly sorted and organic content ranged from 4.10% to 6.52%. Stations 3 and 6 had intermediate values for silt-clay, were poorly sorted, and had a mean grain size in the coarse silt range (Folk 1974). Four stations (5, 7, 8, 9) had sediments consisting of well sorted fine sands (Folk 1974). Sand content at these stations ranged from 90% to 99% and organic content was very low ranging from 0.64% to 1.20%.

General community description

A total of 2803 individuals representing 20 invertebrate taxa (Table 1) was collected. Annelids comprised 48.4% of the total number of individuals collected, insects 48.2%, other arthropods 2.5% and molluscs less than 1%.

Larvae of the insect *Chironomus riparius* represented the most abundant species and accounted for 45.5% of total number of individuals and 28.2% of the biomass (AFDW) collected. The spionid polychaete *Scolecolepides viridis* accounted for 33.0% of the specimens recorded and 56.5% of the biomass (AFDW).

Density ranged from 7973 ind/m^2 (Station 2) to 3747 ind/m^2 (Station 7). However, there were no significant differences in mean density between stations ($p>0.05$). Biomass (AFDW) ranged from 4611 mg/m^2 at Station 7 to 1376 mg/m^2 at Station 10. There was a significant difference in mean community biomass between stations ($p<0.05$). The number of species per replicate, species richness, and species diversity was highest at Station 5. There were no significant differences in any of the diversity indices between stations ($p>0.05$).

Spatial patterns in community structure

On the basis of the classification analysis, three site groups were recognized: 1) the Mud Site Group - composed of those stations with the highest silt-clay and organic content (Stations 1, 2, 10), 2) the Mixed Site Group - comprised of Stations 3 and 6 with an intermediate silt-clay content, and Station 8 which had a low silt-clay and organic content, and 3) the Sand Site Group composed of the remaining stations with a high sand content and low organic content (Stations 5, 7, 9) and Station 4 (Fig. 3).

Table 2 presents the top density dominants for each of the three site groups. Density dominants were those species which accounted for a minimum of 1% of the number of individuals collected at each site group. Species composition between site groups was relatively homogeneous and major differences between site groups were due primarily to differences in the abundance of dominant species.

Abundance of *C. riparius* was significantly higher at the Mud site group than the Sand Site Group but not significantly different at the Mixed Site Group (Table 3). Biomass of *C. riparius* was significantly higher at the Mud Site Group (Table 4). Abundance and biomass of the chironomid *Clinotanypus pinguis* were significantly higher at the Mud Site Group (Tables 3-4). The oligochaete *Tubificoides heterochaetus* and the amphipod *Leptocheirus plumulosus* had significantly higher abundances and biomass at the Mixed Site Group (Table 3-4). Abundance and biomass of the polychaetes *S. viridis* and *Hobsonia florida*, the chironomid *Polypedilium convictum*, and the bivalve *Rangia cuneata* were significantly higher at the Sand Site Group (Tables 3-4). There were no significant differences in density or biomass between site groups for the oligochaete *Limnodrilus* spp., or the amphipods *Gammarus daiberi* and *Monoculodes edwardsi* (Table 3-4).

The MANOVA indicated a significant difference between the centroids of the site groups. There was a significant separation between site groups with respect to the first (DF-1) and second (DF-2) discriminant functions. DF-1 accounted for 52% of the variance and DF-2 explained 48% of the variance. Separation of the site groups occurred along both DF-1 and DF-2 (Fig. 4). The Sand Site Group can be characterized as having higher abundances of *S. viridis*, *H. florida*, *P. convictum* and *R. cuneata* (Fig. 5A-D), while the Mud Site Group had higher densities of *C. riparius* and *C. pinguis* (Fig. 6A-B). The Mixed Site Group had higher densities of *T. heterochaetus* and *L. plumulosus* (Fig. 6C-D).

Table 5 lists the mean community parameters for each of the site groups. Total community density was slightly higher at the Mud and Mixed sites although there was no significant difference in community density between site groups (Table 5). Total community biomass was significantly higher at the Sand Site Group (Table 5). There were no significant differences in any of the diversity indices between site groups (Table 5).

There was a significant difference in centroids between site groups with respect to the physical parameters. There was a significant separation between site groups with respect to the first discriminant function (DF-1), which explained 97% of the variance. The Mud and Sand sites appear to separate well in relation to silt-clay content, volatile solids and mean phi size ; however, there was some overlap between these two sites groups and the Mixed Site Group (Fig. 7). Mean values of the physical and sedimentary parameters for each site group are presented in Table 6.

Figure 8 shows the mean values of silt-clay, organic content, and mean phi for each station. Sediments at Station 8 were similar to those of the Sand Site Group while those at Station 4 more closely resembled those of the Mud Site Group. Stations 3 and 6 of the Mixed Site Group had intermediate values for silt-clay, organic content, and mean phi. This could explain the degree of overlap between site groups in relation to the physical parameters.

Temporal trends in community structure

The second classification analysis identified three temporal groups: 1) Summer 2) Fall and 3) Winter-Spring (Fig. 9).

Abundance and biomass of *C. riparius*, *P. convictum*, and *R. cuneata* were significantly higher during the Summer (Table 7-8). Abundance and biomass of the amphipods *Gammarus daiberi* and *Monoculodes edwardsi* were highest during the Winter-Spring temporal periods (Tables 7-8). Abundance of *S. viridis* was significantly higher during the Winter-Spring season (Table 7); however, there was no significant difference in biomass between temporal groups for this species (Table 8). There were no significant differences in abundance or biomass of *T. heterochaetus*, *Limnodrilus* spp., *H. florida*, *L. plumulosus*, and *C. pinguis* between temporal groups (Table 7-8).

Multivariate analysis of variance indicated a significant difference between the centroids of the temporal groups. There was a significant separation between temporal groups in relation both the first (DF-1) and second (DF-2) discriminant functions, which explained 93% and 7% of the variance, respectively. The Fall and the Winter-Spring group separated from the Summer group along DF-1 (Fig. 10). This separation reflects a drastic decline in abundance of *C. riparius*, *P. convictum*, and *R. cuneata* which occurred during the Fall and continued into the Winter-Spring (Fig 11 A-C). Abundances of *G. daiberi* and *M. edwardsi* increased during these two time periods (Fig. 11D-E). The Winter-Spring group separated from the Fall group along DF-2 and was due primarily to recruitment of *S. viridis* (Fig. 11F).

All site groups showed a dramatic decline in total community density from the Summer to the Fall followed by an increase in density during the Winter-Spring (Table 9). This was due to a precipitous decline in abundance of *C. riparius* during the Fall followed by heavy recruitment of *S. viridis* during the Winter-Spring (Fig. 12-14A).

Total community biomass at the Mud and Mixed Site Groups showed a similar decline from the Summer to the Fall and continued to decrease during the Winter-Spring (Table 9). Changes in total community biomass at these two site groups primarily reflected changes in biomass of *C. riparius* (Fig. 12-13B). Total community biomass at the Sand Site Group increased from the Summer to the Fall and decreased slightly during the Winter-Spring period (Table 9). These changes were the result of changes in biomass of *S. viridis* (Fig. 14b).

The Mud and Mixed Site Group showed a drop in the number of species per replicate from the Summer to Fall followed by an increase during the Winter-Spring temporal period. The number of species per replicate at the Sand Site Group also decreased during the Fall but only slightly increased during the Winter-Spring period (Table 9). Species richness, species diversity, and evenness gradually increased from the Summer to the Winter-Spring at the Mud site groups (Table 9). The Mixed Site Group showed a decline in all of the diversity indices during the Fall followed by an increase during the Winter-Spring temporal period. These indices declined from the Summer to the Winter-Spring at the Sand sites (Table 9). The variance in macrobenthic community structure was primarily associated with temporal effects (76.2%). Spatial effects accounted for 19.3% of the variance while the interaction between site and time groups accounted for less than 5% of the variance.

Discussion

General Patterns

Few studies of macrobenthic communities have focused on the tidal freshwater or oligohaline portions of estuarine systems (Crumb 1977; Dean and Haskin 1964; Jordan and Sutton 1984). In the Chesapeake Bay, oligohaline-tidal freshwater regions have been studied for the purpose of examining general trends in the benthos in relation to the estuarine gradient (Boesch 1972, 1977; Boesch et al. 1976a; Dauer et al. 1989; Holland et al. 1988). Back Bay can be classified as an oligohaline estuary. Oligohaline estuaries of the Southeastern United States tend to be dominated by the tubificid oligochaete *Tubificoides heterochaetus*, the spionid polychaete *Scolecolepides viridis*, the bivalve *Rangia cuneata*, the isopod *Cyathura polita*, the amphipods *Leptocheirus plumulosus* and *Gammarus daiberi*, and the chironomid *Clinotanypus pinguis* (Boesch 1976; Boesch 1977; Dauer et al. 1988; Diaz 1980; Holland et al. 1988; Jordan and Sutton 1984; Tenore 1972). Tidal freshwater areas are characterized by tubificid oligochaetes of the genus *Limnodrilus*, the chaoborid larva *Chaoborus punctipenis*, and the chironomid larva *Chironomus* sp., *Cryptochironomus* sp., and *Polypedilium* sp.(Crumb 1977; Dauer et al. 1988; Dean and Haskin 1964; Diaz 1980; Holland et al. 1988; Wass 1972). Species composition of the macrofauna in Back Bay can be characterized as being a mixture of oligohaline and tidal freshwater species.

Community density values for Back Bay were higher than those obtained in the Chesapeake Bay while community biomass values were lower (Dauer et al. 1988, 1989). This difference was related to the absence of adult *R. cuneata* which accounts for most of the biomass in oligohaline areas of this estuary (Dauer et al. 1988). Although *R. cuneata* was collected, the individuals were small juveniles ranging in size from 1 to 3 mm.

Values for the number of species per replicate and the species diversity indices obtained in Back Bay were typical for oligohaline estuaries (Boesch 1972; Dauer et al. 1988). In general, species diversity tends to be much lower in the oligohaline portion of an estuary because polyhaline and estuarine endemic species are unable to colonize areas with reduced salinities and freshwater species cannot acclimate to an increase in salinity due to osmotic stress (Boesch 1977a; Remane and Schlieper 1971). Changes in hydrochemical propeties such as calcium content, chlorinity and ion ratios associated with decreasing salintiy may also produce a physiological barrier to freshwater and marine species (Kinne 1971).

Spatial patterns in community structure

Three spatial groups were identified by the cluster analysis and confirmed by the MANOVA and discrimnant analyses. A comparison between the plots of discriminant functions of the biological and environmental parameters indicated that the Mud and Sand Site Groups separated well in relation sedimentary parameters but the Mixed Site Group showed some overlap between both of these site groups.

The discriminant analysis identified eight species which accounted for most of the variation between site groups. Distribution patterns of several of the species identified by the discriminant analysis seem to correspond to previously demonstrated sedimentary preferences.

C. riparius, is found in a wide range of aquatic habitats and is primarily associated with fine grained sediments with a high organic content (Crumb 1977; Davies and Hawkes 1981; Gower and Buckland 1978; Rasmussen 1984a and 1984b). Rasmussen (1984b) found that gut contents of *C. riparius* consisted mainly of silt, microdetritus, and benthic diatoms indicating that this species was a deposit feeder. This species preference for fine-grained sediments is probably related to its deposit feeding life style.

C. pinguis is a ubiquitous species found in habitats ranging from small ponds to large rivers and also prefers soft mud bottoms (Roback 1976).

S. viridis is primarily found in sediments characterized by a high sand fraction of the sediment (Dauer et al. 1981; Kinner and Maurer 1978; Robinson 1978;). This species depends on a high sediment permeability in order to maintain an efficient respiratory current (Dauer 1985).

The distribution pattern of *P. convictum* could be related to its feeding mode. The larvae of this species are filter-feeders (Simpson and Bode 1980). Infaunal suspension feeders require contact with the sediment surface in order to feed (Sanders 1960). Areas with high silt-clay content may have a sediment surface which is too unstable to enable suspension feeders to maintain a connection with the overlying water.

R. cuneata is found in a wide variety of sediment types, however; a high silt-clay and organic content of the sediment has been shown to adversely affect growth and mortality in this species (Tenore et al. 1968). This could explain the lower densities of and small size of individuals obtained at the Mud Site Group.

H. florida is often found in sandy, or muddy sand sediments and is often associated with plant detritus (Pettibone 1977).

L. plumulosus has been described as prefering muddy sediments (Sanders et al. 1965); however, Feeley and Wass (1976) indicate that this species is found in many substrate types. Results of this study agree with those of Feeley and Wass (1976).

T. heterochaetus is found in a wide variety of sediment types but is most abundant in substrates characterized by fine grained sediments with a high organic content (Diaz 1980). The results of this study do not support previously reported sedimentary preferences for this species.

Differences in sediment type seem to influence distribution patterns of certain species but they do not fully explain the groupings produced by the cluster analyses. Several other factors, discussed below, may influence community structure of the macrobenthos in Back Bay.

Several of the stations on the western side of Back Bay were located near incoming freshwater streams. High numbers of insect larvae found at these stations may be carried there by currents from these streams.

Robinson (1978) found that distribution patterns of nearshore macrofauna in Back Bay were related to vegetation patterns. Adult migration from nearshore populations may influence distribution patterns in offshore areas. Several of the species collected in Back Bay (i.e. chironomids, *L. plumulosus, M. edwardsi* and *S. viridis*) have good powers of dispersal (Dauer 1980; Dauer et al. 1982; Mundie, 1959). As such, variations in nearshore plant communities could indirectly effect community structure of some offshore areas.

Alden (1989) has examined temporal and spatial patterns in water quality in Back Bay. Results of his study indicted that certain areas of Back Bay, notably several of the small tributary creeks, had elevated levels of nutrients. These areas had high levels of nitrogen (NH_3 and NO_3) and phosphorus (TP and OPO4) probably as a result of agricultural and residential runoff. Several of the benthic sampling stations (Stations 1, 2, 3, and 10) were located at or close to the mouths of these creeks. The top density dominant at all of these stations was *C. riparius*. This species has often been described as being an indicator of organic pollution (Gower and Buckland 1978; Simpson and Bode 1980; Davies and Hawkes 1981). The absence of adult *R. cuneata* could also be related to the high nitrogen and phosphorus levels in Back Bay. Tenore et al. (1968) reported that elevated levels of nitrogen and phosphorus in sediments adversely effected growth rates and mortality of *R. cuneata*.

Interspecific interactions may also influence community structure in Back Bay. Burrowing and feeding activities of chironomid larvae are known to disturb feeding and respiratory activities of tubificid oligochaetes (McCall and Tevesz 1982). This could explain why *T. hetreochaetus* was not found in high densities at the Mud Site Group where *C. riparius* was the dominant species.

Temporal patterns in community structure

Three temporal groups were defined in the cluster analyses and were confirmed by MANOVA and discriminant analyses. The discriminant analysis identified six species which accounted for most of the variation between the temporal groups. Temporal changes in the abundance of these species seem to correspond to known reproduction and recruitment events.

The life cycle of *C. riparius* is characterized as multivoltine i.e. several generations per year (Gower and Buckland 1978; Davies and Hawkes 1981). Larval densities are highest during late summer and early autumn and decline dramatically later in the fall as adults emerge. Some larvae overwinter and adults emerge again during the spring (Davies and Hawkes 1981; Gower and Buckland 1978). *C. riparius* in Back Bay exhibited a similar pattern of high densities during the summer followed by a precipitous decline during the fall.

Reproduction and recruitment of *S. viridis* occur during winter and early spring (Boesch et al. 1976b; Dauer et al. 1982; George 1966). Recruitment results in denser spring populations which gradually decline throughout the year (Boesch et al. 1976b). Densities of S. viridis in Back Bay followed this pattern declining from the Summer to the Fall followed by an increase during the Winter-Spring due to recruitment of many small individuals.

The amphipods *G. daiberi* and *M. edwardsi* reproduce throughout the year; however, reproduction peaks during the early spring (Feeley and Wass 1969). This could explain the higher abundances of these two species obtained during the Winter-Spring temporal period.

P. convictum showed a seasonal pattern similar to *C. riparius*. The decrease in abundance during the Fall was probably the result of emergence of adults sometime during the late summer suggesting a similar life history to that of *C. riparius*.

Newly recruited *R. cuneata* were found almost exclusively during the Summer. This species has two peaks in recruitment; one during the late summer and early fall and the second during midwinter (Cain 1975; Jordan and Sutton 1984). The presence of *R. cuneata* juveniles during the Summer temporal period is probably the result of the summer reproductive event.

The comparison of mean variance attributable to site and time groups indicated that most of variance in macrofaunal abundance was due to temporal effects. This seems reasonable since most of the species collected have annual life cycles. Previous studies suggest that species composition of oligohaline macrofaunal communities tend to be qualitatively persistent over time but the dominant species exhibit wide seasonal fluctuations in abundance (Boesch et al. 1976b; Jordan and Sutton 1984). Results of this study seem to confirm this general trend.

High seasonal variability may overshadow some subtle spatial patterns in community structure. Further investigations of the macrofauna in Back Bay should have more frequent temporal sampling so that seasonal variations can be more clearly defined and their effects on spatial patterns elucidated.

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Table 1. List of macrobenthic species collected in the Back Bay study area from August, 1987 to May, 1988.

Phylum ANNELIDA

Class Polychaeta
Hobsonia florida (Hartmann)
Laeonereis culveri (Webster)
Scolecolepides viridis (Verrill)

Class Oligochaeta
Limnodrilus hoffmeisteri Claparede
Limnodrilus spp. juveniles
Tubicoides heterochaetus (Michaelson)

Phylum MOLLUSCA

Class Bivalvia
Rangia cuneata Sowerby

Phylum ARTHROPODA

Class Crustacea
Order Isopoda
Cyathura polita (Stimpson)
Edotea triloba (Say)

Order Cumacea
Almyracuna proximoculi (Jones and Burbanck)

Order Amphipoda
Corophium lacustre Vanhoffen
Gammarus daiberi Bousfield
Leptocheirus plumulosus Shoemaker
Monoculodes edwardsi Holmes

Class Insecta
Order Diptera
Chironomus attenatus (Walker)
Chironomus riparius (Meigen)
Clinotanypus pinguis (Loew)
Cryptochironomus parafulvus (Beck and Beck)
Djalmabetista pulcher (Johannsen)
Polypedilium convictum (Walker)

Table 2. Abundance of the dominant species for each site group. Density is expressed in number of individuals per square meter and biomass (AFDW) is given in milligrams per square meter.

Taxon code: A=Amphipoda I=Insecta O=Oligochaeta P=Polychaeta.

Mud Site Group

Species	% Total Abund.	Mean Density	% Total Biomass	Mean Biomass
Chironomus riparius (I)	84.5	4715	71.1	1280
Scolecolepides viridis (P)	5.6	312	8.5	153
Clinotanypus pinguis (I)	3.8	214	6.1	110
Limnodrilus spp. (O)	2.1	116	4.8	86
Tubificoides heterochaetus (O)	1.1	61	1.3	24

Mixed Site Group

Species	% Total Abund.	Mean Density	% Total Biomass	Mean Biomass
Chironomus riparius (I)	38.9	2130	29.3	686
Scolecolepides viridis (P)	27.4	1500	47.5	1114
Tubificoides heterochaetus (O)	22.0	1206	8.4	196
Limnodrilus spp. (O)	3.5	190	3.1	73
Hobsonia florida (P)	2.9	159	2.3	55
Gammarus daiberi (A)	1.2	67	1.6	37
Monoculodes edwardsi (A)	1.0	55	1.3	31
Leptocheirus plumulosus (A)	1.0	55	1.3	31

Sand Site Group

Species	% Total Abund.	Mean Density	% Total Biomass	Mean Biomass
Scolecolepides viridis (P)	63.3	2893	69.9	2553
Chironomus riparius (I)	15.8	721	6.8	248
Hobsonia florida (P)	6.5	299	3.6	133
Tubificoides heterochaetus (O)	4.3	197	2.5	92
Polypedilium convictum (I)	2.0	91	1.0	36
Limnodrilus spp. (O)	1.9	87	<1.0	32
Rangia cuneata (B)	1.8	83	5.1	188
Monoculodes edwardsi (A)	1.2	55	<1.0	27

Table 3. Results of univariate comparisons of log transformed abundance of the dominant species between site groups. Comparisons were made using Duncan's Multiple Range Test. Values in the table not underscored by the same line are significantly different (P<0.05). Values in pararentheses are mean density values for each site group and are expressed in numbers of individuals per square meter. A. Mud Dominants - Species with greatest mean value at the Mud Site Group. B. Mixed Dominants - Species with the greatest mean value at the Mixed Site Group. C. Sand Dominants - Species with the greatest mean value at the Sand Site Group. D. Ubiquitous Species - Species with no mean differences between site groups.

A. Mud Dominants

Chironomus riparius
Mud (4714) Mixed (2130) Sand (721)

Clinotanypus pinguis
Mud (214) Mixed (31) Sand (0)

B. Mixed Dominants

Tubificoides heterocheatus
Mixed (1206) Sand (197) Mud (61)

Leptocheirus plumulosus
Mixed (55) Mud (6) Sand (5)

C. Sand Dominants

Scolecolepides viridis
Sand (2893) Mixed (1500) Mud (312)

Hobsonia florida
Sand (298) Mixed (159) Mud (31)

Polypedilium convictum
Sand (92) Mixed (12) Mud (0)

Rangia cuneata
Sand (83) Mud (18) Mixed (12)

D. Ubiquitous species

Limnodrilus spp. juveniles
Mixed (190) Mud (116) Sand (87)

Gammarus daiberi
Mixed (67) Mud (37) Sand (28)

Monoculodes edwardsi
Mixed Sand Mud

Table 4. Results of univariate comparisons of log transformed biomass of the dominant species between site groups. Comparisons were made using Duncan's Multiple Range Test. Values in the table not underscored by the same line are significantly different (P<0.05). Values in pararentheses are mean biomass values for each site group and are expressed in milligrams (AFDW) per square meter. A. Mud Dominants - Species with greatest mean value at the Mud Site Group. B. Mixed Dominants - Species with the greatest mean value at the Mixed Site Group. C. Sand Dominants - Species with the greatest mean value at the Sand Site Group. D. Ubiquitous Species - Species with no mean differences between site groups

A. Mud Dominants

Chironomus riparius
Mud (1280) Mixed (686) Sand (721)

Clinotanypus pinguis
Mud (110) Mixed (31) Sand (0)

B. Mixed Dominants

Tubificoides heterocheatus
Mixed (196) Sand (92) Mud (24)

Leptocheirus plumulosus
Mixed (31) Mud (12) Sand (5)

C. Sand Dominants

Scolecolepides viridis
Sand (2553) Mixed (1114) Mud (153)

Hobsonia florida
Sand (133) Mixed (55) Mud (24)

Polypedilium convictum
Sand (37) Mixed (6) Mud (0)

Rangia cuneata
Sand (188) Mud (55) Mixed (37)

D. Ubiquitous species

Limnodrilus spp. juveniles
Mixed (190) Mud (116) Sand (87)

Gammarus daiberi
Mixed (67) Mud (37) Sand (28)

Monoculodes edwardsi
Mixed (31) Sand (28) Mud (18)

Table 5. A. Mean values of community parameters by site group. Density is expressed in numbers of individuals per square meter and biomass in milligrams (AFDW) per square meter. B. Results of the univariate comparisons of community parameters between site groups. Comparisons were made using Duncan's Multiple Range Test. Values in the table not underscored by the same line are significantly different ($P<0.05$).

A. Community parameters

Site Group	Density	AFDW Biomass	Species per replicate	H′	J	SR
Mud	5578	1800	2.42	1.23	0.61	1.08
Mixed	5474	2345	3.53	1.50	0.63	1.10
Sand	4570	4629	3.29	1.36	0.61	1.05

B. Univariate comparisons between site groups

Density (ind./m²)

<u>Mud Mixed Sand</u>

AFDW Biomass (mg/m²)

Sand <u>Mixed Mud</u>

Species per replicate

<u>Mixed Sand Mud</u>

Diversity (H′)

<u>Mixed Sand Mud</u>

Evenness (J′)

<u>Mixed Sand Mud</u>

Species Richness (SR)

<u>Mixed Sand Mud</u>

Table 6. Mean values of A. physical and B. sedimentary parameters by site group.

A. Physical parameters

Site Group	Salinity o/oo	D.O.	Temp. °C
Mud	2.40	10.24	14.98
Mixed	2.45	10.24	15.08
Sand	2.48	10.72	15.05

B. Sedimentary parameters

Site Group	%Silt-Clay	Mean Phi	Sorting	%Volatile Solids
Mud	84.45	5.39	1.87	5.72
Mixed	34.55	3.77	1.53	3.77
Sand	22.29	3.59	1.21	1.45

Table 7. Results of univariate comparisons of log transformed abundance of the dominant species between temporal groups. Comparisons were made using Duncan's Multiple Range Test. Values in the table not underscored by the same line are significantly different (P<0.05). Values in pararentheses are mean density values for each temporal group expressed in numbers of individuals meter square. (Sum=Summer W-Spr=Winter-Spring). A. Summer Dominants - Species with greatest mean value during the Summer Temproal Group. B. Winter-Spring Dominants - Species with the greatest mean value during the Winter-Spring Temporal Group. C. Species with no seasonal trend - Species with no mean differences between temporal groups.

A. Summer

Chironomus riparius
Sum (8773) Fall (309) W-Spr (143)

Polypedilium convictum
Sum (162) Fall (0) W-Spr (0)

Rangia cuneata
Sum (132) Fall (29) W-Spr (4)

B. Winter-Spring

Gammarus daiberi
W-Spr (70) Fall (29) Sum (0)

Monoculodes edwardsi
W-Spr (96) Fall (15) Sum (0)

Scolecolepides viridis
W-Spr (2936) Sum (523) Fall (411)

C. Species with No Seasonal Trend

Tubificoides heterochaetus
W-Spr (489) Fall (448) Sum (411)

Limnodrilus spp. juveniles
Sum (140) W-Spr (132) Fall (103)

Hobsonia florida
W-Spr (206) Sum (191) Fall (103)

Leptochierus plumulosus
W-Spr (29) Fall (15) Sum (7)

Clinotanypus pinguis
Sum (110) W-Spr (73) Fall (37)

Table 8. Results of univariate comparisons of log transformed biomass of the dominant species between temporal groups. Comparisons were made using Duncan's Multiple Range Test. Values in the table not underscored by the same line are significantly different (P<0.05). Values in pararentheses are mean biomass values for each temporal group expressed in milligrams (AFDW) per meter square. (Sum=Summer W-Spr=Winter-Spring). A. Summer Dominants - Species with greatest mean value during the Summer Temproal Group. B. Winter-Spring Dominants - Species with the greatest mean value during the Winter-Spring Temporal Group. C. Species with no seasonal trend - Species with no mean differences between temporal groups.

A. Summer

Chironomus riparius
Sum (2087) Fall (419) W-Spr (125)

Polypedilium convictum
Sum (66) Fall (0) W-Spr (0)

Rangia cuneata
Sum (330) Fall (66) W-Spr (7)

B. Winter-Spring

Gammarus daiberi
W-Spr (40) Fall (15) Sum (0)

Monoculodes edwardsi
W-Spr (44) Fall (15) Sum (0)

C. Species with No Seasonal Trend

Tubificoides heterochaetus
W-Spr (110) Sum (103) Fall (88)

Limnodrilus spp. juveniles
Sum (73) Fall (58) W-Spr (55)

Hobsonia florida
Sum (102) W-Spr (81) Fall (44)

Leptochierus plumulosus
W-Spr (18) Fall (15) Sum (7)

Clinotanypus pinguis
Sum (59) W-Spr (40) Fall (29)

Scolecolepides viridis
Fall (1786) W-Spr (1312) Sum (1198)

Table 9. Mean values of community parameters of each site group for each temporal group. Density is expressed in numbers of individuals per square meter and biomass in milligrams AFDW per square meter.

A. Mud Site Group

Temporal Group	Density	AFDW Biomass	Species per replicate	H′	J	SR
Summer	18663	4629	2.88	0.35	0.16	0.72
Fall	833	1004	1.56	1.20	0.75	0.98
Winter-Spring	1408	783	2.56	1.67	0.76	1.31

B. Mixed Site Group

Temporal Group	Density	AFDW Biomass	Species per replicate	H′	J	SR
Summer	9895	3943	3.56	1.67	0.77	1.31
Fall	2179	2400	2.67	0.98	0.39	0.96
Winter-Spring	4910	1518	3.94	1.68	0.75	1.20

C. Sand Site Group

Temporal Group	Density	AFDW Biomass	Species per replicate	H′	J	SR
Summer	4996	3943	4.58	1.97	0.73	1.36
Fall	1635	4372	2.83	1.59	0.75	1.10
Winter-Spring	5823	3160	2.88	0.95	0.47	0.87

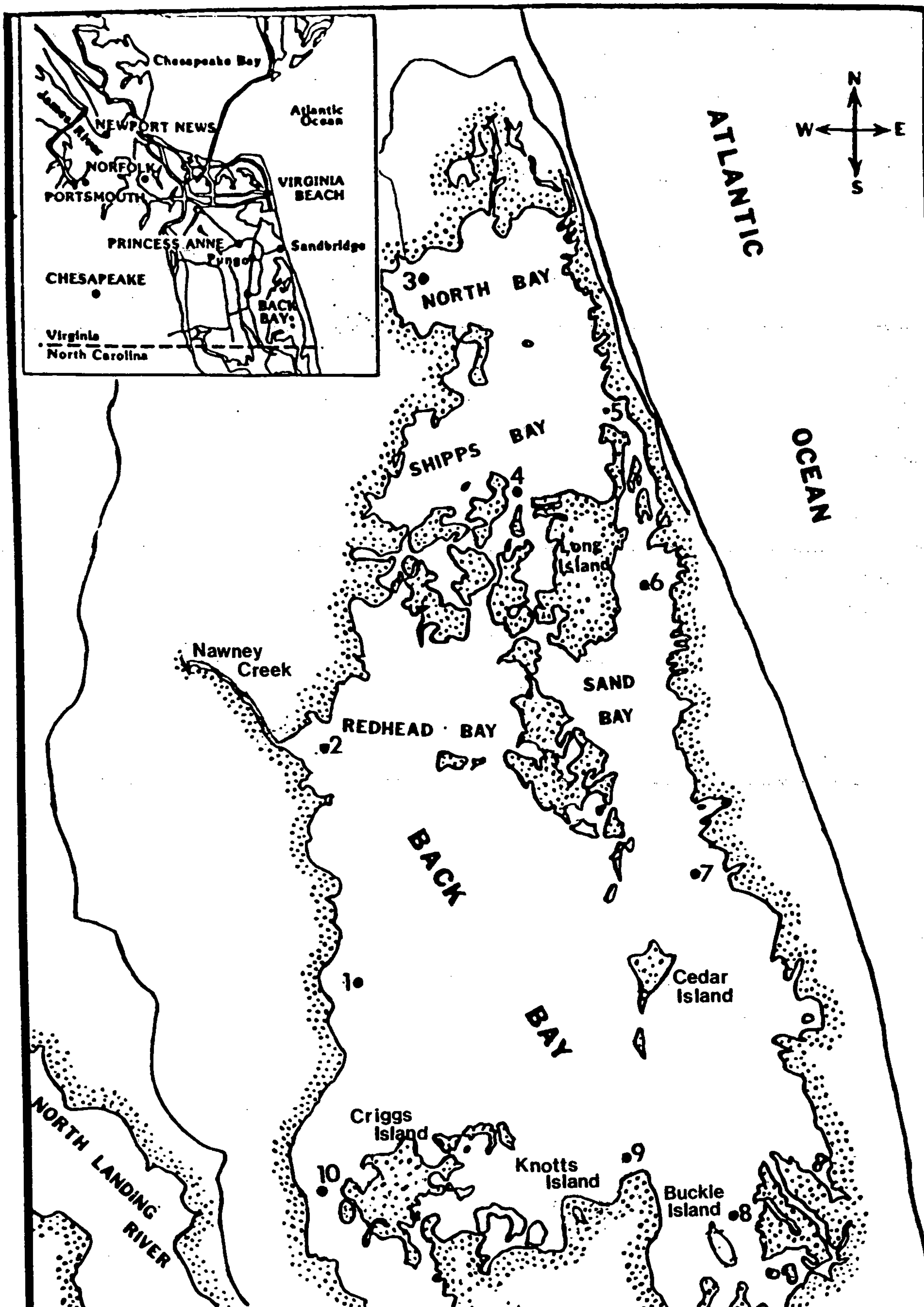


Figure 1. Map showing location of the study area (insert) and the sampling stations.

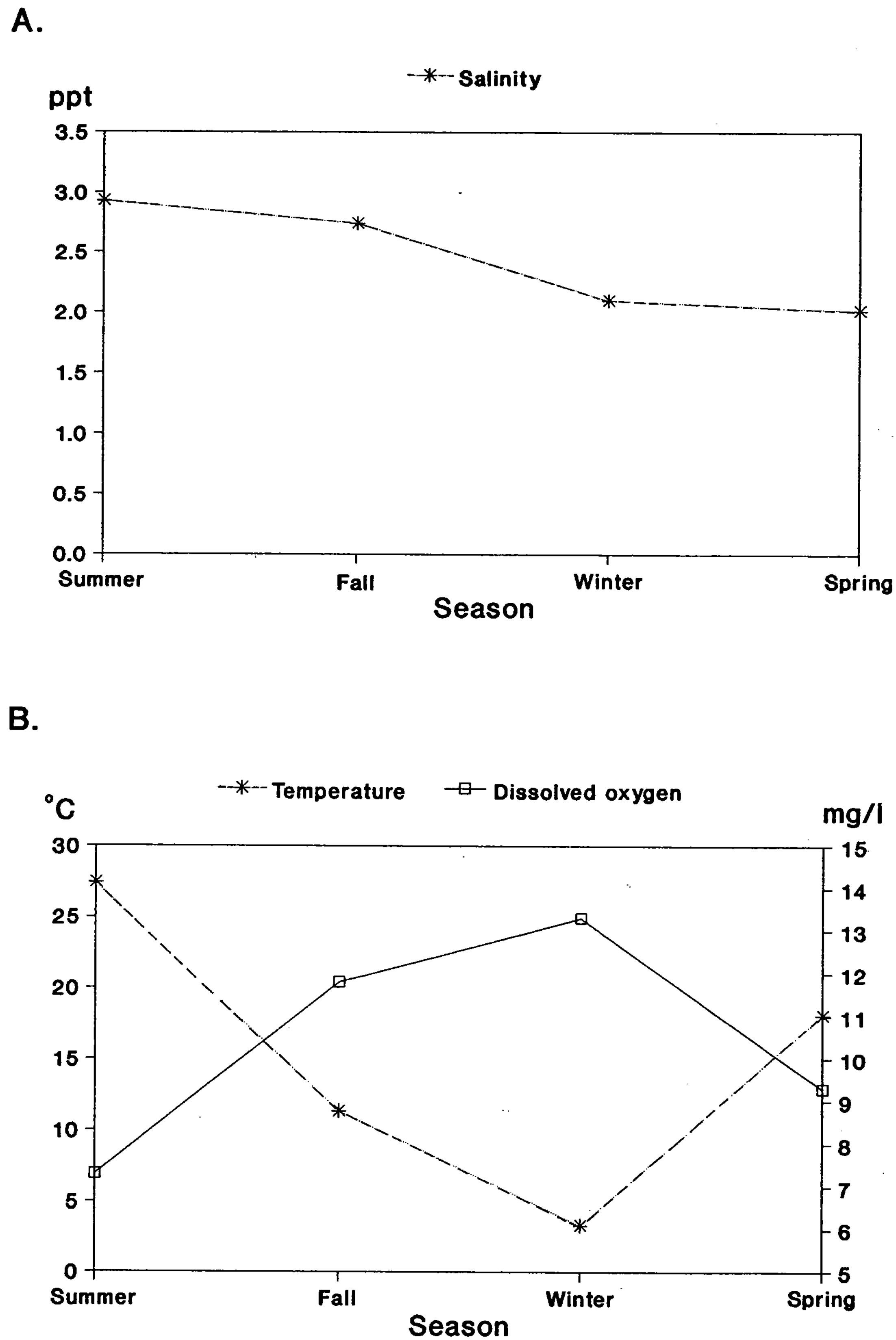


Figure 2. Bay wide seasonal means A. salinity and B. temperature and dissolved oxygen.

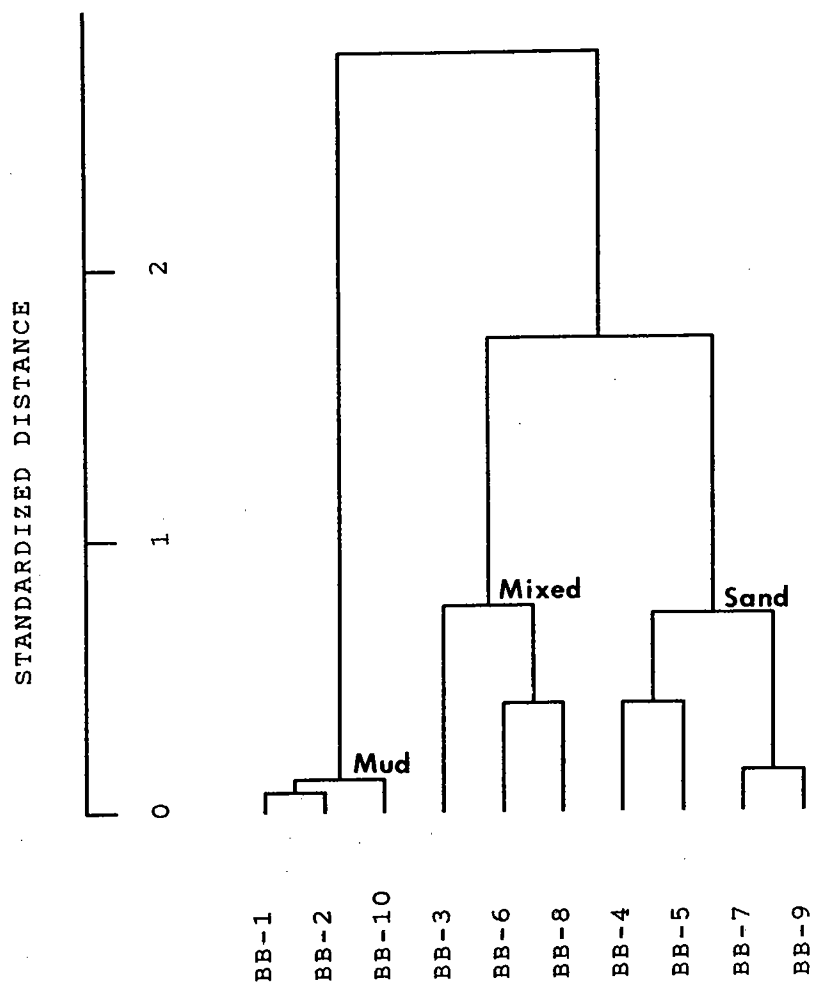


Figure 3. Standardized distance dendrogram for classification of sampling sites with respect to macrobenthic taxa.

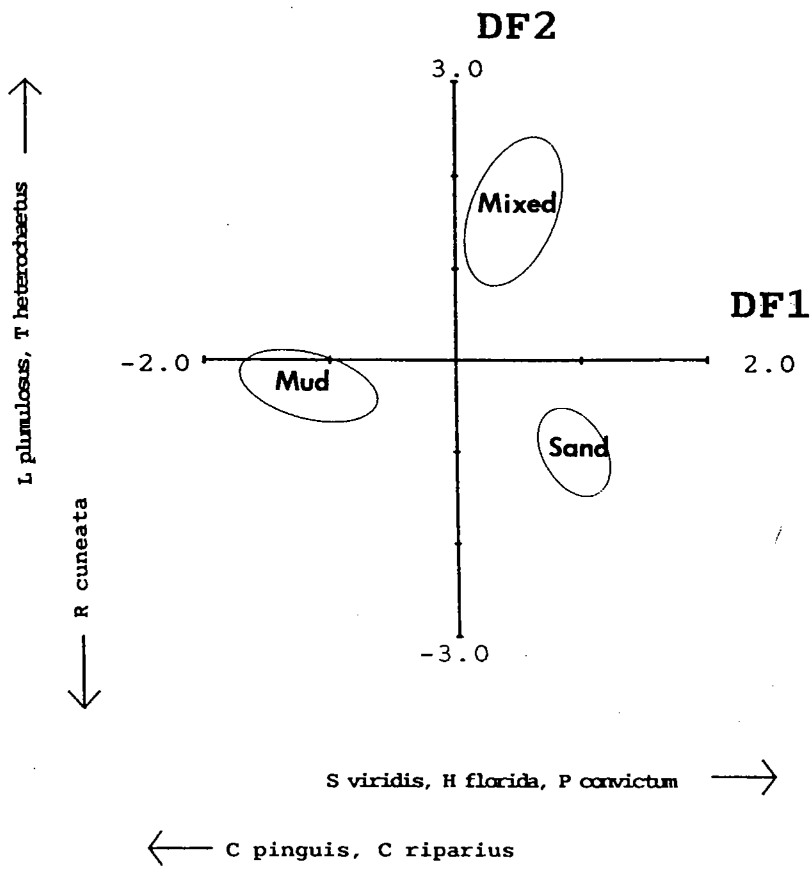


Figure 4. Confidence ellipses (a=0.05) for canonical discriminant functions describing separation between spatial groups in relation to macrobenthic taxa. The site groups are those defined in Figure 3. Species listed along axes had a significant difference between site groups (one-way ANOVA) and high loading on the discriminant function. Direction of the arrow indicates the sign of the loading.

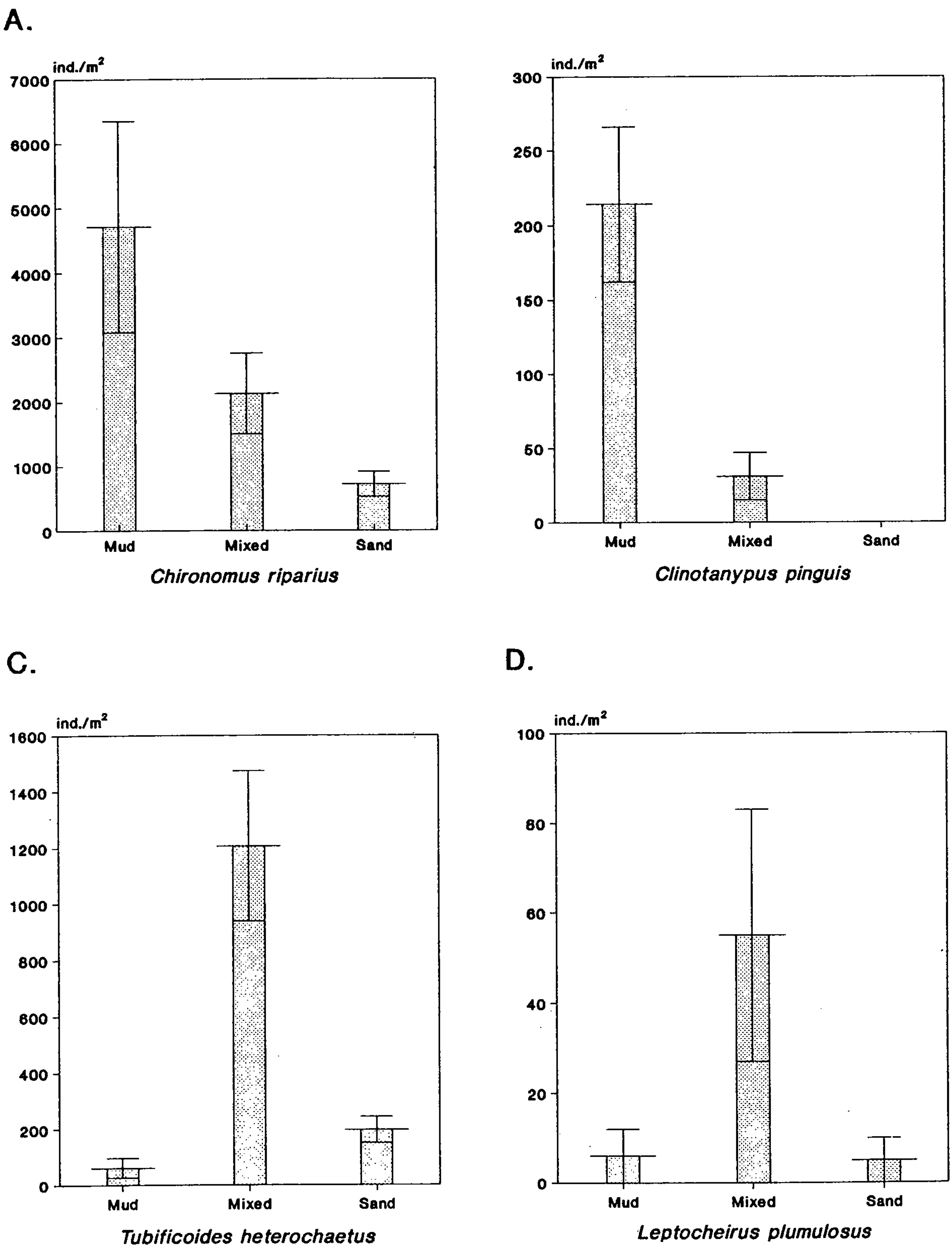


Figure 5. Mean density of dominant species for each site group. Species shown had a significant difference in abundance between site groups (one-way ANOVA). Vertical bars represent /– one standard error of the mean. Density is expressed as the number of individuals per square meter. (A. *Chironomus riparius* B. *Clinotanypus pinguis* C. *Tubificoides heterochaetus* D. *Leptocheirus plumulosus*).

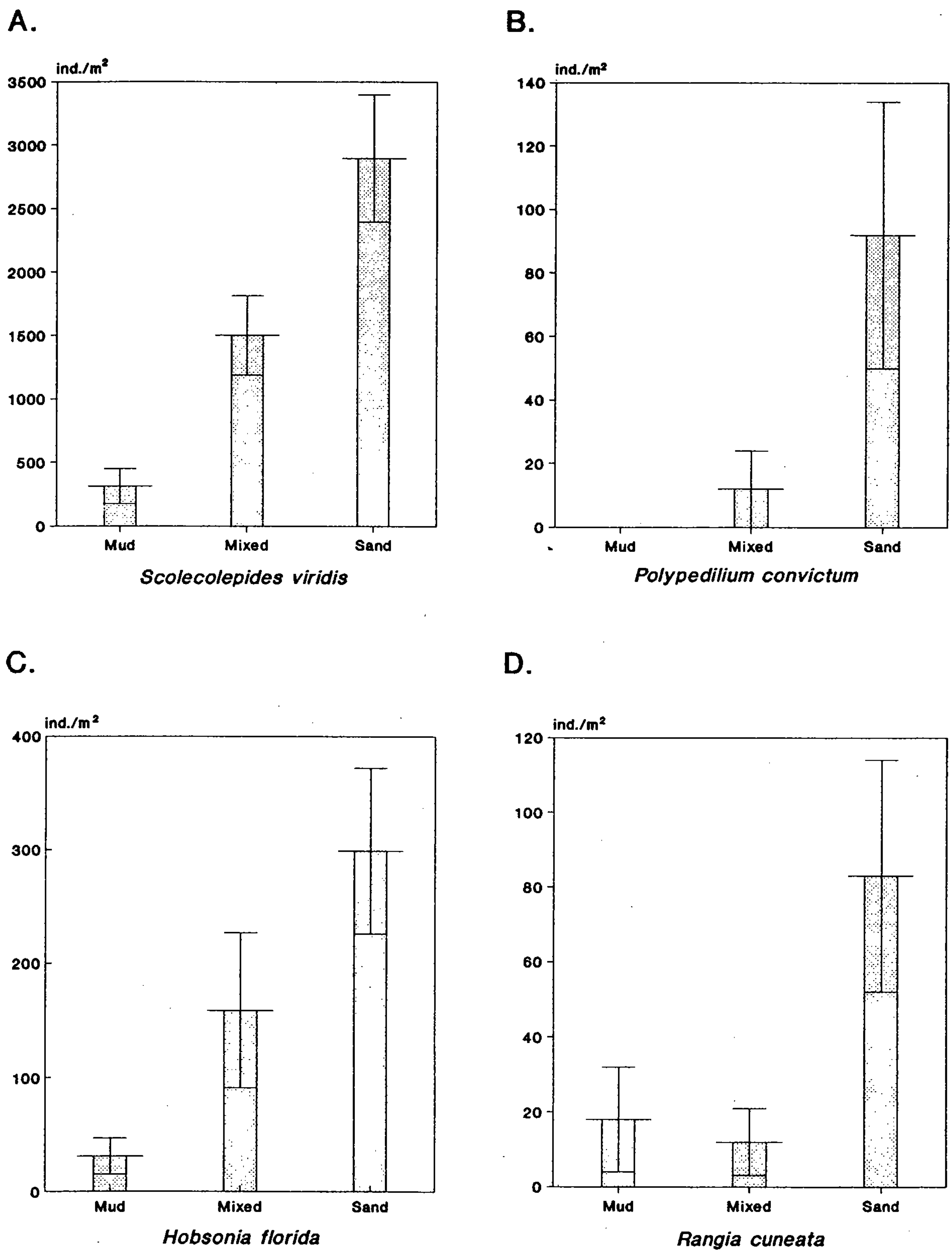


Figure 6. Mean density of dominant species for each site group. Species shown had a significant difference in abundance between site groups (one-way ANOVA). Vertical bars represent + or – one standard error of the mean. Density is expressed as the number of individuals per square meter. (A. *Scoelecolepides viridis* B. *Polypedilium convictum* C. *Hobsonia florida* D. *Rangia cuneata*).

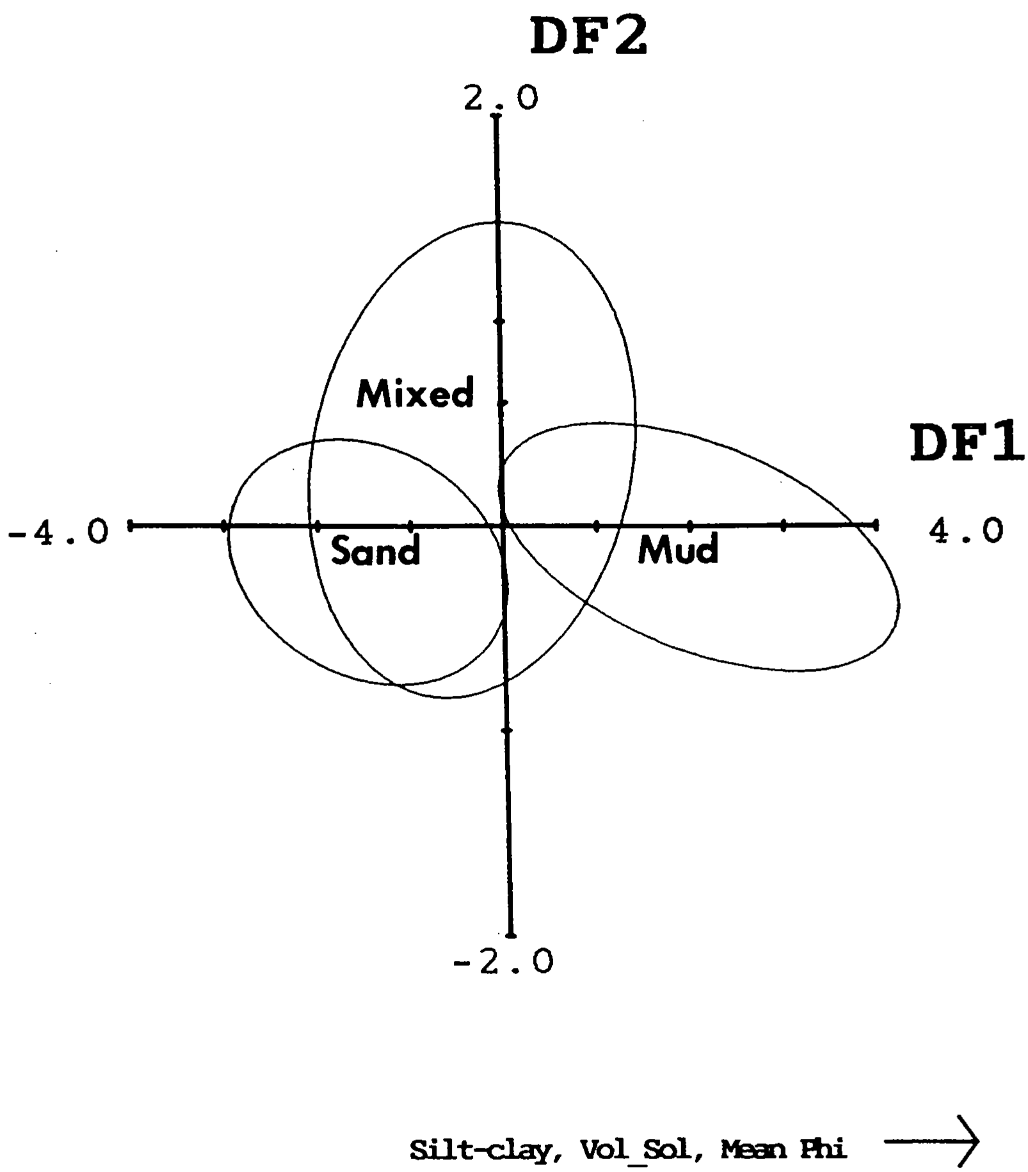


Figure 7. Confidence ellipses (a=0.05) for canonical discriminant functions describing separation between spatial groups in relation to physcial and sedimentary parameters. The site groups are those defined in Figure 3. Parameters listed along axes had a significant difference between site groups (one-way ANOVA) and high loading on the discriminant function. Direction of the arrow indicates the sign of the loading.

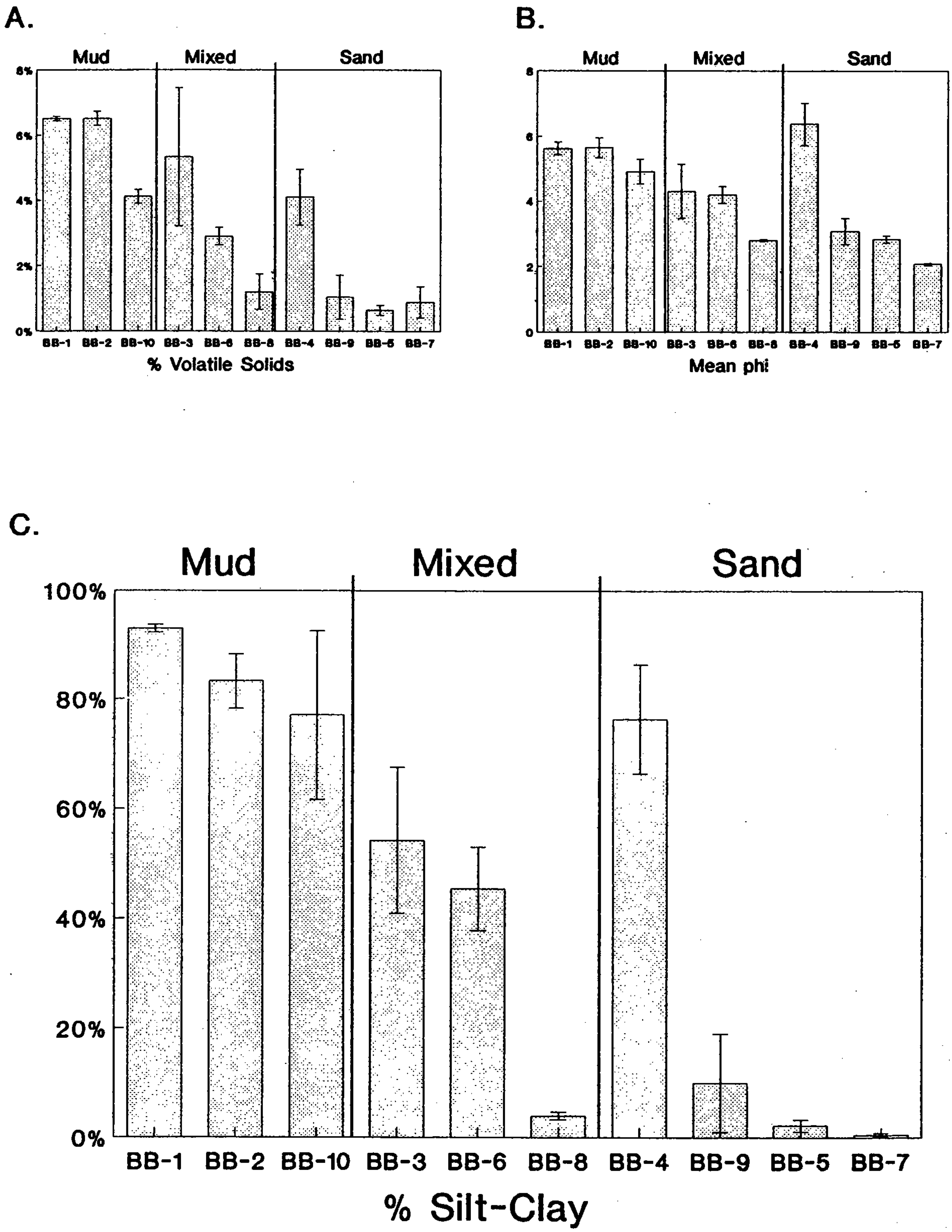


Figure 8. Mean values for A. organic content, B. mean phi, and C. silt-clay for each station. Vertical bars represent + or – one standard error of the mean.

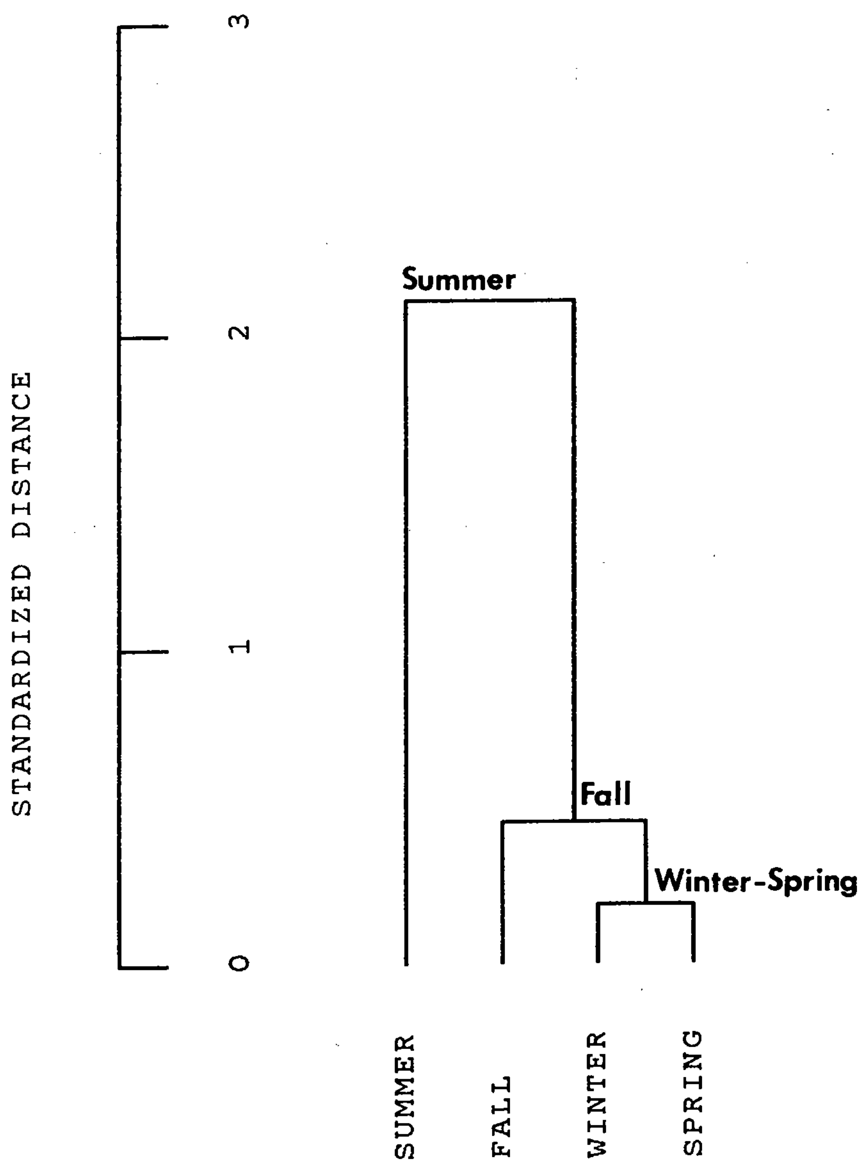


Figure 9. Standardized distance dendogram for classification of cruises with respect to macrobenthic taxa.

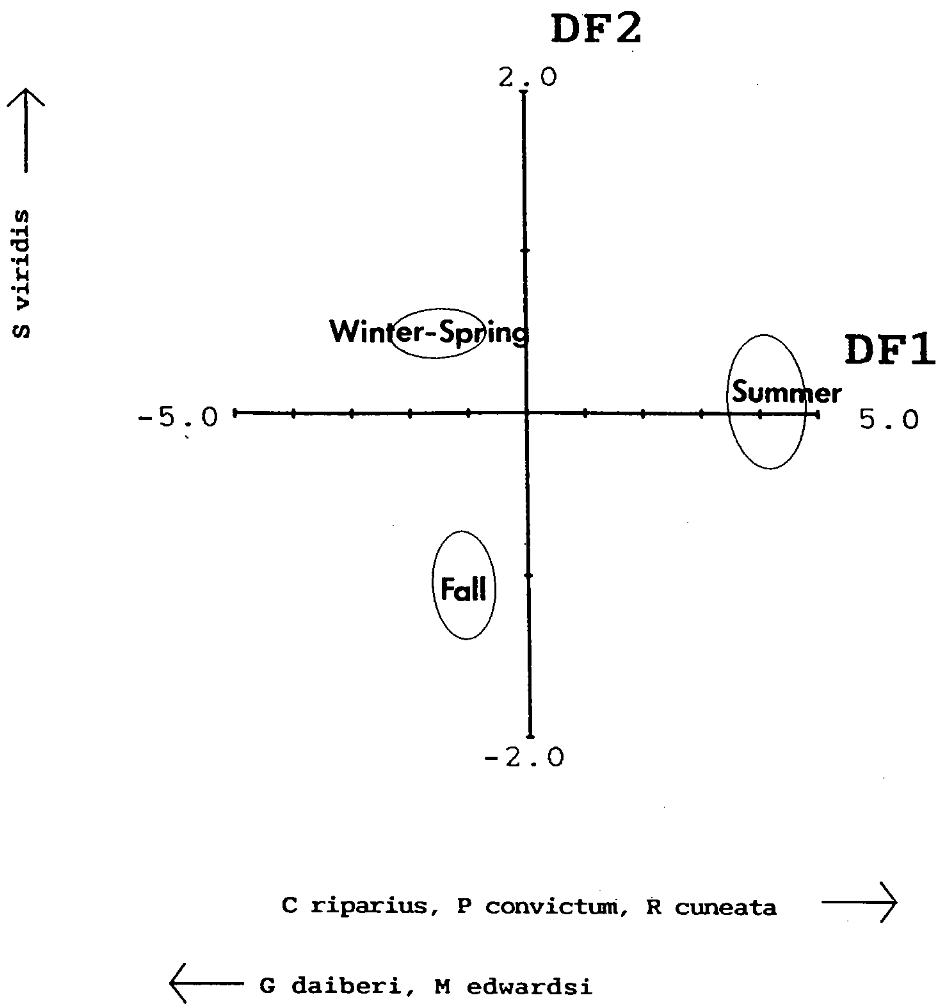


Figure 10. Confidence ellipses (a=0.05) for canonical discriminant functions describing the separation of the temporal groups in relation to macrobenthic taxa. Species listed along axes had a significant difference between temporal groups (one-way ANOVA) and high loading on the discriminant function. Direction of the arrow indicates the sign of the loading.

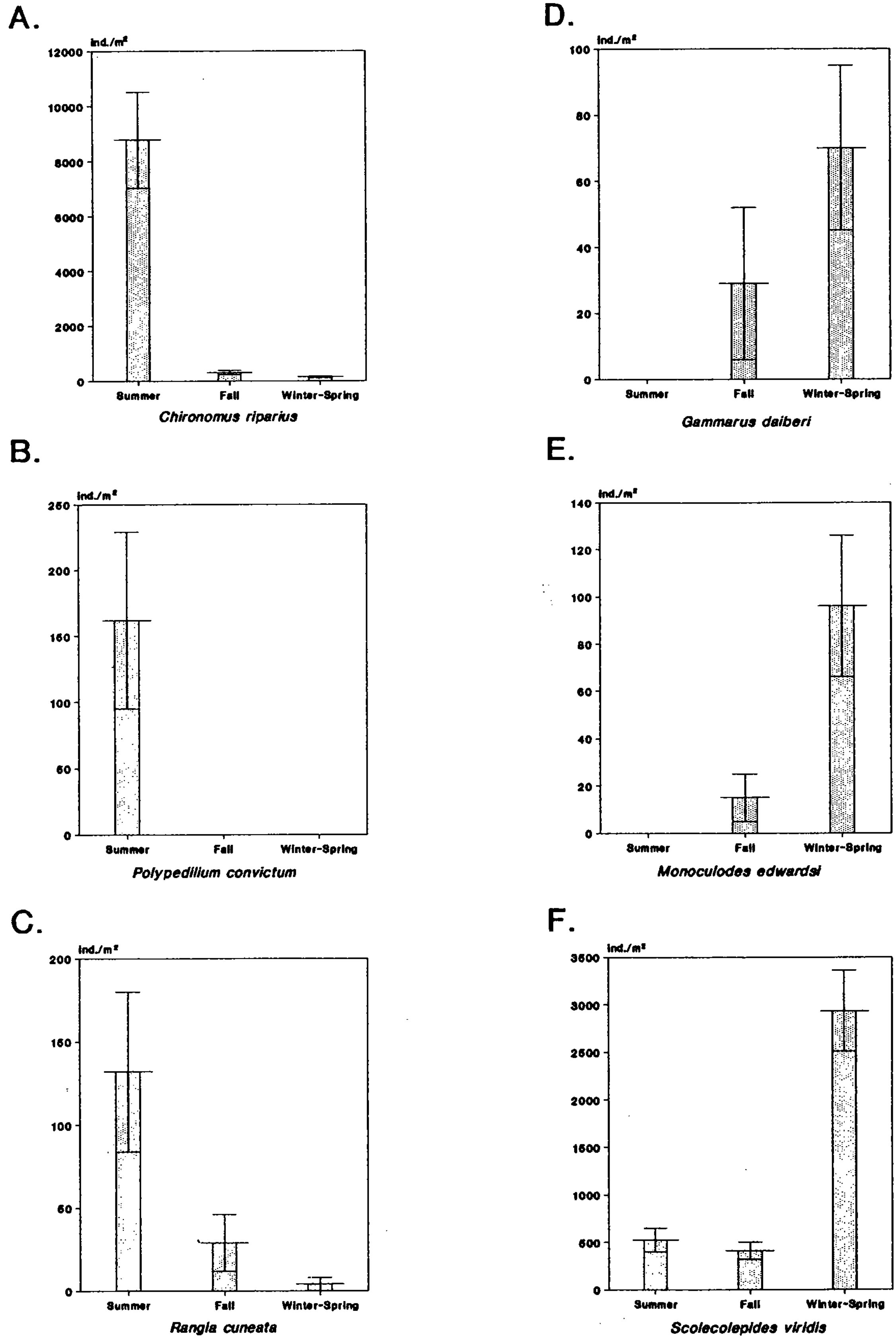
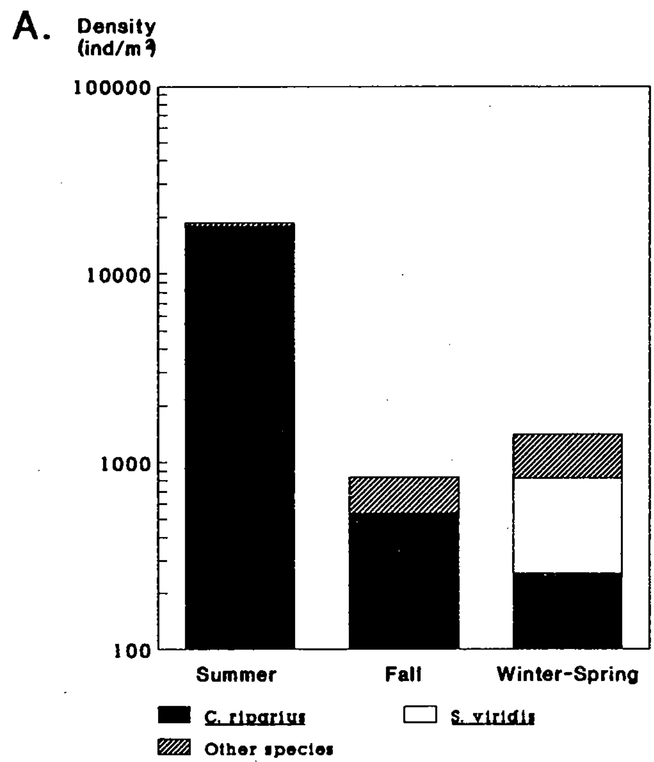


Figure 11. Mean density of the dominant species for each temporal group. Species shown had a significant difference in abundance between temporal groups (one-way ANOVA). Vertical bars represent + or – one standard error of the mean. (A. *Chironomus riparius*, B. *Polypedilium convictum*, C. *Rangia cuneata*, D. *Gammarus daiberi*, E. *Monoculodes edwardsi*, F. *Scolecolepides viridis*).



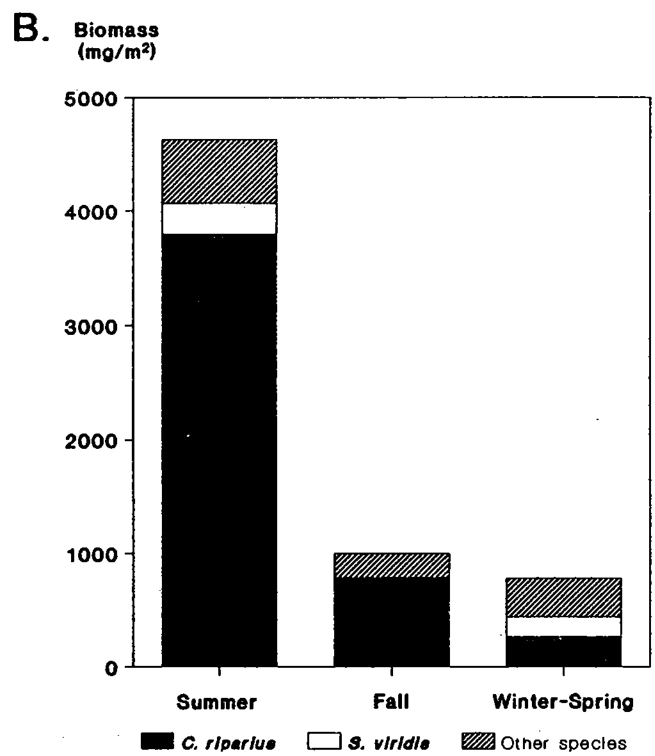
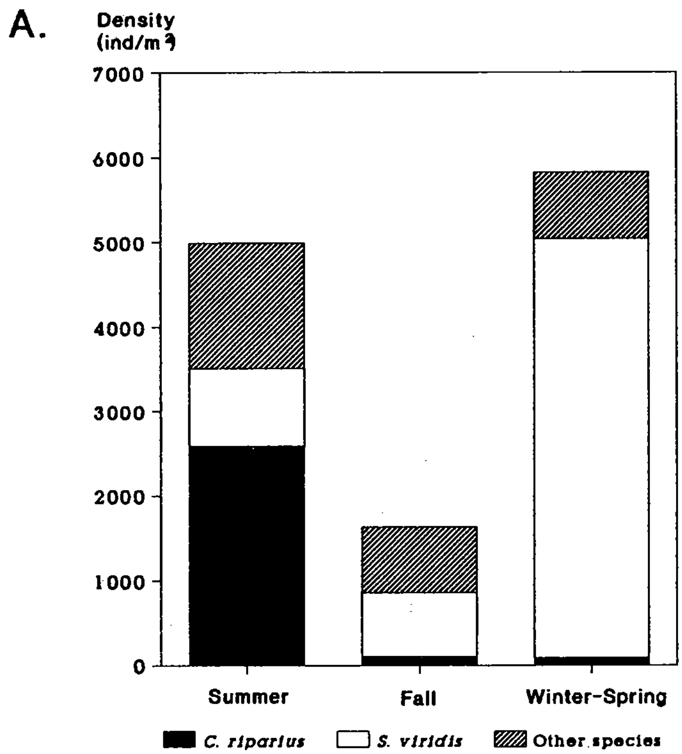


Figure 12. Mean community A. density and B. biomass values for the Mud Site Group for each temporal group. Density is expressed as the number of individuals per square meter and biomass in milligrams (AFDW) per square.



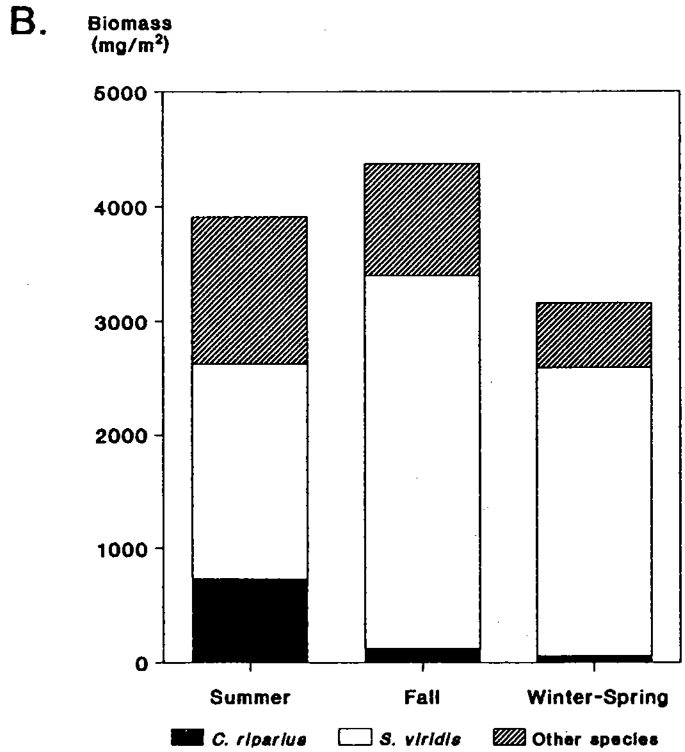


Figure 13. Mean community A. density and B. biomass values for the Mixed Site Group for each temporal group. Density is expressed as the number of individuals per square meter and biomass in milligrams (AFDW) per square meter.

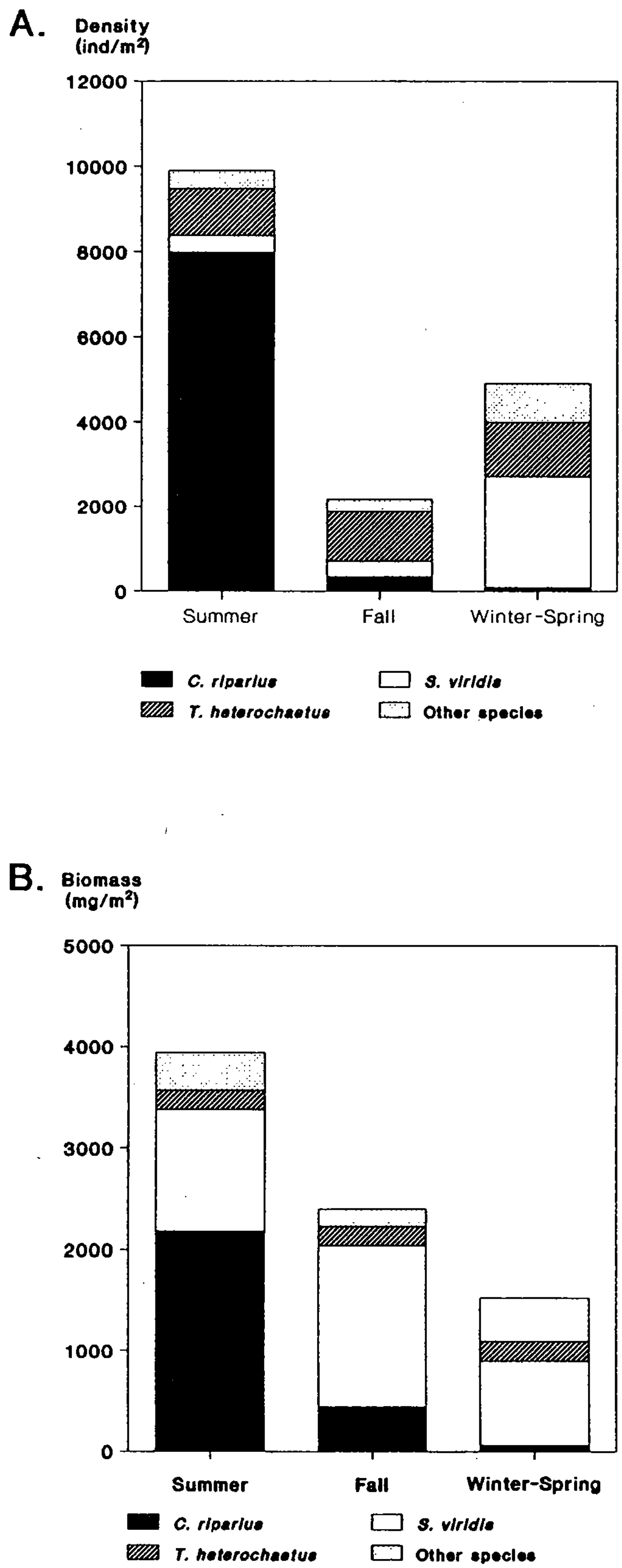


Figure 14. Mean community A. density and B. biomass values for the Sand Site Group for each temporal group. Density is expressed as the number of individuals per square meter and biomass in milligrams (AFDW) per square meter.

Zooplankton Populations in Back Bay, Virginia

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Abstract: Back Bay contains two distinct populations of zooplankton. One is a micro-zooplankton component composed primarily of ciliated protozoans, the other is a macrozooplankton group dominated by calanoid copepods, crustacean larvae, rotifers and polychaete larvae. Seasonal periods of abundance for these zooplankters are identified and discussed.

Introduction

The purpose of this study is to determine the seasonal composition and abundance of zooplankton in Back Bay over a one year period. Emphasis is directed to both the microzooplankton (<150 µm) and the larger zooplankton (>150 µm) populations.

Methods

Zooplankton samples were taken twice a month from April 1987 through October 1987, once monthly from November through February 1988, and twice in March 1988, at four stations in Back Bay. These stations were the same used for phytoplankton collections (No's. 3, 9, 20, 22). Refer to Figure 1 in Marshall (1991) of this proceedings for their location. For zooplankton >150 µm a Clarke-Bumpus plankter sampler, with a #10 filter cup and net, was towed at the surface (<1m) for one minute, with the sample preserved immediately in buffered formalin. Each sample concentrate was brought to a known volume by adding distilled water. After mixing, a 1 ml subsample was taken and placed in a Sedgewick-Rafter cell for microscopic examination and counting. A total of three 1 ml replicates from each sample was counted and averaged. For the micro-zooplankton (<150 µm), a surface (< 1m) water sample of one liter was taken at each station. This was preserved in Lugols solution and allowed to settle for five days. This was followed by three siphoning and settling periods where the original volume was reduced to 20 ml. The final concentrate was placed in a settling chamber of an inverted Zeiss plankton microscope and subsequently analyzed using a random field minimum count basis. Initially, three different preservatives were evaluated for use with the microzooplankton. These were buffered formalin, Bouins, and Lugols solution. A study over several collection periods indicated the Lugols gave a greater representation of animal forms and a more distinct presentation of their features. Lugols was then selected as the preservative to be used for this component during the study.

All counts were determined on a per unit volume (no./l) basis. The majority of the taxonomic forms were grouped into major categories during the monthly analyses. However, more specific identification of the major species, was conducted once for each season at two of the stations.

Results

The monthly temperature, salinity, and secchi readings for this period are given in Marshall *et al.* (1988). The seasonal temperature pattern is typical for temperate waters. A temperature rise during spring continued to a summer high of 30.5°C in July 1987 and a low of 0.5°C in January 1988. In January there were periods when a thin layer of ice formed over the Bay, but this was a rare event that would last for only brief periods. Similar temperature ranges and seasonal patterns were found at each station. Lowest salinities occurred during late winter and early spring when they were associated with spring rains and enhanced drainage into Back Bay. Highest salinities were in late summer and fall, before declining into winter. Station differences were common. The less saline waters were generally found at Station 9. This site was farthest from the southeast region of the Bay that connects with Currituck Sound. Similar seasonal patterns were at each station, but the degree of differences between stations varied throughout the year. The salinity range for this year of study was from 1.1 o/oo (January 1988) to 3.2 o/oo (August 1987). Both of these extremes were noted at Station 9.

The secchi disc readings followed similar patterns at the four stations. Highest readings (greatest transparency) were in summer, declining into fall to winter lows, before rising in spring. Light entry was consistently deepest at Station 22 and least at Station 9. A major influence on the secchi readings was the changing seasonal patterns of wind direction and the intensity of prevailing winds. Whenever wind speed was excessive (>10 knots) there was upwelling action, increased turbidity, and often added salt water to the water column. Increased saline water entry was most common when there were strong winds of long duration from the south or southeast. Secchi readings ranged from 7.6 cm in January 1988 to 40.6 cm in June 1987.

A list of the zooplankton categories with their mean sample concentrations for the year and the percentage of this total to the whole collection are given in Table 1. This table lists both the macrozooplankton and microzooplankton components. The macrozooplankton consisted of mainly copepods, cladocerans, rotifers, and a miscellaneous zooplankton category. This last grouping included polychaete larvae, insect larvae, harpacticord copepods, crab zoea and a variety of other crustacean larval forms. Within the microzooplankton, the major components were tintinnids and other protozoan microzooplankton.

Microzooplankton

Seasonal fluctuations were common for the microzooplankton, with the different stations having generally similar patterns (Fig. 1). However, higher concentrations were common at the more southern stations (Stations 20 and 22). Peak concentrations were in late spring 1987, then decreased into summer and fall, with lowest numbers in mid-winter. A sharp increase in abundance occurred in late winter and continued into spring 1988. There were also seasonal differences in abundance within this group. The tintinnids had their highest concentrations in spring, decreasing during summer and fall, with lowest numbers in winter (Fig. 2). A comparison of the seasonal concentrations for the tintinnids averaged 256 cells/l during winter, compared to the spring when their mean count was 36,825 cells/l. The other protozoan ciliates had peak concentrations in late winter and early spring, decreasing in late spring during the tintinnid pulse of growth, with fluctuating maxima during summer and fall (Fig. 3). There appeared to be a slight pattern of inverse abundance relationships between the tintinnids and the other ciliates. However, the other ciliates (non-tintinnids) maintained high, but fluctuating concentrations throughout the sampling period.

The individual tintinnids possessed distinct seasonal patterns of abundance. These were typically a spring high, that decreased into summer and fall, with a low during winter. In contrast, there were generally overlapping patterns among the other ciliates. However, these other protozoans were most abundant in summer, with several having a second peak in late fall to early winter.

Macrozooplankton

The general trend of macrozooplankton abundance in Back Bay indicated highest concentrations from late winter through spring, decreasing into summer, rising again in fall, to decrease into winter (Fig. 4). This general pattern was found at each station, with Station 9 having the highest concentrations. The rotifers were most abundant during spring with lowest numbers during summer and fall (Fig. 5). The polychaete larvae were most common in fall and winter in contrast to spring-summer lows. The copepods had more of a spring-fall bimodal pattern of greatest abundance, with lower concentrations for summer-winter (Fig. 6). Mean seasonal concentrations of the miscellaneous zooplankton category indicated a winter abundance low, but varied, having higher concentrations during other seasons, with a general high during summer. Many constituents in this category were crustacean larvae, that preceded the adult concentrations noted for copepods in the fall. The seasonal concentrations for the different zooplankton categories are given in Table 2. In Table 3 a more detailed identification of the macrozooplankton is given seasonally at Station 9 and 22. Among the copepods, *Acartia tonsa* was most common, with highest numbers during spring. *Acartia clausi* was also noted in spring, but not at other times. *Eurytemora affinis, Cyclops vernalis* and *Cyclops varicans rubellus* were found during several seasons, but were most common in winter, or spring. The nauplii and copepodites were most abundant in late winter and spring.

There were distinct seasonal patterns among the different rotifers. For instance, spring development was noted for *Brachionus angularis, Filinia* sp. and *Keratella quadrata. Brachionus calyciflorus* peaked in late winter-early spring, but was also common in low concentrations other times of the year. In contrast, *Keratella cochlearis* had major development in late winter and through spring, before declined into summer. Among other groups, the nauplii were common year-round, but had their highest concentrations in spring at

Station 9, with numbers decreasing southward to Station 22. The crab zoea were noted only in summer and early fall, with several insect larvae present in late spring and summer. The cladocerans (e.g. *Bosmina coregoni, B. longirostris*) did not represent a major community in Back Bay, and occurred only sporadically in low numbers.

Conclusions

Zooplankton populations in Back Bay may be divided into two distinct groups. One is a microzooplankton component that is dominated by a variety of ciliated protozoans, and characterized by an abundant tintinnid component. The other group is represented by a macrozooplankton assemblage, characterized by copepods, rotifers and a miscellaneous group of zooplankters.

Seasonal patterns of abundance were identified for various zooplankton components. Spring assemblages were characterized by calanoid copepods, rotifers, tintinnids, and other protozoan ciliates. Concentrations generally decreased with the increased temperatures and salinities of summer, with the protozoan ciliates and various copepod larval stages becoming more abundant. In fall, salinity values and temperatures decreased with the calanoid copepods added to the summer assemblages. Populations decreased to a winter low, but calanoid copepods were again increasing in abundance and the polychaete larvae reached a seasonal peak. At this time, there also occurred the lowest temperature, salinity and secchi disc readings for the year.

In general, the macrozooplankton had their lowest total concentrations at Station 22, with abundance and temporal patterns for this group similar at the four Bay stations. The microzooplankton had greater station differences, but similar temporal patterns of abundance. Highest concentrations of microzooplankton were associated with Station 9. Only a few zooplankters seasonally dominated these samples which were characterized by low species diversity. This may be a product of the oligohaline nature of the habitat that is seasonally variable and appears to favor only a limited number of dominant species throughout the year. There is also little opportunity for an exchange pattern to be developed through the Back Bay - Currituck Sound connection. This reduces any flushing action and the entry of additional species into Back Bay from nearby estuaries. Freshwater species entering from canals, ditches or creeks into Back Bay apparently have a low survival rate for their appearance in the oligohaline waters are rare.

However, the zooplankton of Back Bay are not unique and these species are found in other regional estuarine habitats (Birdsong *et al.*, 1988) and there appears to be a lower species diversity in comparison to these other locations. The microzooplankton were abundant throughout the year. However, more detailed study of the microzooplankton is needed in relation to their identity and seasonal contribution to the trophic status of Back Bay. Additional investigations of predator-prey relationships throughout the trophic steps within Back Bay and over a multi-year period are also considered essential for a clearer understanding of this Bay ecosystem. In relation to recent plankton studies in Back Bay, Marshall (1988, 1991) conducted a two year investigation (1986-87) of the phytoplankton, with the second year overlapping this zooplankton study. In general, there were highest phytoplankton concentrations during summer, with these cells composed mainly of cyano-bacteria less than 5μm in size. This season was the period of decreasing populations for many of the macrozooplankton (e.g. rotifers, copepods), with the tintinnids also in decline, but other ciliates were increasing in number. The larger phytoplankters had limited periods of high abundance with major development during spring for the diatoms and chlorophyceans, in spring and fall for cryptomonads, and in summer for dinoflagellates. The growth pulses for many of the larger phytoplankters and zooplankters were similar. The smaller pico-nanoplankton (<5μm) cyanobacteria were common year-round, and their major pulses coincided with the high abundance of the non-tintinnid ciliates. However, these relationships cannot adequately be interpreted without more annual data and the inclusion of other predators in the analysis, such as the various life stages of the local fish populations.

Acknowledgement

Appreciation is given to David Bird for providing taxonomic and general information on the macrozooplankton observed in this study. Special thanks are also extended to Mitchell Norman from the Virginia Department of Game and Inland Fisheries who assisted during sample collections and provided data on salinity, temperature and secchi readings during this study. This study was funded by the Virginia Department of Game and Inland Fisheries.

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Table 1. Mean sample concentrations and percent of total composition for zooplankton at Back Bay stations from April 1987 to March 1988 in numbers per liter and percent of the annual total concentration.

	Concentration	%
CILIATA		
Ciliate #1	7738.515	10.48
Ciliate #2	9185.065	12.44
Ciliate #3	211.780	0.29
Ciliate #4	171.872	0.23
Ciliate #5	17846.126	24.18
Ciliate #6	12000.427	16.26
Tintinnid #1	15059.037	20.40
Tintinnid #2	657.115	0.89
Tintinnid #3	9650.667	13.07
CRUSTACEA: CLADOCERA		
Bosmina coregoni	0.033	0.00
Bosmina longirostris	0.001	0.00
Bosmina sp.	0.001	0.00
Ceriodaphnia sp.	0.001	0.00
Cladoceran (unident.)	0.001	0.00
Eurycerus sp.	0.001	0.00
Latonopsis occidentalis	0.001	0.00
CRUSTACEA: COPEPODA		
Copepod #1	1.297	0.00
Copepod #2	0.069	0.00
Copepod #3	0.001	0.00
Harpacticoid copepods	0.001	0.00
CRUSTACEA: OTHERS		
Nauplii (unident.)	0.094	0.00
Ostracod (unident.)	<0.001	0.00
ROTIFERRA		
Ascomorpha sp.	0.001	0.00
Asplanchna sp.	<0.001	0.00
Brachionus angularis	0.001	0.00
Brachionus calyciflorus	0.735	0.00
Brachionus sp.	<0.001	0.00
Filinia sp.	0.027	0.00
Keratella cochlearis	0.259	0.00
Keratella quadrata	0.129	0.00
Pleurotrocha sp.	<0.001	0.00
Rotifer (unident.)	<0.001	0.00
ZOOPLANKTON: MISC		
Brachyuran larvae	<0.001	0.00
Crab zoea	0.001	0.00
Insect larvae	<0.001	0.00
Magalopa	<0.001	0.00
Polychaete larvea	0.426	0.00
Zooplanter #1	498.502	0.68
Zooplanter #2	45.760	0.06
Zooplanter #3	7.200	0.01
Zooplanter #4	20.640	0.03
Zooplanter #5	711.198	0.96
Zooplanter #6	7.680	0.01

Table 2. Mean seasonal concentrations for zooplankton categories at the four Back Bay Stations between April 1987 and March 1988. Numbers are individuals per liter.

	Winter	Spring	Summer	Fall
STATION 3				
I. Macrozooplankton				
Cladocerans	——	0.52	——	——
Copepods	0.66	1.78	0.73	1.99
Misc. Zooplankton	86.94	576.00	1,472.00	819.54
Rotifers	0.14	1.94	0.01	0.01
II. Microzooplankton				
Tintinnids	256.00	36,825.60	12,681.50	15,872.00
Other Ciliates	50,714.66	22,105.60	17,323.00	19,302.40
STATION 9				
I. Macrozooplankton				
Cladocerans	0.01	0.01	0.01	——
Copepods	1.47	1.50	0.91	——
Misc. Zooplankton	43.92	4,288.01	2,363.67	1,254.87
Rotifers	0.22	2.23	0.01	0.01
II. Microzooplankton				
Tintinnids	554.66	10,352.00	24,957.83	19,251.20
Other Ciliates	30,848.00	36,835.60	45,511.33	21,708.80
STATION 20				
I. Macrozooplankton				
Cladocerans	——	——	——	——
Copepods	0.44	1.25	1.01	1.16
Misc. Zooplankton	2.02	921.60	2,538.66	1,664.56
Rotifers	0.03	1.57	0.01	0.01
II. Microzooplankton				
Tintinnids	768.00	77,081.60	17,418.66	21,273.60
Other Ciliates	32,768.08	32,780.80	27,472.16	26,624.01
STATION 22				
I. Macrozooplankton				
Cladocerans	0.01	0.01	——	0.01
Copepods	1.51	1.15	0.77	0.40
Misc. Zooplankton	87.34	409.61	1,350.33	
Rotifers	0.01	2.14	0.01	0.01
II. Microzooplankton				
Tintinnids	682.66	35,315.20	9,005.83	7,398.40
Other Ciliates	43,477.33	36,416.00	32,079,83	21,516.80

Table 3. Seasonal concentrations of macrozooplankton at Stations 9 and 22 between April 1987 and January 1988 in numbers of individuals per liter.

	Station 9				Station 22			
Date:	4/29	7/22	10/23	1/25	4/29	7/22	10/23	1/25
Acartia tonsa	0.37	0.19	0.02	0.02	0.09	0.05	——	0.24
Acartia clausi	0.12	——	——	——	——	——	——	——
Acartia copepodite	2.75	0.43	3.51	——	1.25	1.20	0.10	0.03
Eurytemora affinis	0.25	——	——	——	0.12	——	——	0.03
Cyclops vernalis	1.15	——	——	——	0.06	——	——	——
Cyclops varicans rubellus	——	0.01	——	——	0.06	0.01	——	0.06
Orthocyclops modestus	——	——	——	——	——	0.01	——	——
Canthocamptus spp.	0.03	——	——	——	——	——	——	——
Unk. harpacticoida	——	0.01	——	——	——	——	——	——
Copepod nauplii	0.25	0.01	0.18	——	——	0.01	0.01	——
Rithropanopeus harrisi zoea	——	0.01	——	——	——	——	——	——
Palaeomonetes zoea	——	0.01	——	——	——	——	——	——
Podon polyphemoides	——	——	——	——	——	——	0.01	——
Barnacle nauplii	0.12	0.01	——	——	16	——	——	——
Spionidae nectochaete	——	——	0.37	——	——	0.01	2.81	——

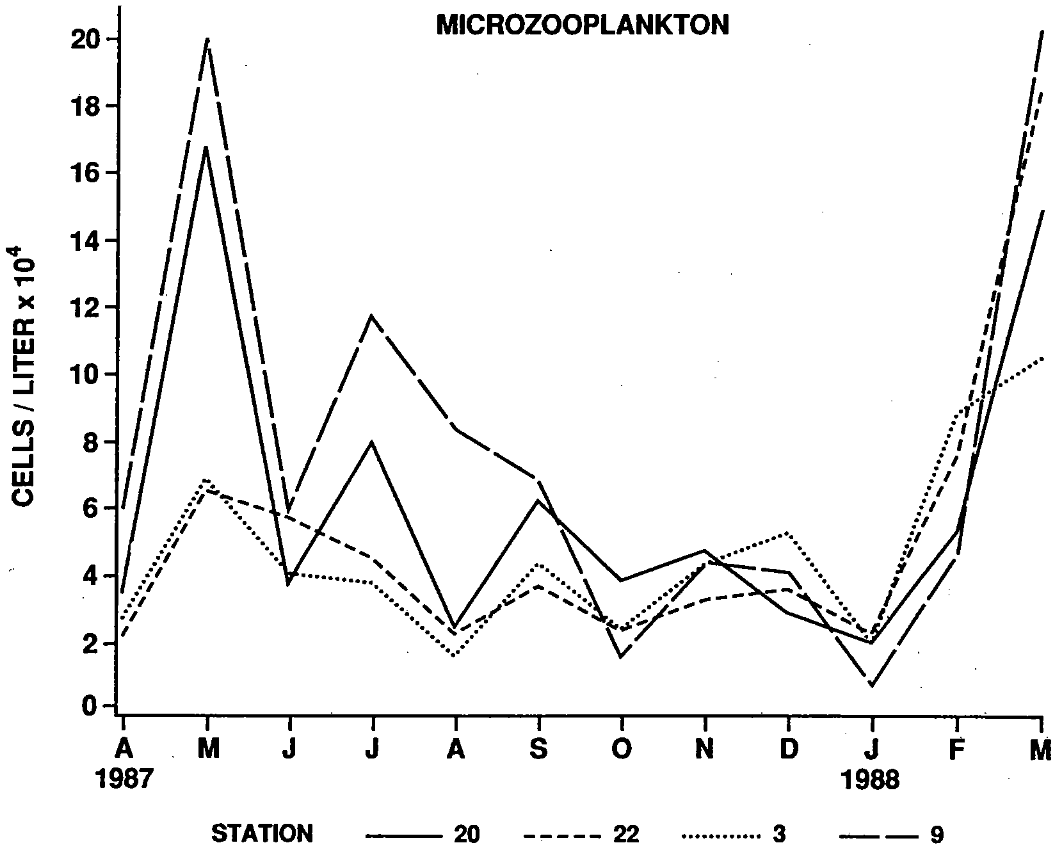

Figure 1. Concentrations of microzooplankton from April 1987 through March 1988 at stations in Back Bay.

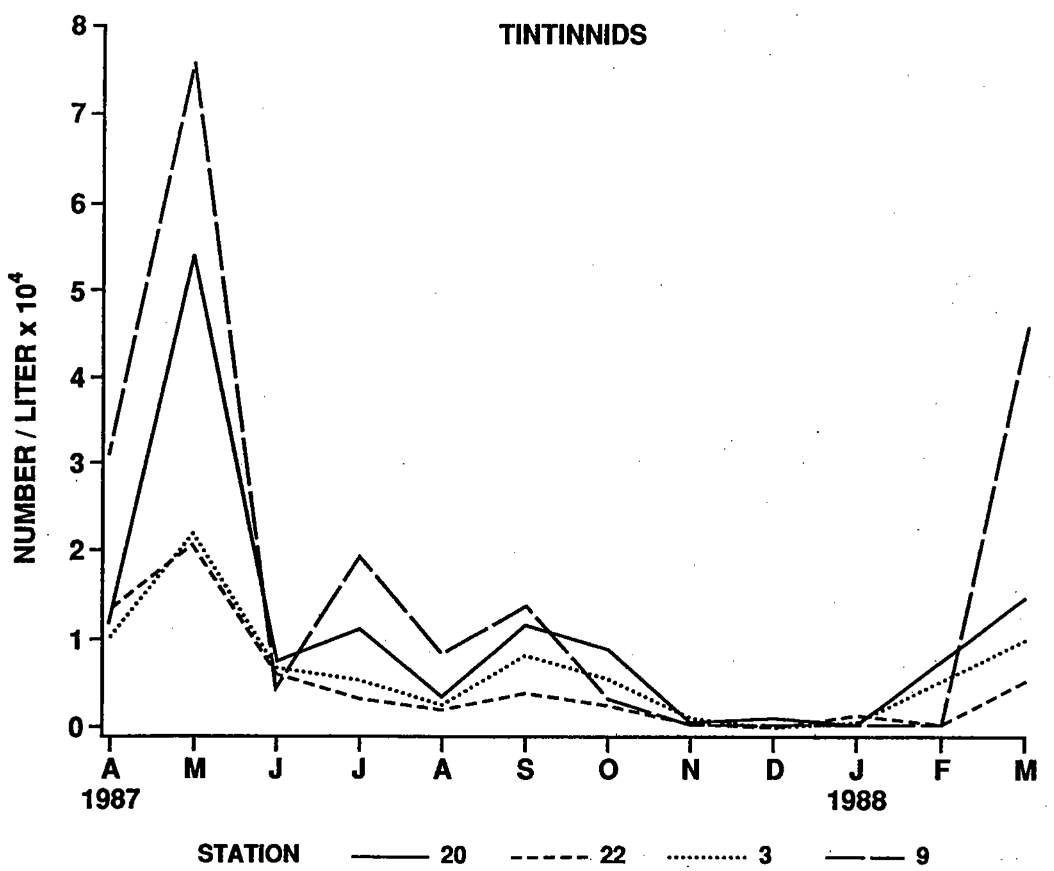

Figure 2. Concentrations of tintinnids from April 1987 through March 1988 at stations in Back Bay

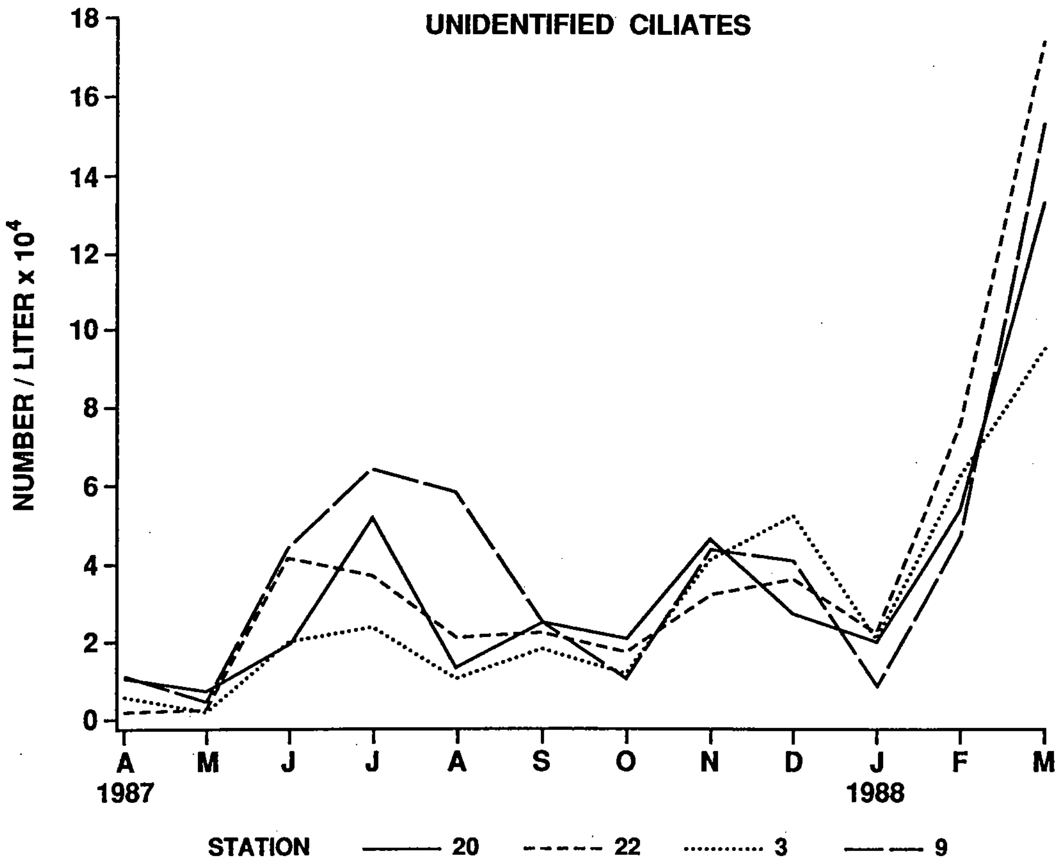

Figure 3. Concentrations of unidentified ciliates from April 1987 through March 1988 at stations in Back Bay

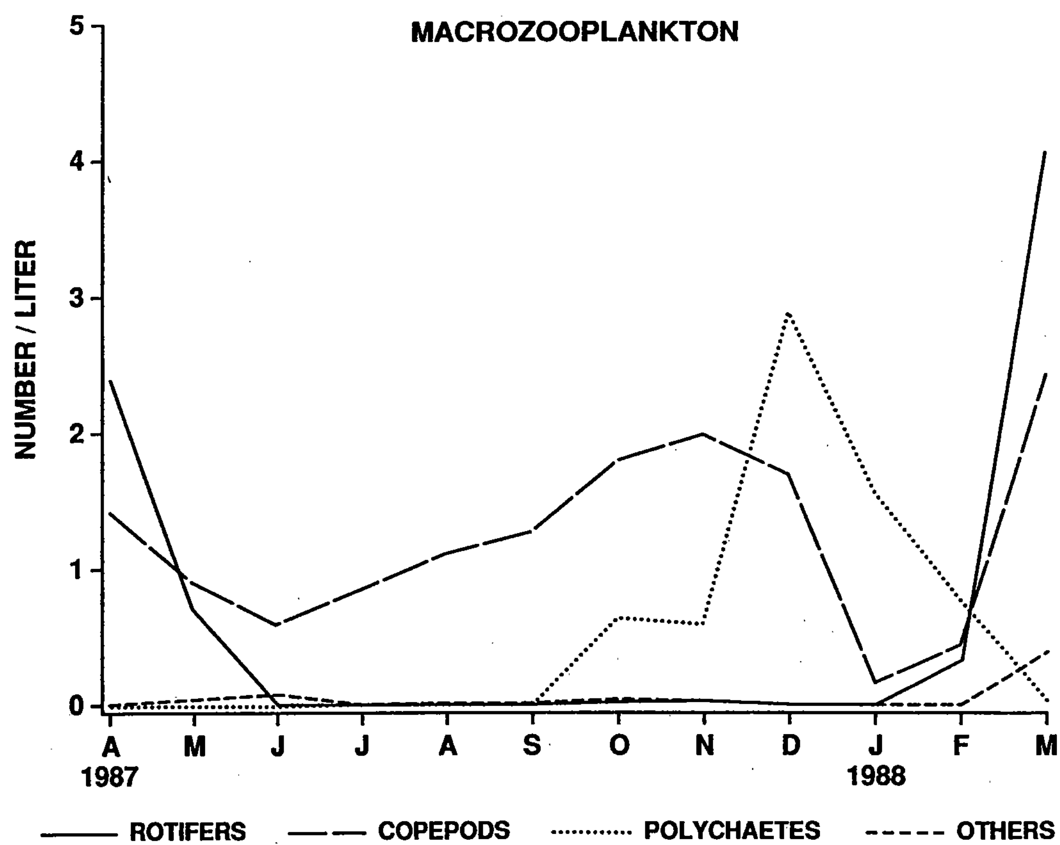

Figure 4. Mean concentrations of macrozooplankton components at stations in Back Bay from April 1987 through March 1988

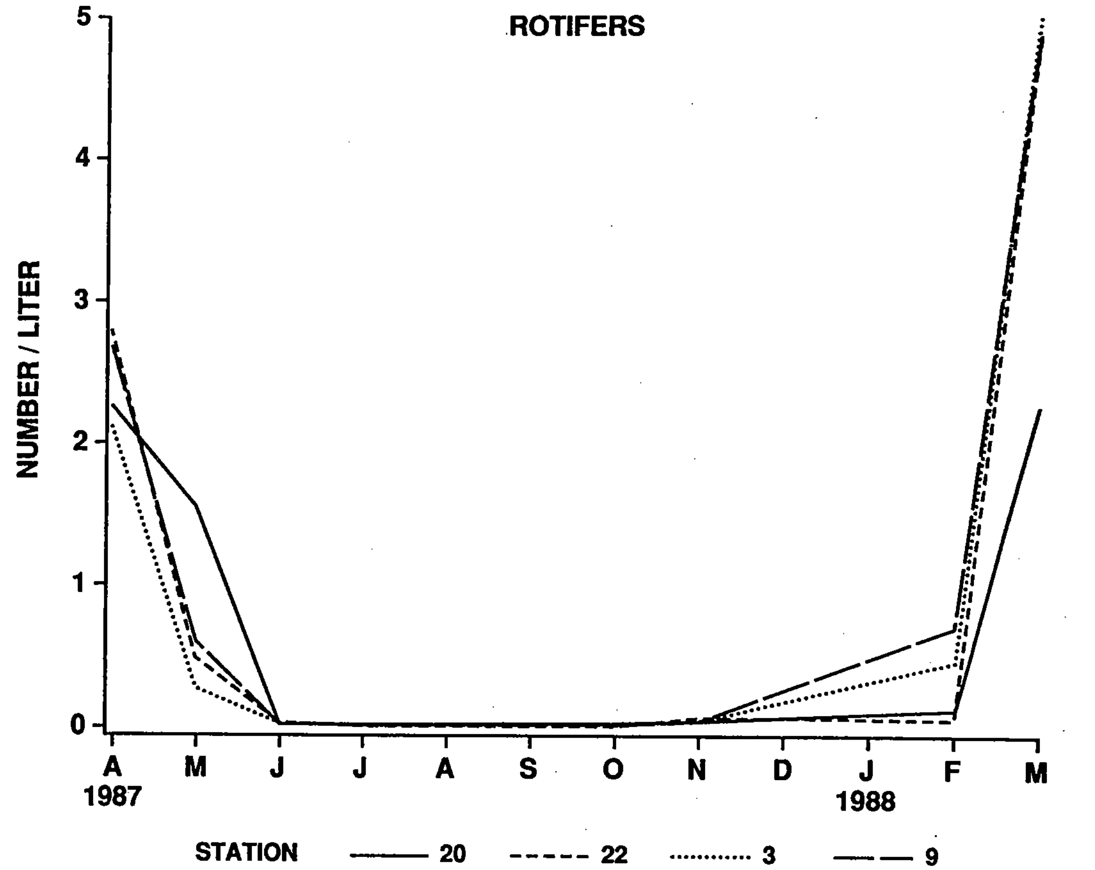

Figure 5. Concentrations of rotifers from April 1987 through March 1988 at stations in Back Bay

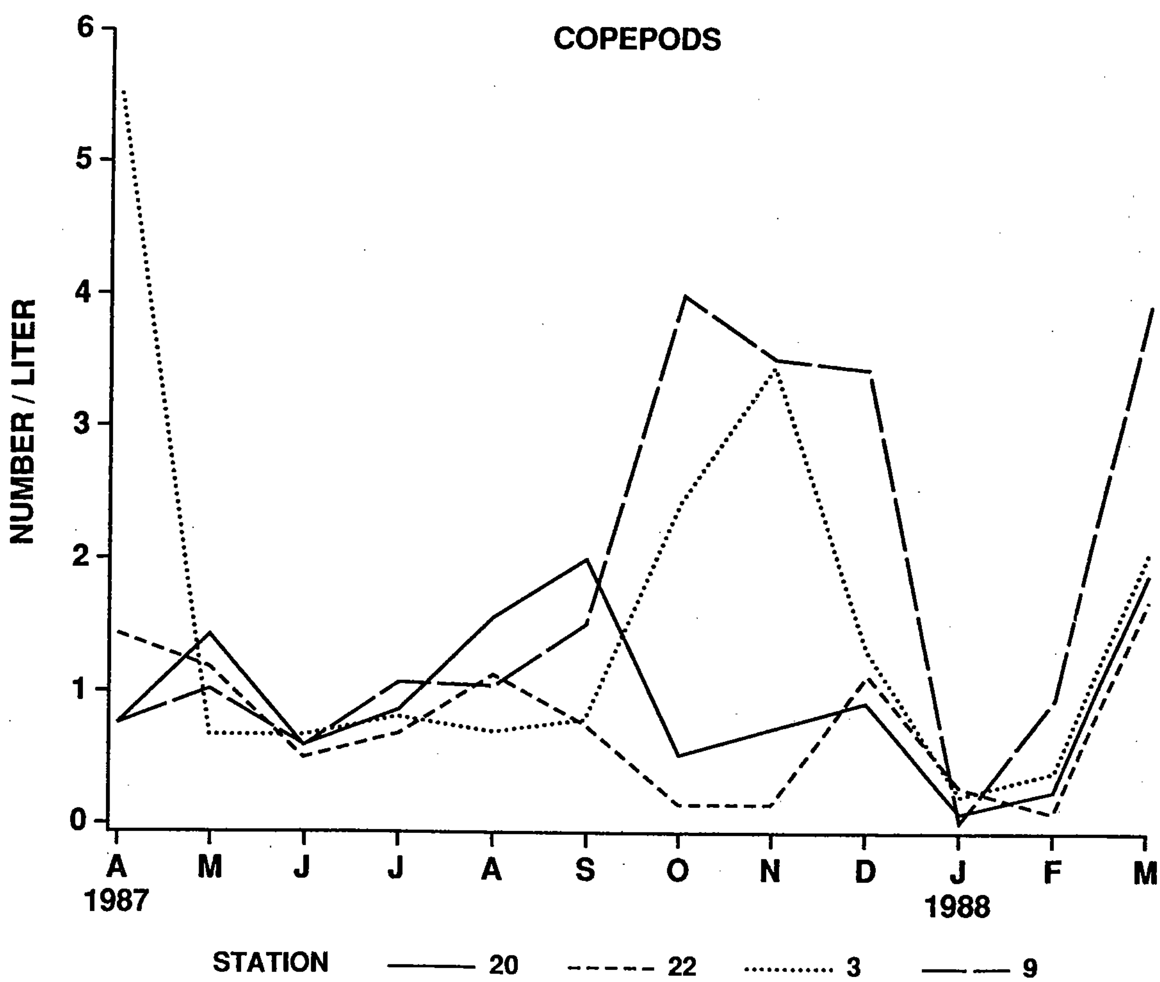

Figure 6. Concentrations of adult copepods from April 1987 through March 1988 at stations in Back

Impact of Salinity Changes on Fish Populations in Back Bay, Virginia, 1950-1989

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Abstract: Studies conducted of Back Bay during 1950-51 and 1959-62 showed the fish populations were dominated by freshwater species. Major species included largemouth bass, channel catfish, yellow perch and carp. The average salinities during the study periods were below 0.7 ppt. Salt water was pumped into the Bay by the City of Virginia Beach from 1965-1973 increasing the average salinity to 2.8 ppt. When pumping was discontinued in 1973, salinity decreased to pre-pumping levels until August, 1978.

The fish population was surveyed in 1978, 1979 and 1980 when it was again found to be dominated by freshwater species, providing an outstanding sport fishery for largemouth bass, black crappie and bluegill. The City resumed saltwater pumping in August, 1978 and continued to August, 1987 maintaining salinities from 1.7 to 5.3 ppt. Surveys conducted during 1985 and 1986 showed the (freshwater) fishery had shifted to predominantly brackish/marine species, which included bay anchovy, white perch, spot and Atlantic menhaden. The results from rotenone and trawl/seine samples showed the fish population comprised of 74 to 97 percent brackish/marine species. After pumping was discontinued the salinity gradually declined to less than 1.0 ppt by 1989. Fish population surveys during 1989 showed an increase in freshwater fishes, mainly in the tributary creeks and canals, where over 60 percent of the fishes were freshwater.

Introduction

Back Bay has undergone several ecological changes since the natural closing of Old Currituck Inlet (VA-NC line) prior to 1830. Before that time the bay was estuarine, supporting a commercial fishery for oysters, clams, shrimp and marine fishes (Roy Mann and Assoc., 1984). Transition from a marine to freshwater ecosystem occurred over a relatively short period, and by the turn of the century U.S. Fish and Wildlife Service (USFWS) records for commercial fish landings indicated that a substantial largemouth bass (*Micropterus salmoides*) fishery was established in Back Bay. Approximately 100 commercial fishing crews harvested from 34,000 to over 136,200 kg/yr of largemouth bass from 1901-1930 (Rosebery, 1952). Other commercially important species were carp (*Cyprinus carpio*), white perch (*Morone americana*), and channel catfish (*Ictalurus punctatus*).

There have been several studies conducted of the Bay's fish population since 1951, including surveys before and after saltwater introduction. Prior to the City of Virginia Beach pumping salt water into Back Bay in 1965, the fish population was predominanted by freshwater species. The City pumped saltwater until 1973 increasing salinities up to 3 ppt. Salinity dropped to pre-pumping levels from 1974 to 1978, and a fishery survey in July, 1978 showed the fish population was still mainly freshwater species. The City resumed saltwater pumping in August, 1978, raising salinity as high as 5.3 ppt. Subsequent surveys found that the increase in salinity had an adverse effect on the freshwater fish population, primarily in a decrease of reproductive success. In addition, the sportfishery for largemouth bass, black crappie (*Pomoxis nigromaculatus*) and bluegill (*Lepomis macrochirus*) became virtually non-existant by 1984. Pumping was discontinued in August, 1987 and salinity dropped gradually to less than 1.0 ppt by 1989. Qualitative analysis of surveys conducted on the tributary waters of the Bay in 1989 indicated that freshwater fishes increased in number as salinity declined.

A total of 48 species of fish were collected from all studies dating back to 1951, including 19 freshwater, 23 fresh/brackish and 6 marine types (Table 1).

Discussion

Three major studies of the Bay's fishery have been conducted since 1951. Rosebery (1952) conducted a fisheries survey from 1951-1952. The study assessed the effects of both sport and commercial fishermen on the fish population. Data from cove rotenone samples, creel surveys, a largemouth bass tagging study and monitoring of commercial fishing operations were collected and analyzed.

Freshwater species accounted for 68% of the total fish collected from rotenone samples. The most abundant species were channel catfish, largemouth bass and carp. With the exception of bowfin (*Amia calva*), evidence of reproduction was found for all species collected. Other major fishes found in the samples were white perch, striped mullet (*Mugil cephalus*) and spot (*Leiostomus xanthurus*) (Table 2). Salinity during the study period averaged 0.7 ppt.

Rosebery found that commercial fishing, primarily by haul seines, had declined since the 1920's. During the commercial fishing season in 1950-51, only 10 active crews were operating on the Bay. Species most abundant in the catches were carp (62%), yellow perch (*Perca flavescens*) and white perch (21%), and channel catfish (7%). Largemouth bass were classified as "gamefish" and were not allowed to be taken commercially.

The next comprehensive study of Back Bay (and Currituck Sound) was done by the Virginia Department of Game and Inland Fisheries (VDGIF), the USFWS, and the N.C. Wildlife Resource Commission from 1959-1962 (Sincock, et al. 1966). The study was undertaken to determine the cause for the paucity of submerged aquatic vegetation (SAV) and waterfowl in the Bay, and what effects that saltwater introduction would have on freshwater fish. Because of the poor SAV conditions in the Bay, local hunting groups proposed that the City of Virginia Beach introduce salt water to improve waterfowl habitat, by reducing turbidity, thus allowing SAV to grow.

Comparison of the fish population data collected from 1959 1962 with Rosebery's results found species composition had changed very little (Table 2). The major sportfish were largemouth bass, bluegill, and pumpkinseed (*Lepomis gibbosus*). Commercially important species were carp, perch (white and yellow) and channel catfish.

Laboratory experiments were performed during the study to determine the possible effects of increased salinities on largemouth bass and bluegill (Wollitz 1962; Tebo and McCoy 1964). The results showed that survival of eggs and fry of largemouth bass was reduced by 50 percent in salinity concentrations of 1.8 ppt, and there was no survival above 3.5 ppt. Mortality of bluegill eggs and fry was 100 percent at salinities above 3.9 ppt. Based on these results, it was recommended in the *Sincock Report*, that if the introduction of salt water was to be undertaken as a management practice, salinities in the bay should not exceed 3.5 ppt.

Researchers also had the opportunity to study the effects of increased salinity on the bay's fishery when a severe "northeaster" (Ash Wednesday Storm) in March, 1962 caused several breaks in the dunes allowing seawater introduction. Fish kills were observed in the immediate areas of the seawater intrusions where salinities as high as 26 ppt were recorded (Wollitz, 1962) The high salinities were only temporary, as winds mixed the salt water with the fresh water of the bay. The storm raised the average salinity to 4.2 ppt. A comparison of the data collected before and after the saltwater intrusion revealed that there were no major changes in the overall species composition. One significant observation following the storm was that largemouth bass and bluegill reproduction did not occur or was reduced in areas where salinity remained above 3.5 ppt (Johnston and Davis 1962), which concurred with the laboratory studies.

The City of Virginia Beach began pumping salt water in 1965 and continued until around 1973, maintaining salinities between 2 and 3 ppt Unfortunately, there were no fishery studies of Back Bay during this period, and any inferences concerning the fishery would be speculative.

Back Bay had undergone several ecological changes from 1962 to 1978. It went from a freshwater ecosystem (1962-1964), to slightly brackish and moderately vegetated (1965-1972), back to a fresh, but heavily vegetated body of water (1973-1978). It was during the latter period that the freshwater sportfishery flourished, primarily for largemouth bass, bluegill and black crappie.

Saltwater pumping by the City of Virginia Beach resumed in August, 1978. A fisheries study was conducted by the VDGIF from 1978-1980 to evaluate the effects of the pumping. The study included annual fish population sampling, creel survey and water quality monitoring (Norman and Southwick 1981).

The first year's fish population sampling (cove rotenone) was conducted in July, 1978 when salinities in the Bay were still "normal" (<0.7 ppt). The results of the 1978 survey found standing crop had nearly doubled since 1962, although species composition was essentially the same as that found by Rosebery and Wollitz (Table 2).

The saltwater pumping increased salinity from 0.7 to 5.3 ppt during the subsequent two years of the study. Although species composition changed very little, there was a significant ($P < 0.05$) change in the proportion of freshwater fishes from 1979 to 1980. The standing crop of freshwater fish dropped from 128.9 kg/ha (1978) to 85.8 kg/ha in 1980 (Table 2). Freshwater fish reproduction also declined substantially with the increase in salinity. Reductions in young-of-the-year (YOY) numbers were found in largemouth bass, black crappie, pumpkinseed, and white perch from 1978 to 1980 (Table 3). During the spawning period (April-June) of each year, the mean salinity was 0.8 ppt (1978), 2.3 ppt (1979) and 3.4 ppt (1980). Based on the earlier studies, the high salinities in 1979-80 would have prohibited reproduction or resulted in significant reductions in survival of eggs and fry of several freshwater species.

Back Bay's sport fishery was rated as one of the finest along the East Coast (Almy, 1980). Anglers caught more citation size (greater than 3.63 kg) largemouth bass from 1977 to 1983 than in any other water in Virginia. This phenomenon was more the result of SAV and not salinity (Figure 1). SAV covered up to 80 percent of the Bay from 1973 to 1978, and salinity during this time had dropped to less than 1.0 ppt making conditions ideal for the freshwater fish population. However, the vast abundance of SAV during the earlier years made it very difficult for boat navigation and fishing. When the SAV started to disappear, anglers "honed in" on the scattered patches of vegetation which provided the only cover for the bass.

The fish population was not surveyed again until October, 1985. During this period, the average monthly salinities exceeded 3.0 ppt nearly 68% of the time, and was below this level in only 2 of the 15 potential spawning months. Fish sampling was conducted monthly through December, 1986 (Norman & Southwick, 1987) using several techniques in an attempt to evaluate the entire fishery. These included open water haul seining, shoreline seining, mid-water trawling, and cove rotenone.

All areas of Back Bay were sampled by trawl and seines, collecting a total of 35,132 fish (39 species). Each species was categorized as "freshwater", "brackish", or "marine" (Table 4), as designated by Robins, et al (1980). The number of freshwater fish totaled 1,009 (2.8%) and included 15 species. No YOY freshwater fish were observed in the seine or trawl samples. The most abundant fishes collected were bay anchovy (*Anchoa mitchilli*), spot, white perch, Atlantic menhaden (*Brevoortia tyrannus*) and Tidewater silversides (*Menidia peninsulae*). These species made up 90.7% of the total catch.

Cove rotenone samples in 1986 were done on the same two coves treated in 1978-80. Freshwater species constituted only 23.8% of the total number of fish collected in 1986, which was a significant ($P < 0.05$) difference from 1978, when freshwater fish made up 67.6% of that sample (Table 2). The major declines were in largemouth bass, pumpkinseed, yellow perch, and longnose gar (*Lepisosteus osseus*). Although some freshwater YOY fishes were collected, the number was significantly lower than in 1978 (Table 3). Based on the sampling results of 1985 and 1986, the VDGIF was able to persuade the City of Virginia Beach to discontinue saltwater pumping into Back Bay, and the pumping operation was shut down in August, 1987. The average salinity in the Bay at that time was 3.3 ppt.

The salinity dropped gradually, and did not reach pre-pumping levels (<1 ppt) until August, 1989. Electrofishing samples conducted in 1989 by the VDGIF found large concentrations of freshwater fish in the creeks and canals leading into the Bay (Table 5). Another encouraging observation was the presence of YOY largemouth bass, bluegill and black crappie, showing that salinity was finally low enough for these species to reproduce successfully.

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Table 1. Fishes collected from Back Bay, 1951, 1959-62, 1978-80, 1985-86 and 1989.

	Year Collected				
	1951	**1959-62**	**1978-80**	**1985-86**	**1989**
FRESHWATER					
Lepisosteidae					
Lepisosteus osseus longnose gar	X	X	X	X	X
Amiidae					
Amia calva bowfin	X	X	X	X	X
Umbridae					
Umbra pygmaea eastern mudminnow		X	X		
Esocidae					
Esox americanus redfin pickerel		X	X		
Esox niger chain pickerel	X	X	X	X	
Cyprinidae					
Cyprinus carpio carp	X	X	X	X	X
Notemigonus crysoleucas golden shiner	X	X	X	X	X
Ictaluridae					
Ictalurus catus white catfish		X		X	X
Ictalurus natalis yellow bullhead		X			X
Ictalurus nebulosus brown bullhead	X	X	X	X	X
Ictalurus punctatus channel catfish	X	X	X	X	X
Centrarchidae					
Centrarchus macropterus flier		X	X		
Enneacanthus gloriosus bluespotted sf.	X	X	X	X	X
Lepomis gibbosus pumpkinseed	X	X	X	X	X
Lepomis gulosus warmouth		X			X
Lepomis macrochirus bluegill	X	X	X	X	X
Micropterus salmoides largemouth bass	X	X	X	X	X
Pomoxis nigromaculatus black crappie	X		X	X	X
Percidae					
Perca flavescens yellow perch	X	X	X	X	X
SUBTOTAL	**13**	**18**	**16**	**14**	**15**
FRESH/BRACKISH					
Elopidae					
Elops saurus ladyfish		X		X	
Anguillidae					
Anguilla rostrata American eel	X	X	X	X	X
Clupeidae					
Alosa aestivalis blueback herring			X	X	X
Alosa pseudoharengus alewife	X	X	X	X	
Alosa sapidissima American shad	X				
Dorosoma cepedianum gizzard shad	X	X	X	X	X
Dorosoma petenense threadfin shad			X		X
Engraulidae					
Anchoa mitchilli bay anchovy			X	X	X
Belonidae					
Strongylura marina Atlantic needlefish	X	X	X	X	X
Cyprinodontidae					
Cyprinodon variegatus sheepshead minnow			X	X	X
Fundulus diaphanus banded killifish	X	X	X	X	X
Fundulus heteroclitus mummichog				X	
Poecilidae					
Gambusia affinis mosquitofish		X	X	X	X

Table 1. (cont.)

	Year Collected 1951	1959-62	1978-80	1985-86	1989
Atherinidae					
Menidia menidia Atlantic silverside			X	X	
Menidia peninsulae tidewater silverside		X	X	X	X
Gasterostridae					
Gasterosteus aculeatus 3 spine stickleback			X	X	
Percicthyidae					
Morone americana white perch	X	X	X	X	X
Morone saxatilis striped bass	X	X			
Sciaenidae					
Bairdiella chrysoura silver perch				X	
Leiostomus xanthurus spot	X	X	X	X	X
Micropogonias undulatus Atlantic croaker				X	
Mugilidae					
Mugil cephalus striped mullet	X	X	X	X	X
Gobiidae					
Gobiosoma bosci naked gobi				X	X
SUBTOTAL	**10**	**12**	**16**	**20**	**14**
MARINE					
Clupeidae					
Brevoortia tyrannus Atl. menhaden	X	X	X	X	X
Syngnathidae					
Syngnathus fuscus northern pipefish				X	
Sciaenidae					
Cynoscion regalis weakfish				X	
Pleuronectidae					
Pseudopleuronectes americanus winter flounder				X	X
Soleidae					
Trinectes maculatus hogchoker				X	
Cynoglossidae					
Symphurus plagiusa blackcheek tonguefish				X	
SUBTOTAL	**1**	**1**	**1**	**6**	**2**
TOTALS	**24**	**31**	**33**	**40**	**31**

Table 2. Comparison of standing crop data (kg/ha) for Back Bay fishes collected in rotenone samples in 1951, 1962, 1978-80 and 1986.

	1951	1962	1978	1979	1980	1986
Freshwater						
Longnose gar	0.06	0.37	19.36	0.03	0.02	9.65
Bowfin	3.09	4.37	0.52	2.57	1.11	0
Eastern mudminnow	0	0.10	0.03	0.01	0	0
Chain pickerel (Redfin)	0	0.11	0	(0.21)	0	0.01
Carp	11.10	3.92	1.81	0.15	0.01	9.78
Golden shiner	5.62	3.25	0.51	0.49	0.66	0.17
White catfish	0	0.78	0	0	0	0
Channel catfish	20.51	2.46	0	0	0	0
Yellow bullhead	0	0	0	0	0	0.28
Brown bullhead	3.65	2.58	2.65	1.81	5.51	0.08
Flier	0	0.11	0.22	0	0	0
Bluespotted sunfish	0	0.67	1.06	0.15	0.11	0.72
Warmouth	00.45	0	0	0	0	
Pumpkinseed	7.02	20.27	44.51	69.91	40.30	5.98
Bluegill	0.06	3.36	1.69	11.69	4.54	0.94
Largemouth bass	15.60	6.83	21.83	18.19	20.92	2.78
Black crappie	0	0	1.46	1.48	2.36	0.06
Yellow perch	2.25	4.82	7.74	22.26	10.21	0.33
Subtotal	68.96	54.45	103.39	128.95	85.75	30.78
Brackish						
Ladyfish	0	0	0	0	0	0.22
American eel	0.06	0.78	1.12	1.82	2.08	0
Gizzard shad	0	0.10	0.28	0	11.25	0.20
Threadfin shad	0	0	0.01	0	0	0
Alewife	2.36	0	0	0	0	0
Bay anchovy	0	0	0	0.17	0	0
Atlantic needlefish	0.06	0.10	0.22	0.04	0.19	0.35
Sheepshead minnow	0	0	0	0.06	0.37	9.24
Banded killifish	0.06	0.67	0.03	0.25	0.35	6.57
Mummichog	0	0	0	0	0	0.10
Mosquitofish	0	0.10	0.01	0.01	0	0.29
White perch	10.26	6.38	9.17	2.10	16.24	33.26
Tidewater silversides	0	0.11	0.33	0.04	0.55	1.66
Spot	7.70	7.95	30.07	0	4.31	22.72
Striped mullet	8.29	22.96	5.27	0.53	3.44	22.11
SUBTOTAL	**28.79**	**39.15**	**46.51**	**4.85**	**38.78**	**96.89**
Marine						
Atlantic menhaden	0.15	0.78	3.11	0	0	0.85
Winter flounder	0	0	0	0	0	0.96
SUBTOTAL	**0.15**	**0.78**	**3.11**	**0**	**0**	**1.81**
TOTALS	**97.90**	**94.38**	**153.01**	**133.80**	**124.53**	**129.48**

Table 3. Comparison of reproductive success of selected species from cove rotenone samples (# yoy/ha) in Back Bay for the periods 1959-62, 1978, 1979-80 and 1986.

SPECIES	1959-1962	1978	1979-1980	1986
Largemouth bass	175.4	331.0	93.9	56.8
Bluegill	*	39.5	29.6	0
Black crappie	0	93.9	9.9	4.9
Pumpkinseed	946.0	745.9	9.9	247.0
White perch	353.2	1,963.7	61.8	39.5
Mean annual salinity (ppt)	**0.6**	**0.7**	**3.5**	**3.5**

(* bluegill number combined with pumpkinseed)

Table 4. Collective results of trawl/seine sampling in Back Bay September 1985-December 1986.

	Total Captured	Percent of Catch
Freshwater		
Longnose gar	46	
Bowfin	14	
Chain pickerel	10	
Carp	236	
Golden shiner	5	
White catfish	65	
Channel catfish	48	
Yellow bullhead	7	
Brown bullhead	10	
Bluespotted sunfish	9	
Pumpkinseed	183	
Bluegill	13	
Largemouth bass	17	
Black crappie	311	
Yellow perch	35	
SUBTOTAL	**1,009**	**2.8**
Brackish		
Ladyfish	2	
American eel	77	
Blueback herring	69	
Alewife	8	
Gizzard shad	656	
Bay anchovy	7,883	
Atlantic needlefish	2	
Sheepshead minnow	282	
Banded killifish	118	
Mummichog	6	
Mosquitofish	65	
Threespine stickleback	1	
White perch	7,286	
Tidewater silversides	4,639	
Spot	7,659	
Atlantic croaker	452	
Silver perch	60	
Striped mullet	39	
Naked goby	8	
Hogchoker	6	
Subtotal	29,318	83.5
Marine		
Atlantic menhaden	4,790	
Pipefish	10	
Weakfish	2	
Black tonguefish	1	
Winter flounder	2	
Subtotal	**4,805**	**13.7**
TOTAL	**35,132**	**100.0**

Table 5. Catch per unit effort (electrofishing) from Hell Point Creek (HPC) and Trojan Canal (TRC), Back Bay in 1989 (No. fish/hour).

Date	4/11/89 (HPC)		7/7/89 (TRC)		9/14/89 (HPC)	
Salinity (ppt.)	0.2		1.2		0.9	
		%		%		%
Freshwater						
Longnose gar	4.2		1.1		2.3	
Bowfin	1.4		1.1		2.3	
Carp	66.2		53.3		*	
Golden shiner	1.4		0		0	
White catfish	1.4		0		0.8	
Channel catfish	0		2.2		0	
Brown bullhead	4.2		1.1		2.3	
Warmouth	1.4		0		0.8	
Pumpkinseed	31.0		6.5		39.9	
Bluegill	71.0		4.4		90.2	
Largemouth bass	14.5		4.4		11.3	
Black crappie	2.8		0		5.3	
Yellow perch	2.1		0		3.8	
Subtotal	201.6	70.9	74.1	49.0	159.0	44.2
Fresh/Brackish						
American eel	*		2.7		*	
Gizzard shad	16.6		1.1		7.5	
White perch	21.4		69.6		70.7	
Tidewater silversides	*		0		0	
Spot	0		1.1		17.3	
Striped mullet	44.1		0		3.0	
Subtotal	82.1	28.9	74.5	49.2	98.5	27.4
Marine						
Atlantic menhaden	0.7		0		101.5	
Winter flounder	0		2.7		0.8	
Subtotal	0.7	0.2	2.7	1.8	102.3	28.4
Totals	284.4		151.3		359.8	

* Did not count

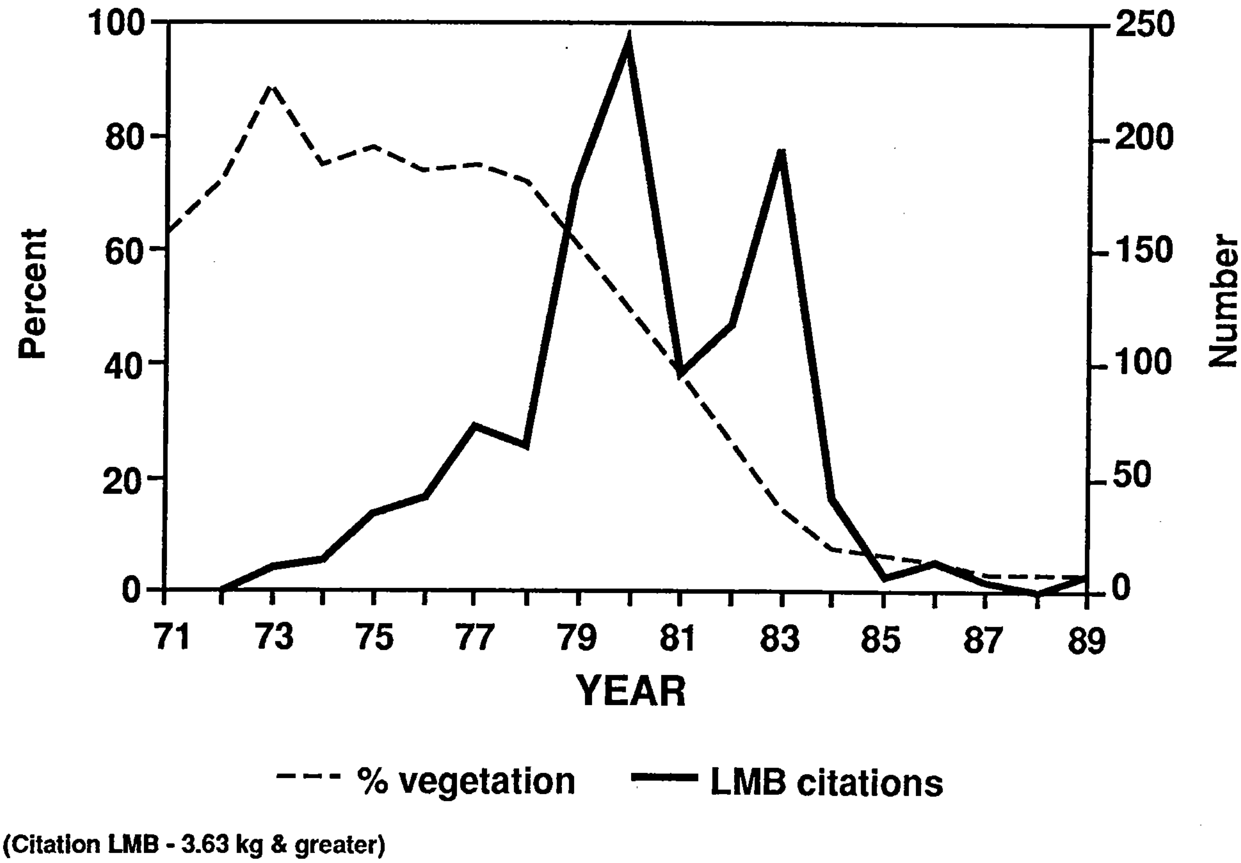

Figure 1. Abundance of submerged aquatic vegetation vs. largemouth bass citations in Back Bay, 1963-1989.

Rare Animals of Back Bay, Virginia Beach, Virginia

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Introduction

The Back Bay region is located in extreme southeastern Virginia and extends into adjacent North Carolina as the upper reach of the Currituck Sound watershed. The Back Bay ecosystem encompasses the only large intact barrier beach system in Virginia south of the Chesapeake Bay. The dynamic natural resource history of Back Bay is well known for waterfowl and fishes; however, the significance of this region is poorly known for the majority of plants, animals, and natural communities (but see Ludwig, et al. this volume).

Yet, its geographic position and relatively undeveloped condition contain habitats that are unique in Virginia and contain the best remaining example of a barrier island beach in southeastern Virginia. Since barrier island systems often contain depauperate, but unique animal communities, rare species of animals could be expected to occur. Additionally, the southeastern region of Virginia is known to constitute the northern limits of many species representative of the Floridian biotic region, increasing the likelihood for state rarieties (Hoffman, 1969).

Much of the land in the Back Bay area is publicly owned and managed as a wildlife refuge, a state park, and a game management area. Therefore it is somewhat surprising that more information is not available on the rare species of the area. Modern conservation strategies that are concerned with the protection of natural diversity emphasize the need to manage natural resource lands by considering the rarest and most sensitive species first and foremost (Soule and Kohm 1989). Other land management practices are judged as to their suitability by the impacts they would have on the rarest and sensitive species.

In this paper we present a synthesis of what is known about the occurrences of rare animal species in the Back Bay area. The fauna is examined by taxonomic groups. A discussion is presented which considers the forms of rarity for each animal grouping. Finally, recommendations for a conservation strategy that will protect the natural diversity of the Back Bay area are presented.

Methodology

Description of the study area

Figure 1 illustrates the Back Bay study area. The Back Bay drainage extends northward to the areas of Dam Neck, Redwing Lake and Lovetts Marsh. For purposes of this paper the land areas included in the study area are divided into four areas including 1) northern, 2) western (west of Back Bay), 3) barrier beach (east of Back Bay), and 4) Back Bay proper (Figure 1). A large portion of the area is in public ownership. This includes False Cape State Park (Va. Dept. of Conservation and Recreation) and Back Bay National Wildlife Refuge (U.S. Fish and Wildlife Service) as well as several military facilities.

The Back Bay area as we know it today has changed dramatically over the past 150 years. Back Bay was connected to the Atlantic Ocean during the period 1657 to 1728 by means of Old Currituck Inlet. The saltwater estuary provided for the development of a thriving fishery. The northern edge of Old Currituck Inlet was marked as the dividing line between Virginia and North Carolina in 1728, at a time when the inlet was closing. New Currituck Inlet opened in 1713 and closed in 1828, whereupon Back Bay became a body of fresh water (Hennigar 1977).

The western area of the Back Bay region consists of marshes, forest, and agricultural land. The Pungo Ridge, an old dune ridge (Oaks and Coch 1973) divides the North Landing River and Back Bay drainages (Figure 1). The ridge defines the western limit of the area considered in this paper. The northern area includes substantial freshwater wetland areas such as Lovett's Marsh, Redwing Lake, Lake Tecumseh, and Black Gut.

Data collection

The available literature was searched to locate records for rare species from the Back Bay area. In addition, the Natural Heritage databases were queried for the occurrences of rare animals (invertebrates and vertebrates). These data are accumulated from other published records from Virginia Beach, as well as regional and state checklists. The preliminary results of the Virginia breeding bird atlas project (Virginia Society of Ornithology, 1989) were included in the literature survey. In addition, knowledgeable individuals were contacted to locate unpublished and historical information. Museum searches were made for previously collected material from the Back Bay region, particularly amphibian, reptile, mammal and selected invertebrate records.

Species were considered rare if they were so considered by the natural heritage methodology of The Nature Conservancy. In Virginia, the ranks are assigned by the Virginia Department of Conservation and Recreation's Division of Natural Heritage. Natural heritage methodology assigns two ranks for each species or natural community, one for its overall or global rank (G#) and the other for its local, or in this case state status (S#). For example, a rank of G5/S5 indicates a species that is very common throughout its range, both globally and within the state. A rank of G5/S1 indicates a very common, secure species globally, but extremely rare in the state. A G1/S1 species is extremely rare throughout its entire range. These ranks are especially useful for evaluating the conservation needs of species at multiple scales at a glance. Natural Heritage ranks are included for all species listed as rare in this paper. For further explanations of natural heritage ranks see Lipford, Rouse, and Clampitt (1987).

Field Work

Inventory for rare species in the Back Bay study area has been conducted for amphibians and reptiles (Pague and Mitchell 1982; 1987; 1991), birds (Virginia Breeding Bird Atlas), dragonflies (Carle 1983), butterflies (S. Nicolay, unpublished data) and general inventory (Division of Natural Heritage, unpublished data). Ground-dwelling invertebrates were sampled with several different techniques, including drift fence arrays with pitfalls modified from Campbell and Christman (1982). Other standard methods included aerial netting (butterflies and dragonflies), sweep-netting (grasshoppers, miscellaneous insects), dip-netting (aquatic invertebrates), turning cover objects (reptiles and amphibians), and general visual searching. Amphibians and reptiles have been sampled using swim-in type turtle traps, minnow traps, dip-netting, and listening for calls (frogs) (Pague and Mitchell, 1991; Mitchell and Pague, 1991). Small mammals were sampled with pitfall, live, and snap-traps.

Results

Invertebrates: Kosztarab (1987) summarized the current status of inventory for the invertebrates of Virginia. He emphasized the poor level of knowledge for most of the groups, particularly insects. For the purposes of this paper we have restricted our presentation of invertebrate groups to those that have had sufficient study to make the results meaningful. There are only seven invertebrate groups which we feel are known well enough to include in this report.

Molluscs (non-marine): No freshwater unionid mussels are known from the Back Bay area. Thirteen species of land snails are known to occur in the City of Virginia Beach (Hubricht 1985). Three of these species are listed as rare by the Division of Natural Heritage, but none have been recorded from Back Bay. There has been no organized inventory for land snails in the study area.

Odonata: The dragonflies of Virginia were intensively surveyed and reported on by Carle (1983). Approximately 132 species of dragonflies are known from Virginia; 32 species occur in Virginia Beach; 17 of those occur in the Back Bay area. Of the 17, three species are considered rare (Table 1): *Brachymesia gravida*, *Erythrodiplax minuscula*, and *Libellula axilena*. These species are common throughout their range, but are known from few localities in Virginia. All are examples of southern species at the northern edges of their ranges. Two of the three species have been observed in the Back Bay area during 1990 (pers. obs.).

Data on the Zygoptera (damselflies) were not specific enough to indicate which species occurred within the Back Bay area. No rare species that were known from Virginia Beach could be confidently judged to be from Back Bay. Apparently there has been no inventory of damselflies in the Back Bay study area.

Orthoptera: Complete information on the distribution of grasshoppers in Virginia is lacking. However, at least 6 rare species are known from Virginia Beach (Otte, 1984). At present, no rare species are known from the Back Bay area, but there has been no inventory reported from Back Bay.

Heteroptera: (Shield bugs) Hoffman (1971) reviewed the shield bugs of Virginia and reported approximately 79 species that occurred in the Commonwealth. Several of the species are rare, a few globally so. However, most species show distributions that are indicative of perceived rarity that in fact is due to lack of effort or to the difficult nature of capturing the species. Future inventory will in all probability indicate that only a few of these species are truly rare. While there has been some collecting for heteropterans in the Sandbridge area, there has been no intensive study for the Back Bay area.

Only 19 species are known from Virginia Beach and only 2 of those from the Back Bay area. These species are *Camirus porosus* and *Podisus fretus*. Both have wide ranging coastal distributions and represent state rarities.

Heteroptera: (Squash Bugs) Hoffman (1975) determined that there are approximately 27 species of the heteropteran suborder Coreoidea known from Virginia. Several of the species are rare, a few globally so. However, like the shield bugs, most species show distributions that are indicative of perceived rarity and some of which will assuredly be proven to be more common. Only 9 of these species are known from Virginia Beach and none assuredly from the Back Bay area (Hoffman 1975). Again, there has been no thorough inventory of the study area.

Coleoptera: (Cicindelidae-Tiger beetles) The southeastern beach tiger beetle (*Cicindela dorsalis media*) was recorded from the Cape Henry area of Virginia Beach (Knisley 1987). Historic records exist for "Virginia Beach" (1918)(U. Michigan Mus. of Comparative Zoology and for "Cape Henry" (no date) (Amer.Mus. Nat. Hist.) (B. Knisely, pers. comm). No records of *C. d. media* are known and recent inventory did not reveal the presence of this species on the False Cape/Back Bay beaches in 1990 (pers. obs.). This beetle occurs on the barrier island beaches of Virginia's Eastern Shore and portions of the Outer Banks of North Carolina. It is likely that this subspecies of tiger beetle occurred along the entire Atlantic coast of Virginia prior to beach disturbance by vehicular traffic.

Lepidoptera: Nineteen species of rare butterflies have distributions that include southeastern Virginia (Scott 1986). Of these, 4 species are known from or adjacent to the Back Bay area where the proper food plants exist. *Agraulis vanillae* (Gulf fritillary) is a southern species which often migrates northward in late summer. It was observed in False Cape State Park during the summer of 1990 and presumed to be breeding (J. C. Ludwig, unpub. data); it is unknown if an established population exists there. *Poanes aaroni* (saffron skipper) and *P.yehl* (Yehl skipper) are commonly seen in the Back Bay marshes (S. Nicolay, pers. comm.). *Euphyes dukesi* (scarce swamp skipper) is known from the North Landing River marshes and should be found near its host food plant, *Carex hyalinolepis*, which is known from the Back Bay marshes.

Vertebrates

Characteristically, the vertebrates have been more thoroughly studied than most invertebrate groups. There are 19 species that have sufficient supporting evidence to record as rare breeding species of the Back Bay area. Data appear to be reasonably strong for most groups; however, birds, which are undoubtedly the most popular form of wildlife, have many species that are recorded from the area, but with no information to indicate the status of the species or whether or not they breed in the habitats of Back Bay (Virginia Society of Ornithology, 1989).

Fish: There are no rare fishes known from Back Bay (R. Southwick, pers. comm.; pers. obs.), presumably due to the highly dynamic recent history of the aquatic habitats. Fish have been thoroughly studied in Back Bay (Southwick and Norman, 1991).

Amphibians: Intensive studies conducted in the 1980's have documented the amphibian fauna of the Back Bay region (Pague and Mitchell 1982, 1987, 1991). In summary, 9 amphibian species are known from the Back Bay area; two of these species are rare.

Siren lacertina (greater siren) has been collected from freshwater marshes at the northern part of the Back Bay region (Buhlmann, in press). *Rana virgatipes* (carpenter frog) occurs in freshwater marshes on Knotts Island in the southern part of the area (C.A. Pague, pers. obs.). 7 of 16 amphibian species are known only from the more diverse habitats of the northern part of the Back Bay area (Figure 1)(Pague and Mitchell, 1991).

Reptiles: The reptiles of the study area have been studied in the past decade (Pague and Mitchell 1982, 1987, 1991, Mitchell and Pague 1990, Schwab 1988). Forty-five species are known to inhabit the study area of which three species are rare.

Ophisaurus ventralis (eastern glass lizard) is known from the barrier beach grasslands and high marshes, having been observed as recently as the summer of 1990 (D. Schwab, pers. comm.). This species was first reported from the area in 1942-44 (Werler and McCallion, 1951), but since no specimens were taken, it cannot be determined whether this or a similar species, *O. attenuatus*, was actually found. The eastern glass lizard has been found in ephemeral wet grasslands, high marshes, and dead on the sand road through maritime forests.

Crotalus horridus atricaudatus (canebrake rattlesnake) is known only from historic records from Pungo, in the western region of the study area (Werler and McCallion, 1951). No recent sightings of this species from the Back Bay area have been verified.

Caretta caretta (loggerhead sea turtle) nests on the barrier beaches of the Back Bay area including Back Bay National Wildlife Refuge and False Cape State Park. This species is considered globally rare due to its low numbers throughout most of its range. Several nests were discovered in 1989, but none in 1990 (Anthony Leger, pers. comm.). In addition, dead specimens regularly wash up on the ocean beach of the area, probably as a result of drownings from fishing nets (John Keinath, pers. comm.).

Birds: There are approximately 80 species of birds which are confirmed or probable breeding species in Virginia Beach, Virginia. There are 25 additional species that are possible breeders according to the VSO Breeding Bird Atlas preliminary results (VSO 1989). Of the confirmed/probable breeders, 61 breed in the Back Bay area. Of those species that breed in the Back Bay area, there are 3 confirmed/probable breeding species with an additional possible 8. None of the species are considered rare globally since they have wide distributions, but nearly all of the species are restricted to the barrier beach or low coastal habitats. These habitats are restricted and often threatened in Virginia.

The confirmed/probable breeding species of herons include *Ardea herodias* (great blue heron), *Egretta caerulea* (little blue heron), and *Casmerodius albus* (great egret). *Sterna hirundo* (common tern) has been observed in the Back Bay area during the breeding season (Virginia Society of Ornithology 1989), but we are aware of no nesting colonies in the area.

Possible breeding bird species include *Podilymbus podiceps* (pied-billed grebe), *Ixobrychus exilis* (least bittern), *Nycticorax nycticorax* (black-crowned night-heron), *Laterallus jamaicensis* (black rail), *Rallus elegans* (king rail), *Rallus limicola* (Virginia rail), and *Actitis macularia* (spotted sandpiper). These species are associated with brackish marshes and bordering woodlands and may likely nest in the Back Bay area. Further inventory is needed to document the nesting occurrences of these species and several other species strongly suspected to breed in the Back Bay marshes.

Mammals (non-marine): Twenty-five rare mammals are documented from Virginia. Five of those species are found in Virginia Beach and three of those are found in the Back Bay area.

Plecotus rafinesqui (Rafinesque's big-eared bat) is documented by a road-killed specimen from the Sandbridge area (R. Cashwell, unpub. data). This poorly known Virginia species is listed as a state endangered species by the Virginia Department of Game and Inland Fisheries. The specific sites inhabited by big-eared bats remain unknown.

Sylvilagus palustris (marsh rabbit) has been documented from the marsh and dune swale habitats of Back Bay National Wildlife Refuge and False Cape State Park (Handley and Patton 1947, personal observation), as well as the western area near Pungo (Handley 1979).

Peromyscus leucopus easti (Pungo mouse) is a diminutive sub-species of the white-footed mouse *P. l. leucopus* (Paradiso 1960). The entire known range is limited to the Atlantic coast beaches from Virginia Beach, Virginia south to near Duck, North Carolina (C. O. Handley, Jr., pers. comm.). Its described habitat is the beach dune habitat. The species is widespread; however, the subspecies is considered globally rare due to its restricted range.

Trichechus manatus (manatee) has been reported during summer months from the Currituck Sound (Campbell 1977) and from Virginia's marine and estuarine waters (Handley, 1979). However, Handley considered its occurrence in Virginia due to accidental summer wandering. There are no reports of the manatee from the Back Bay study area, but its wanderings into Currituck Sound combined with the once vegetation rich waters of Back Bay make it possible that it once occurred there sporadically. Handley (1979) considered this species extirpated from Virginia although there are still occasional reports from the Chesapeake Bay in the appropriate season.

Discussion

Examining the status of survey of the fauna of the Back Bay area revealed that only three groups of organisms were well known: amphibians, reptiles, and fishes. Birds have been extensively viewed and studied, yet no comprehensive inventory has been completed. Of the mammals only the larger species, which are often viewed by the casual observer, and game or fur-bearing species are well known.

The invertebrate fauna of the Back Bay region has not been comprehensively inventoried. The dragonflies and butterflies are well known, but with the butterflies considerably less so. The ongoing inventory efforts of the Virginia Department of Conservation and Recreation and the Virginia Museum of Natural History should greatly expand our knowledge of several of the taxa (Orthoptera, Coleoptera (particularly the Carabidae), Heteroptera, and Arachnida). Although the area must be considered impacted, its relatively well-preserved condition of the terrestrial habitats presents a unique opportunity to examine an invertebrate fauna that represents a best approximation of what may have occurred prior to severe human impacts now occurring in southeastern Virginia.

Of the known animal species occurring in the Back Bay area, eleven vertebrate and nine invertebrates are considered rare. This is 2.3% of Virginia's currently recognized rare, threatened and endangered species. The rarity ranks of The

Nature Conservancy's natural heritage methodology show that only a single species *Caretta caretta*, is considered globally rare (G1-G3) (Table 1). A single subspecies, *Peromyscus leucopus easti*, is also globally rare. Table 2 shows the numbers of Virginia's and Back Bay's known rare species in each animal group. Since the Back Bay study area encompasses approximately 1% of the state's acreage, the numbers of rare species inhabiting the area are slightly higher than its relative acreage. It is noteworthy that of the 232 rare vertebrates of Virginia, approximately 8% occur within the Back Bay ecosystem.

Interpretation of regional or site checklists must be done with the understanding that the species found in the Back Bay area today may not be the same as the composition of a previous time. For example, it is highly likely that the tiger beetle, *Cicindela dorsalis media* existed on the Atlantic beach of the Currituck Banks. However, intensive use of the beach by humans, particularly vehicular traffic, is known to eliminate this species (Knisley, 1987) and this species is not found there today. Certainly the beach nesting birds, common on the barrier islands of Virginia's Eastern Shore, utilized the beaches of Back Bay, but are also not found there today. Other documented human impacts including timbering, overgrazing, and alteration of the sand dune system may have impacted other species, perhaps eliminating some. Therefore, this discussion of rare species may be based on a reduced number of species, or at least a different species composition from that of a pristine Back Bay area.

It is useful to examine the composition of rare species relative to the causes of the rarity. The notion of rarity may seem broadly understood, yet there is not a consensus on the causes or definitions of it, particularly natural rarity (Cody 1986, Gentry 1986, Rabinowitz et al., 1986). The topic is clouded further by anthropogenic causes of rarity, all of which may, in the broadest sense, be considered natural. Drawing from numerous sources we will consider the following causes of rarity: narrow geographic range, restricted habitat specificity, small numbers (even if widespread), anthropogenic losses, and peripheral populations (Table 1). It is important to consider that virtually all rare species may be considered to have suffered habitat losses from human causes; however, they may have been naturally rare due to habitat specificity or other reasons prior to human impacts.

Table 1 illustrates the causes of rarity for each rare species known from Back Bay. Each of the causes of rarity listed in the above paragraph appear to act on at least one species from the Back Bay area. However, the only species which is considered to have a narrow range is the mouse, *Peromyscus leucopus easti*. The low amount of endemism is likely a result of the relatively young composition of the flora and the dynamic nature of near coast barrier island systems (Fisher 1977).

Three species are rare because they appear to always occur in relatively low numbers. For example, *Rana virgatipes* is distributed in much of the middle Atlantic states, but occurs in disjunct areas and often occurs in relatively low numbers at each site.

While humans have no doubt impacted all of these species, only three species were considered to have been so used or abused by humans and are now considered rare. The bat, *Plecotus rafinesqui*, used caves and large hollow trees for roosting and overwintering. These habitats have been largely destroyed or disturbed, causing declines in the numbers of bats. The rattlesnake, *Crotalus horridus atricaudatus*, as are most venomous snakes, is persecuted out of fear of their ability to injure humans and their animals. The sea turtle, *Caretta caretta*, has been killed in fishing nets, its eggs robbed from the beaches, and killed directly for food. Its numbers have declined dramatically as a result of overharvesting. However, human persecution and endemism are not the major causes of rarity in the Back Bay ecosystem.

Human impacts are not solely direct. The Back Bay area has been utilized by European-derived humans for nearly 400 years. The impacts to the natural habitat are detailed by Hennigar (1977). Aerial photographs of the Currituck Banks from 1937 make it clear that the vegetation, and therefore the animals, that we observe on the barrier beaches of southeastern Virginia today are quite different than 60 years before. In fact, Pague and Mitchell (1991) believe that the human alterations of the barrier beach habitats are the primary cause of the present amphibian and reptile species composition. Certainly, most of the other animal groups have been similarly affected.

Fourteen species of rare animals from Back Bay have specific habitat requirements or preferences that restrict them to or near the coast. Such species will be naturally rare since their habitat consists of a thin band adjacent the oceans, bays and larger rivers. Such a limited distribution combined with the popularity of the coastline with people predisposes these species to the need for special consideration.

The most frequent cause of rarity in the Back Bay area is due to species that occur at or near the northern limits of their ranges. These are considered peripherals (Table 1) and sixteen species are so distributed. This distributional pattern was considered by Hoffman (1969) in the discussion of biotic regions of Virginia and is not restricted to the fauna, but exhibited even more strongly in plants. Of the 37 species of rare plants found in the Back Bay area, almost all are found in Virginia as peripherals (Ludwig, et al. 1991). They point out that the diversity of natural communities of the Back Bay area are generally of types found commonly south of Virginia.

The conservation significance that can be placed on an area is derived from many factors including: 1) how rare are the inhabitants, 2) how many rare species occur and are viable at the site, and 3) how important is the site to other rare or potentially rare species that may not inhabit the area (such as habitat corridors and concentration points). So how significant is the Back Bay area for the conservation of rare species?

For the single subspecies that is narrowly distributed, *Peromyscus leucopus easti*, the barrier beaches are the largest possible preserve remaining. Only two much smaller managed areas occur in North Carolina, and the remaining habitat in Virginia is currently under development. The barrier beaches may act as a genetic corridor. The Back Bay area also serves as an important corridor for other rare species, not generally considered in this paper. For example, the peregrine falcon (*Falco peregrinus*) uses the coastal beaches as a major migratory route, feeding and resting along the way. Many shorebirds, wading birds and waterfowl use the Back Bay habitats for temporary feeding and resting areas. Other organisms that assemble in or pass through Back Bay include shorebirds, waterfowl, wading birds, some warblers, several species of butterflies, and bats. Further investigations will be necessary to determine the significance of the Back Bay area to these groups. Therefore, Back Bay is significant to a few rare and other more common species as a corridor or stopover site.

The greatest significance of the Back Bay area for the conservation of rare species is for those species that are limited to the coastal habitats, therefore rare, and those species that occur at the periphery of their ranges. As for plants (Ludwig, et al. this volume), the Back Bay area supports the only Virginia populations of several rare animals and the best remaining sites for other peripheral species. The natural communities and their inhabitants should be protected as the best examples of what was always rare in Virginia.

Conservation land managers in the Back Bay area should be concerned first and foremost with the protection of known rare species and the natural communities that they inhabit. This is particularly significant in view of the increasing isolation and fragmentation of this ecosystem resulting from the rapid development of the southeastern Virginia and northeastern North Carolina coastal habitats. Efforts should be made to assure that large areas of significant habitats and their supporting ecosystem level functions, are protected from alterations which may affect the populations of rare species. Specific strategies to protect rare invertebrates will have to wait until a more thorough inventory has been completed. However, it is likely that the protection of the rare vertebrates of the Back Bay area will aid in the protection of the invertebrate fauna.

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Table 1. The rare animals known from the Back Bay study area and their causes of rarity. Ranks are those of The Nature Conservancy's Natural Heritage Methodology.

Group	Natural Heritage Rank[1]	Range Narrow	Habitat Specific	Low Numbers	Human Losses	Peripheral Population
INVERTEBRATES						
Odonata (dragonflies only)						
Brachymesia gravida	G5/S1					X
Erythrodiplax minuscula	G5/S2					X
Libellula axilena	G5/S1					X
Heteroptera (shield bugs)						
Camirus porosus	G5/S1		X			X
Posidus fretus	G5/S1		X			X
Lepidoptera (butterflies only)						
Agraulis vanillae	G5/S1					X
Poanes aaroni	G4/S3					X
Poanes yehl	G4/S3					X
Euphyes dukesi	G3G4/S2		X			X
VERTEBRATES						
Amphibia						
Siren lacertina	G5/S1					X
Rana virgatipes	G5/S3			X		
Reptilia						
Ophisaurus ventralis	G5/S1					X
Crotalus horridus atricaudatus	G5/S1				X	X
Caretta caretta	G3/S1		X	X	X	X
Aves[2]						
Ardea herodias	G5/S3		X			
Egretta caerulea	G5/S2		X			
Casmerodius albus	G5/S2		X			
Sterna hirundo	G4/S2		X			
Podilymbus podiceps	G5/S3					X
Ixobrychus exilis	G5/S2		X			
Nycticorax nycticorax	G5/S3		X			
Laterallus jamaicensis	G4/SU		X			
Rallus elegans	G4/S2		X			
Rallus limicola	G5/S2		X			
Actitis macularia	G5/S3		X			
Mammalia						
Plecotus rafinesqui	G4/S1			X	X	X
Sylvilagus palustris	G5/S31					X
Peromyscus leucopus easti	G5T1/S1	X				

[1] Natural Heritage Ranks are based on the numbers of occurrences of the species, numbers of individuals, threats, and viability. G-ranks represent its rarity throughout the world and S-ranks represent its rarity throughout the state. S1 - extremely rare or low numbers, S2 - very rare or low numbers, S3 - rare, S4 - abundant or large numbers, and S5 - common and believed to be secure. The abbreviation SU represents an uncertain status. A T-rank represents that of a subspecies throughout its range.

[2] Includes the three known and 8 rare species thought to breed in the Back Bay area.

Table 2. The numbers of rare species extant in Back Bay and Virginia, by group. The numbers for invertebrates are based on only a few well known taxa.

GROUP	STATE	BACK BAY
Selected Invertebrates		
Odonata (dragonflies only)	132	3
Heteroptera (shield bugs only)	79	2
Lepidoptera (butterflies only)	34	4
Total Invertebrate	**245**	**9**
Vertebrates		
Fish (freshwater only)	95	0
Amphibia	18	2
Reptilia	16	3
Aves	79	3
Mammalia	24	3
Total Invertebrate	**232**	**11**
Total Animals	**477**	**20**

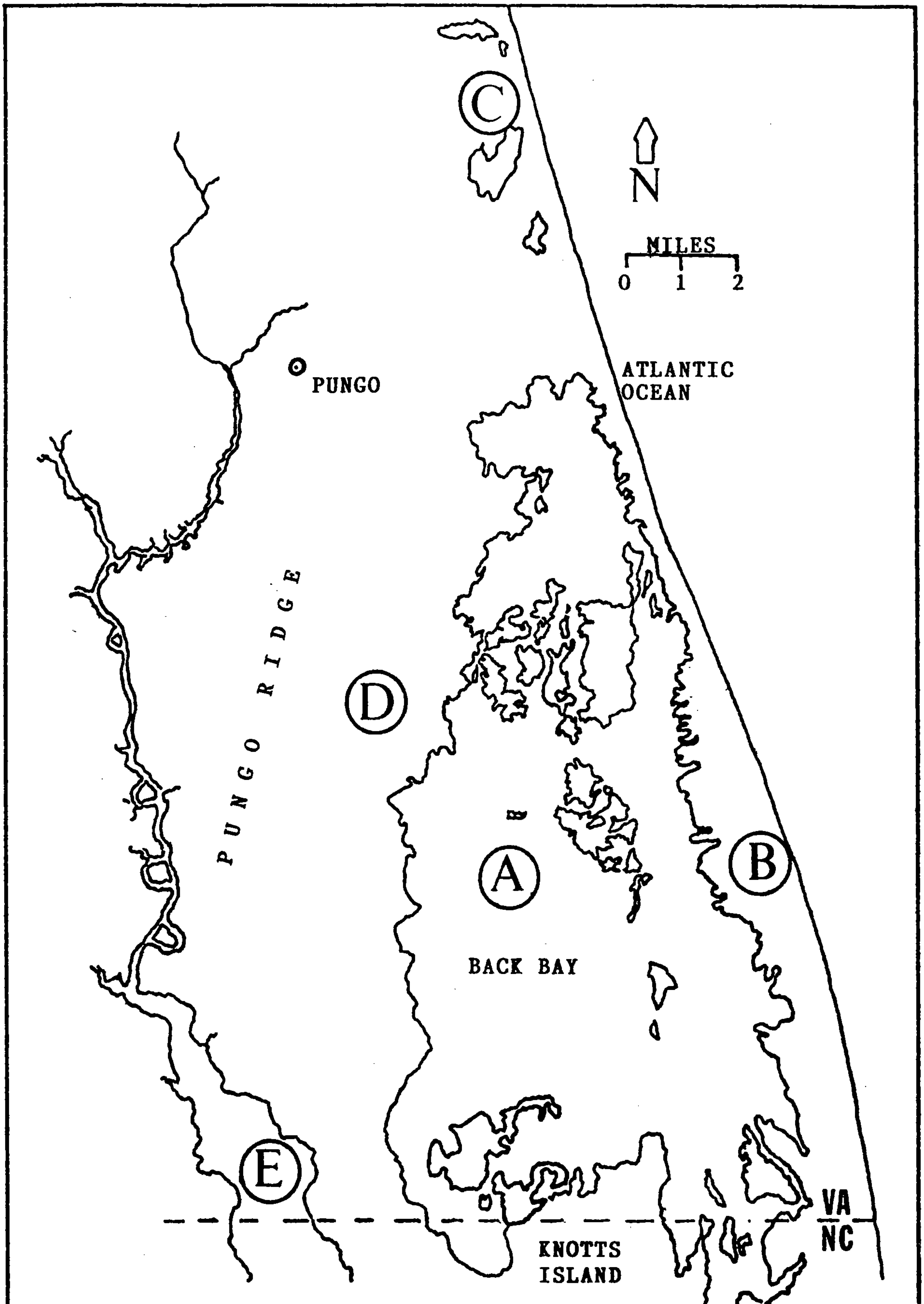

Figure 1. The Back Bay drainage study area in southeastern Virginia. Capital letters represent the following portions of the study area: A = Back Bay Proper, B = the barrier beach area, C = northern portion, D = western area, and E = North Landing River. The Pungo Ridge divides the North Landing and Back Bay drainages.

The Amphibians and Reptiles of Back Bay, Virginia

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Introduction

Past authors who documented the distributions of eastern North American amphibians and reptiles illustrated the southeastern corner of Virginia as the northern limit of distribution for many species (Conant 1958, 1975; Martof et al. 1980). These maps were not sufficiently detailed to allow resolution of specific areas; the entire region was completely shaded.

The Back Bay drainage is the most prominent topographical feature of southeastern Virginia east of the Great Dismal Swamp. It is connected by water to the Currituck and Albermarle sounds of North Carolina. Back Bay is bordered along its western margin by extensive marshes to sandy soils of the Pungo Ridge. To the east of Back Bay is the narrow northern extreme of the Currituck Banks. The waters of the Bay have historically alternated between salt and fresh due to the dynamic nature of the Atlantic shoreline.

In spite of the prominence of the Back Bay drainage, the study of amphibians and reptiles lagged far behind other nearby areas, such as Cape Henry and the Great Dismal Swamp. The lack of data was probably directly related to the inaccessibility of the habitat since it was not until World War II that the roads allowed penetration of areas south of Dam Neck, Virginia. John Werler and James McCallion visited Princess Anne County (now the City of Virginia Beach) in the early 1940's, and reported several important species (Werler and McCallion, 1951). Richard L. Hoffman and H. I. Kleinpeter visited the area in the late 1940's, but restricted their collecting in the Back Bay drainage to areas along Sandbridge Road. At that time, the road was dirt and ended at the Atlantic Ocean where nothing more than a little wooden shack stood (R. L. Hoffman, pers. comm.).

During the 1960's the development of vacation and second homes intensified resulting in significant changes to the barrier spit. Oceanfront lots were sold in the Sandbridge area and a paved road was built to the Back Bay Wildlife Refuge. Most significantly, more than five miles of barrier beach was acquired by the Commonwealth of Virginia for a state park (False Cape State Park). The site contained all of the barrier beach portion of Back Bay from the southern boundary of the wildlife refuge to the North Carolina state boundary. Shortly after this time the development of Sandbridge intensified and plans were presented to make False Cape State Park a heavily used public beach and natural area. A list of the amphibians and reptiles of the area was reported in the resulting environmental impact study (Howard et al. 1976).

The need for a more accurate checklist and life history data stimulated our study of the herpetofauna of the Back Bay watershed. Herein we describe the composition and patterns of distribution of this fauna within the study area.

Methods

To obtain a thorough knowledge of the amphibians and reptiles of Back Bay, we accumulated existing information by searching the literature and by querying museums for data on preserved specimens. Where large collections were available or where a significant question of identity was encountered, we visited the museum to verify the records. Field efforts were concentrated during the years 1980-1983, but continued through the summer of 1990. Standard methods of collecting amphibians and reptiles were used. These included turning likely cover objects, minnow traps, turtle traps, seine nets, rubber banding (for lizards), spotlighting, hand collecting, road-cruising, tape recording (of anuran vocalizations), dip-netting (with hand held nets), and the use of telescopes and binoculars. Information collected at each site included: species present, habitat, date, time, ambient temperature, collectors, and other biological notes.

Several sea turtles utilize the Atlantic Ocean adjacent the Currituck Banks (Musick 1988) but, except for one species, were not considered a part of the Back Bay herpetofauna area. *Caretta caretta*, the loggerhead sea turtle, not only uses the nearshore waters of the Atlantic Ocean, but sporadically nests on the beaches, and therefore was included in the faunal list.

Results

All orders of amphibians and reptiles known from Virginia were represented in the Back Bay area. A total of 48 species are currently known, including sixteen amphibians and thirty-two reptiles (Table 1). Four salamanders, two aquatic and two terrestrial, were recorded. The twelve frogs and toads found included four terrestrial, five arboreal, and three aquatic or semi-aquatic species.

Reptiles dominated the herpetofaunal diversity and included nine turtles. Of the turtles species found, one is terrestrial, seven are pond or marsh turtles, and one is a sea turtle.

Of the twenty-one species of squamates, four were lizards. The eighteen species of snakes included ten ground-dwelling, one arboreal, and six semi-aquatic forms. Three species of snakes are venomous, *Crotalus horridus atricaudatus*, *Agkistrodon contortrix*, and *A. piscivorus*.

Ten identifiable habitats were utilized by amphibians and reptiles (Table 2). Of these, greater than 50% of the species occurred in marsh and pond habitats. Approximately one third of all species used the mesic deciduous forest, swamps, or the Back Bay National Wildlife Refuge impoundments. Only one species, the loggerhead sea turtle (*Caretta caretta*), made more than casual use of the foredune and beach habitat.

One subspecies of the slider turtle, *Trachemys scripta elegans*, has been introduced into the waters of the Back Bay watershed. Native to the Mississippi Valley, this subspecies is known as the red-eared turtle. Hatchlings were widely sold as pets prior to the 1970's and were released or escaped into many areas of Virginia (Mitchell and Pague, in preparation). It has apparently survived in the waters of Back Bay (Mitchell and Pague, in press).

Discussion

Werler and McCallion (1951) reported 17 species of amphibians and reptiles from the Dam Neck and Back Bay barrier beach area of Princess Anne County, Virginia (now the City of Virginia Beach) based on their field surveys in the late 1940's. Their notes allow several comparisons.

Hyla cinerea was recorded as "commonly found along the marshy sections of the barrier reef." This species remains an extremely common species throughout the study area.

Werler and McCallion (1951) reported *Ophisaurus ventralis* from the Back Bay area. However, a taxonomic revision of the genus relegated all Virginia specimens to *Ophisaurus attenuatus* (McConkey 1954). The discovery of a road-killed *O. ventralis* in False Cape State Park in the 1980's was considered the first record for the state (Pague et al. 1983). Because no specimens were collected by Werler and McCallion, we will never be able to resolve the question of which species of *Ophisaurus* they actually observed. However, after years of searching in the habitat and finding only *O. ventralis*, it appears likely that their initial identification was correct. They reported a single dead individual and observed several others in the same area. The Back Bay area remains the only extant Virginia locality for this species (Mitchell and Pague, in press) and it remains relatively common (Don Schwab, pers. comm.).

Werler and McCallion (1951) reported that no *Coluber constrictor* were captured south of the town of Virginia Beach (near the resort strip), but they had reliable reports of its occurrence. We found this snake to be among the most common in the area. This species was particularly common in False Cape State Park and Back Bay National Wildlife Refuge. Few specimens were observed in the vicinity of Sandbridge. *Thamnophis sauritus* and *Agkistrodon piscivorus* were common in the marshes of Back Bay in the 1940's (Werler and McCallion, 1951) and were found to be common during our survey as well.

In a preliminary report, Pague and Mitchell (1982) reported that *Clemmys guttata* was not found in Back Bay National Wildlife Refuge or False Cape State Park. However, Werler and McCallion (1951) noted that this species was present. We relocated this species in 1983 in False Cape State Park. It was later regularly encountered in several marshes near Wash Woods in the park (T. K. Padgett, pers. comm.).

A single species, *Crotalus horridus atricaudatus*, is not vouched by an actual specimen. Residents of the Back Bay Area, including guides and sportsmen, report stories of rattlesnakes, even on the barrier beaches. Yet none could remember a recent record. Werler and McCallion (1951) reported that a very large specimen was found dead on the road in the Pungo township. Specimens have been seen in that area as recently as 1985 and residents tout that they are plentiful at the edges of the swamps. Nonetheless, although Pungo is on the boundary of the Back Bay watershed, there are no records of this species within the area. We assume that *Crotalus horridus atricaudatus* occurred at least on the edge of the Back Bay watershed and it should be sought in the forested areas near Muddy Creek.

The herpetofauna of the Back Bay area is divisible into two major groups: those that occurred in the barrier beach and associated habitats (including the brackish Back Bay marshes) and those that occurred only in sites from approximately Sandbridge Road and north. Gibbons and Coker (1978) thoroughly discussed the patterns of distribution of amphibians and reptiles on Atlantic coastal barrier islands. They concluded that some frogs and nearly all salamanders are poor barrier island colonizers while lizards and to a lesser degree snakes and turtles, are good colonizers.

The patterns of distribution of the amphibians and reptiles in the Back Bay drainage corroborate the conclusions of Gibbons and Coker. Pague and Mitchell (1982) reported only 28 species from Back Bay Wildlife Refuge and False Cape State Park. There have been three additional species confirmed since that paper. This species assemblage is typical of those found on barrier islands along the Atlantic coast. In fact, the habitats of the Currituck Banks are indistinguishable from those on the Outer Banks of North Carolina, with a single important exception -- the proximity to the mainland.

Most of the species found on the barrier beach ecosystem are also found in the northern portions of the Back Bay drainage, but with the addition of sixteen species, all of which are usually not found on barrier islands. Therefore, the Back Bay herpetofauna is richer than that found on most barrier islands and is probably due to the land connection of the Currituck Banks in the vicinity of Sandbridge and Dam Neck. Recent investigations by the Virginia Department of Conservation and Recreation's Division of Natural Heritage confirmed that the vegetation of the Dam Neck and Camp Pendleton military bases is dominated by communities that are typical of Virginia Beach mainland habitats (Virginia Department of Conservation and Recreation, Division of Natural Heritage, in press).

Back Bay and the land mass encompassed by the Currituck Banks are well known as a naturally dynamic ecosystem (Fisher 1977). Historical changes in the bay's salinity have apparently limited the dispersal of several salt intolerant species to the barrier spit. Historical changes in vegetative complexity on the Currituck Banks undoubtedly influenced it herpetofaunal composition. However, there are no records of sufficient age to determine whether or not there have been been any local extinctions in the Back Bay watershed in historical times. With the influx of urbanization, however, local extinctions of some species, such as the canebrake rattlesnake, may be inevitable. Although populations in southeastern North America are not yet exhibiting declines like those in western North America and elsewhere (Bury and Corn 1989, Corn et al. 1989, Young 1990), the myriad of impacts associated with increased urbanization could exacerbate a process waiting to happen.

The conservation of amphibians and reptiles the Back Bay area should center around the protection and restoration of the wetland communities and in the protection of the Currituck Banks, particularly those habitats of the barrier spit. Such a conservation scheme in such a large area would maximize the chances of successfully protecting the amphibian and reptile community. However, there are four rare species for which special management and protection prescriptions are desirable: *Caretta caretta* (federally threatened), *Ophisaurus ventralis*, *Crotalus horridus atricaudatus*, and *Siren lacertina*. Protection of these organisms and their habitats will be difficult due to the multiple uses and popularity of the area; however, they should receive priority consideration in the development of management plans for the Back Bay watershed.

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Table 1. Checklist of known amphibians and reptiles of the Back Bay drainage.

CLASS AMPHIBIA	salamanders
Order Caudata	
Family Sirenidae	sirens
Siren lacertina	Greater siren
Family Amphiumidae	congo eels (amphiumas)
Amphiuma means	Two-toed amphiuma
Family Plethodontidae	lungless salamanders
Plethodon chlorobryonis	Coastal Plain slimy salamander
Plethodon cinereus	Red-backed salamander
Order Anura	frogs and toads
Family Bufonidae	toads
Bufo terrestris	Southern toad
Bufo woodhousei fowleri	Fowler's toad
Family Hylidae	treefrogs
Pseudacris brimleyi	Brimley's chorus frog
Pseudacris crucifer crucifer	Spring peeper
Hyla chrysoscelis	Cope's gray treefrog
Hyla cinerea	Green treefrog
Hyla femoralis	Pinewoods treefrog
Hyla squirella	Squirrel treefrog
Family Ranidae	true frogs
Rana catesbeiana	Bullfrog
Rana clamitans melanota	Green frog
Rana utricularia	Southern leopard frog
Family Microhylidae	narrow-mouthed frogs
Gastrophryne carolinensis	Eastern narrow-mouthed toad
CLASS REPTILIA	
Order Testudines	turtles
Family Cheloniidae	modern sea turtles
Caretta caretta	Loggerhead sea turtle
Family Chelydridae	snapping turtles
Chelydra serpentina serpentina	Common snapping turtle
Family Emydidae	
Chrysemys picta picta	Eastern painted turtle
Clemmys guttata	Spotted turtle
Pseudemys rubriventris	Red-bellied turtle
Trachemys scripta scripta	Yellow-bellied slider
Trachemys scripta elegans	Red-eared slider
Terrapene carolina carolina	Eastern box turtle

Table 1 cont'd.

Family Kinosternidae	mud and musk turtles
Kinosternon odoratum	Stinkpot
Kinosternon subrubrum subrubrum	Eastern mud turtle
Order Squamata	lizards, snakes, amphisbaenians
Suborder Sauria	lizards
Family Iguanidae	
Sceloporus undulatus hyacinthinus	Eastern fence lizard
Family Scindidae	skinks
Eumeces fasciatus	Five-lined skink
Family Teiidae	racerunners
Cnemidophorus sexlineatus	Six-lined racerunner
Family Anguidae	legless lizards, glass lizards
Ophisaurus ventralis	Eastern glass lizard
Order Serpentes	snakes
Family Colubridae	
Carphophis amoenus amoenus	Eastern worm snake
Coluber constrictor constrictor	Northern black racer
Diadophis punctatus punctatus	Southern ring-necked snake
Elaphe obsoleta obsoleta	Black rat snake
Farancia abacura	Mud snake
Farancia erytrogramma erytrogramma	Rainbow snake
Heterodon platirinos	Eastern hognose snake
Lampropeltis getula getula	Eastern kingsnake
Nerodia sipedon sipedon	Northern watersnake
Nerodia taxispilota	Brown watersnake
Opheodrys aestivus aestivus	Rough green snake
Storeria dekayi dekayi	Northern brown snake
Thamnophis sauritus sauritus	Eastern ribbon snake
Thamnophis sirtalis sirtalis	Eastern garter snake
Virginia valeriae valeriae	Eastern smooth earth snake
Family Viperidae	vipers and pitvipers
Agkistrodon contortrix contortrix	Northern copperhead
Agkistrodon piscivorus piscivorus	Eastern cottonmouth
Crotalus horridus atricaudatus	Canebrake rattlesnake

Table 2. Habitat associations of amphibian and reptiles of the Back Bay area.

	HABITATS										
SPECIES	A	B	C	D	E	F	G	H	I	J	K
SALAMANDERS											
Siren lacertina											X
Amphiuma means						X					X
Plethodon chlorobryonis		X									
Plethodon cinereus	X										
FROGS AND TOADS											
Bufo terrestris		X	X	X	X	X	X	X			X
Bufo woodhousei fowleri			X	X	X	X	X				X
Pseudacris brimleyi		X				X					
Pseudacris crucifer		X				X		X			X
Hyla chrysoscelis		X						X			X
Hyla cinerea						X	X		X		X
Hyla femoralis		X									X
Hyla squirella		X		X	X	X	X		X		X
Rana catesbeiana	X					X		X	X		X
Rana clamitans						X		X			X
Rana utricularia	X	X			X	X	X	X	X		X
G. carolinensis			X	X	X	X	X		X		X
TURTLES											
Caretta caretta										X	
C. serpentina	X					X		X	X		X
Chrysemys picta	X					X		X	X		X
Clemmys guttata						X		X			X
P. rubriventris	X								X		X
T. s. scripta	X								X		X
Terrapene c. carolina		X					X				
K. odoratus						X		X			X
K. subrubrum	X					X		X	X		X
LIZARDS											
Sceloporus undulatus				X	X						
Eumeces fasciatus		X									
C. sexlineatus			X	X			X				
Ophisaurus ventralis						X	X				
SNAKES											
Carphophis amoenus	X										
Coluber constrictor			X	X	X	X	X				
Diadophis punctatus		X									
Elaphe obsoleta		X			X						
Farancia abacura								X			
Farancia erytrogramma						X		X			X
Heterodon platirinos			X	X	X		X				
Lampropeltis getula		X			X	X					
Nerodia sipedon	X					X		X	X		X
Nerodia taxispilota	X								X		X
Opheodrys aestivus			X	X	X	X	X				

Table 2 cont'd. **HABITATS**

SPECIES	A	B	C	D	E	F	G	H	I	J	K
Storeria dekayi						X	X				
Thamnophis sauritus						X	X		X		
Thamnophis sirtalis						X		X			
Virginia valeriae		X									
Agkistrodon contortrix		X									
Agkistrodon piscivorus	X	X			X	X		X	X		X
Crotalus h. atricaudatus		X									

A = Back Bay waters
B = mesic deciduous forest
C = dunes
D = scrub, shrub dominated
E = maritime forest
F = marshes, fresh or brackish
G = interdunal grasslands
H = swamp
I = impoundments
J = foredune and beach
K = pond, freshwater

The History and Success of the Wood Duck Nest Box Program at Mackay Island National Wildlife Refuge

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Abstract: Coastal southeastern Virginia and northeastern North Carolina are considered to be within the primary breeding and wintering range of the Wood duck (*Aix sponsa*). To restore and expand the local Wood duck population, Mackay Island National Wildlife Refuge introduced 37 pairs of pen-reared Wood ducks in 1970. Concurrently, 34 nest boxes were erected on the refuge. The total number of nesting boxes has expanded at a moderate pace to where the number of boxes now totals 121. The nest box program during all or part of the 10 year period from 1980 - 1989 was evaluated to: (1) assess general nesting success, (2) determine the extent of nest parasitism by European starlings (*Sturnus vulgaris*), (3) measure habitat preference, and (4) identify whether nest box checks made during the spring versus the winter affected accuracy/reliability of nesting data. The accumulative mean rate of nesting success for 1980 - 1989 was estimated to be 81 percent, while the rate of box use or nest starts for the same period was 77 percent. Between 1983 and 1987, starling use of nest boxes grew from 18 to 54 boxes (200 percent). The corresponding mean rate of success for all nesting boxes with starling use declined from approximately 75 percent in 1983 to below 30 percent in 1989. The mean hatching rate parallelled this decline. Commencing in 1987, a modified nest box design that permitted greater light penetration into the cavity was utilized for all box replacements and additions. The rate of starling use in the modified nest box was 20 percent less overall than that for the standard nest box design. Generally, no distinguishable preference was evident between nest boxes placed in open marsh, wooded/semi-enclosed, and marsh-wood edge habitats. When nest box designs were segregated by habitat type, the proportionate rate of starling use was greatest for those standard boxes in open marsh habitats.

Wood duck nest box inspections occurred during both spring/summer and winter seasons from 1980-1989. The relative reliability of winter checks was determined to be equivalent to spring/summer inspections when the spring/summer data of 1980-1982 were compared to the winter records from 1983-1989. Black rat snakes (*Elaphe obsoleta*) were determined to be the principal nest predator. It is unlikely that the season of inspection will influence the reliability of the production estimate unless nest box predator populations undergo significant fluctuation.

The data confirms the growth and fidelity of the Wood duck population on the refuge. Despite an inhibition by Wood ducks to pioneer into new territory, the data suggests that the Back Bay, North Landing River, and Currituck Sound watersheds have the nucleus of a breeding population, at the very least. The judicious selection, placement, and maintenance of nesting boxes, within these integrated watersheds, affords an opportunity to expand the breeding population.

Introduction

The estuaries of southeastern Virginia and northeastern North Carolina have played a vital role in the welfare of continental migratory waterfowl populations. In particular, those drainages that form and include the Back Bay-North Landing River-Currituck Sound watershed have contributed to the health and maintenance of a wide variety of ducks, geese, and swans. The vast majority of these species, however, breed largely in the north central United States, Alaska, and Canada. With the exception of incidental nesting by Mallards and Black ducks (U.S. Fish and Wildlife Service, Mackay Island National Wildlife Refuge, 1984-1988), the most numerous breeding species of waterfowl is the Wood duck (*Aix sponsa*). Because coastal southeastern Virginia and northeastern North Carolina are within the primary range of concentrated Wood duck breeding and wintering populations (Bellrose, 1976.), concurrent opportunities to strengthen and expand their status are good. In fact, traditional references to "summer ducks" that predate migratory bird hunting regulations confirm their fidelity to the area over a long period of time.

Mackay Island National Wildlife Refuge (NWR) was established in 1961. Generally, its mandated purpose was as "...an inviolate sanctuary for migratory birds...." Its functional objectives have focused on the provision and maintenance of habitat for Greater snow geese and other species of waterfowl. One element of the refuge program was directed toward the development of artificial nesting structures for Wood ducks. The use and evaluation of nesting structures to increase or restore local Wood duck populations is well documented (McLaughlin and Grice 1952, Bellrose 1953, Bellrose 1976, Lee and Nelson 1965).

History

Commencing in 1969, a program was instituted with the primary objective to restore a local flock of wild Wood ducks. A secondary objective of the first year was to determine habitat preferences for nesting locations. A total of 34 cypress nest boxes were erected on the refuge. On December 5, 1969, 37 pairs of Wood ducks were delivered to the refuge. The birds were pen-raised at Patuxent Wildlife Research Center, Laurel, Maryland. They were kept in a holding pen on the refuge through February 11, 1970. On that date 72 birds were banded, wing-bleached, and released (two drakes died in captivity) (Florschutz, 1970). Similar projects had been initiated at other National Wildlife Refuges in the southeast, ostensibly to establish local flocks of Wood ducks (Lane, Bond, Julian , 1968). These were generally more intensive because of a recognized absence of natural cavities and estimated low natural production. No known assesssment of natural cavities at Mackay Island NWR, however, was undertaken.

Since 1970, artificial nesting structures for Wood ducks have been part of the management program at Mackay Island NWR. Documentation of nest box success was mostly limited from 1970-1979. During that period, it can only be reported that use of nesting structures was on average below 50 percent, while total available boxes had been increased to 76.

Beginning in 1980, a three year program evaluation was initiated by refuge personnel (McMinn, 1982). The assessment was premised on the assumption that mid-winter nest box inspections were a questionable method for accurately estimating nesting success. Several other parameters were also evaluated. Between 1980 - 1982, all nest boxes were examined every two to five weeks from April through September (n=70-80). It was generally concluded that winter inspections were inaccurate and a better estimate could be made by one April check with a corresponding statistical analysis. This procedure, however, did not preclude the need for winter maintenance inspections. The mean number of eggs hatched/successful nest was found to be 10.4 eggs. This estimate was consistent with other findings (Bellrose, 1976).

Additionally preliminary findings of this three year study inferred that nest parasitism by European starlings was increasing. Furthermore, the influence of habitat type on nest success was determined to be insignificant.

Study Area

Mackay Island NWR is approximately 3198 hectares (ha) in size and straddles Back Bay, Currituck Sound, and the North Landing River. Wood duck nesting structures have been placed in an area which encompasses an estimated 1600 ha. Nest boxes erected in 1970, or their replacements, are still predominately in the original locations. With the exception of two or three boxes, all structures have been placed on Mackay Island proper or in the adjoining marshes. As of 1990, a total of 121 boxes were in place. No boxes have been erected north of State Route 615. All nest boxes are constructed of one inch rough cypress. They are mounted on standard 4 x 4 treated wood posts and fitted with metal predator shields.

Three impoundments are managed for waterfowl on Mackay Island - the East, Middle, and West pools. They comprise approximately 405 ha. Each is managed differently, the East Pool (142 ha) is managed for submerged aquatic vegetation; the Middle Pool (203 ha) as a combined green tree reservoir and for moist soil plants; and the West Pool (12 ha) is managed exclusively as a moist soil unit. The surrounding habitat encompasses emergent, scrub-shrub, and forested estuarine wetlands (Cowardin, L.M., V. Carter, F.C. Golet and, E.T. LaRoe, 1979) interspersed with creeks, ponds, embayments, and smaller drainages. Croplands are present on Mackay Island, and the adjoining lands of Knotts Island.

Methods

From 1983 to 1989, all nest box inspections were conducted between the months of January and March. Nest box checks were made during the spring and summer for the nesting years of 1980 - 1982. Additionally, one partial summer inspection was conducted in 1989 when a sample of 33 boxes was monitored between May and June. Knowledgeable and experienced, full-time employees have conducted the inspections every year since 1984. Prior to the 1983 nesting year, refuge staff, Youth Conservation Corps, Young Adult Conservation Corps, and trained volunteers checked nest boxes.

Commencing with the 1983 nesting year, all existing data on Wood duck nesting, were systematically compiled to document and evaluate eleven program elements. The existing data from 1980 - 1982 were adapted to this format inasmuch as the reported data were applicable or available. The elements that were annually documented were: 1) Box Number, 2) Location, 3) Habitat Type, 4) Maintenance, 5) Contents,

6) Attempt, 7) Success, 8) Wood ducks Hatched, 9) Unhatched Eggs, 10) Box Type, and 11) Other Use.

Box Number and Location were used for administrative purposes. Habitat type conformed basically with designations used during the 1980-1982 study. They were: (1) Open Marsh; (2) Wooded - woody vegetation within three meters and box semi-enclosed on a minimum of three sides; and (3) Marsh/Wood Edge. Contents were identified as either none or Wood duck. This was based upon clear evidence of Wood duck use - nest building/presence of down, eggs, egg fragments or membranes. Attempt was numerically recorded and premised upon the content of the box. Success was numerically recorded also and only considered evident if egg fragments or egg membranes were present. The number of Wood ducks Hatched was correlated to Success and assumed that ten eggs hatched from each successful nest (survival was computed at 50 percent of hatch). This was consistent with findings in the 1980-1982 study and other documented research (Bellrose, 1976) (Semel, Sherman, Byers, 1988). Additionally, it conformed to U.S. Fish and Wildlife Service (FWS) administrative guidance. Unhatched Eggs were reported numerically when found. Box Type listed whether a structure was standard "long" type or modified "short" type. Lastly, Other Use documented any observable evidence of other wildlife use.

Definitions

Two nest box types were utilized during part of the evaluation period. The standard nest box refers to the traditional, one-inch thick wood (cypress) structure with nominal outside dimensions of 61.5 centimeters (cm) by 30.8 cm reduced by 2.6 cm on the front box panel to allow for drainage (U.S. Department of the Interior, Fish and Wildlife Service, 1976). The short nest box refers to a non- traditional, one-inch thick wood (cypress) structure with nominal outside dimensions of 43.6 cm by 30.8 cm. It was likewise reduced by 2.6 cm on the front box panel.

A "dump nest" was defined as any nest parasitized by another Wood duck and had greater than 15 eggs (Grice and Rogers 1965, Haramus and Thompson 1985). Nest parasitism by European Starlings (*Sturnus vulgaris*) was reported as evidence of use when any individuals, their nest material, eggs, or egg fragments were present. A successful nest was one from which it could be inferred that at least one duckling hatched.

Results

Program Development and Continuity

Prior to 1980, Wood duck nest box records reflected discontinuity due to staff turnover and size. Volunteers and temporary employees performed nest box checks as well as the few, full-time employees. No real attempt was made to assess the success of the program until 1980. No significant program expansion occurred between 1980-1985. With the exception of the period between 1985-1986, fewer than ten new nest boxes were erected in any given year during the period between 1980-1989. The annual rate of box growth was on average five boxes (6 percent). The accelerated growth of the program between 1985-1986 was in response to a major management initiative that resulted in the development of the East Pool impoundment. This impoundment provided the most extensive brood habitat on the refuge, consequently, the majority of the additional boxes were located in this area. Overall, the annual growth of the program has been intentionally maintained at a low rate. The purpose for this strategy was predicated on: (1) discouraging any increase in the number of nest box competitors; (2) maintaining densities of nest structures that were comparable to natural conditions, and (3) moderating the costs of program development and maintenance over an extended period of time.

Rates of Success

Table 1 summarizes the ten year results of the program. With the exception of the period between 1980-1982, all data are based upon winter nest box checks. The rate of success is measured as a ratio of the number of successful nests/number boxes used by Wood ducks. During the same period, the mean number of Wood ducks hatched ranged from four to eight ducklings with an overall mean of six ducklings (Figure 1).

Factors Affecting Success

Factors which do influence the breeding biology of Wood ducks are diverse and numerous. During the seven year nest box evaluation period from 1983-1989 an assessment was made of two factors for their relative affect on nesting success—nest parasitism by European starlings and habitat type. These were evaluated as a followup to the refuge study conducted from 1980-1982. Both factors were evaluated independently and relative to each other.

Nest Parasitism by European Starlings

Nest parasitism by European starlings in managed Wood duck nest box programs has been a persistent cause of nest abandonment in some areas (Bellrose, 1976). Nest box checks at Mackay Island NWR confirmed that nest parasitism by starlings was increasing as early as 1984. Figure 2 depicts the total number of boxes with starling use observed from 1983-1989 and the corresponding effect on the number of unhatched eggs. This record reflects starling use as measured during winter or post-season checks. In addition, no regular program of starling control was instituted during this period. Therefore, this assessment was unbiased by any attempt to remove or trap starlings.

Competition by starlings has been evident from the inception of the program in 1970, however use data have only been documented since 1983. The FWS Breeding Bird Survey Trend for the regional strata that includes the coastal plain of North Carolina and southeastern Virginia estimated an average annual increase in the starling population of approximately 1 percent for the period of 1966-1987. The 1988-1989 estimate for North Carolina and Virginia, however, lists an average annual population decline of 7 percent and 5 percent, respectively; the estimate for the regional strata showed an average decline of 10 percent for the same period (U.S. Department of the Interior, Fish and Wildlife Service, Breeding Bird Survey Trends, 1966-1987/1988-1989). Although these data seemingly parallelled the trend in starling use at Mackay Island, no direct relationship can be demonstrated.

Since 1983, the contrasting affect on nesting success for boxes with and without observed use by starlings was notable (Figure 3). By 1985, the rate of nest box use by starlings had reached 40 percent (Table 2). Correspondingly, the Wood duck nesting success rate had declined to below 50 percent in those boxes with starling use. The effect of starling use on the hatching rate paralleled nesting success when the number of eggs hatched/nest declined from nearly seven in 1984 to one in 1989 (Figure 4).

An initial attempt to alleviate nest parasitism by starlings was made in 1985 when 22 starling nest boxes were installed adjacent to Wood duck nesting boxes. In 1986, it was determined that these additional boxes did not reduce starling use in Wood duck boxes, but only served to contribute to the starling population. They were subsequently removed.

Commencing in 1987, the refuge developed a conceptual design for all additional and replacement nesting boxes. That design permitted greater light penetration into the cavity. The concept was predicated upon previous success with starling deterrent structures (McGilvrey and Uhler, 1971). This initiative was supported further by comparative analysis of four nest box designs. Specifically, a comparison of standard metal, wood, Tom Tubbs and Plastic Bucket designs revealed significantly lower rates of starling use in those structures that had shallower cavities (height from bottom of entrance hole to top of nest material) and smaller diameters. Additionally, of those four designs, Wood ducks appeared to select more natural or wood structures over other types (G. Souliere, 1985). Figure 5 illustrates the basic design that has been used since 1987.

Use rates for the short box were compared to the standard box design (Table 2). Only three years of data exist and short boxes account for only 23 percent of the total box inventory, nevertheless, the overall rate of starling use in "short" boxes was nearly 20 percent less than that for standard boxes. This rate remained consistent when both groups of data were compared for years 1987-1989.

Habitat Types

Since 1983, no conscious effort or method has been employed to apportion new or replacement nest boxes according to habitat type. No record of any such effort exists prior to 1983 except in 1970 when a decision was made to place the first 34 boxes in each habitat type represented on the refuge (O. Florschutz, 1970).

The effect of box placement in relation to different habitat types has been demonstrated to influence nest hatchability (ducklings produced/total eggs laid), or the general efficiency of Wood duck nesting attempts (Semel, Sherman, Byers; 1988). Nest hatchability, relative to habitat type, was not assessed as part of this evaluation. The mean comparative nesting success was determined for the three habitat types - (1) open marsh, (2) wooded/semi-enclosed, and (3) marsh/wood edge. Table 3 depicts the relative apportionment of all boxes by habitat type for 1980-1989.

The success rate for the period between 1980-1982 was viewed separately because the data were collected during summer inspections as compared to that obtained between 1983-1989. Both data sets were combined and a mean nesting success was determined for the entire period from 1980-1989 (Figure 6). It was concluded from the 1980-1982 data that there was no significant preference for one habitat type over another since the rates of success in each habitat type were proportionate to the rates of total nest box use and total number of nest boxes (McMinn, 1982). Comparison of nesting success with habitat type from 1983-1989 seemed to confirm this as the proportionate number of nest boxes in each habitat type became more balanced (Figure 6).

Effect of Habitat and Nest Box Type on Starling Use

Habitat type did proportionately affect the rate of starling use in standard nest boxes. When nest box designs were segregated by habitat type, the proportionate rate of starling use was greatest for those standard boxes in open marsh habitats. By contrast, the rate of starling use in short nest boxes was disproportionately low in two of three habitat types represented (Table 4). It had been previously suggested that both nest box design, and placement influence species selection. (G. Soulliere, 1985). In this case, the data suggest that starling selection is habitat and nest box type dependent.

Season Affect on Reliability of Nest Box Checks

The accuracy and dependability of winter nest box checks (post season) versus spring/summer nest box checks has been routinely questioned since the inception of the program in 1970. Spring/summer box checks were thought to be significantly more reliable than winter checks and a subsequent equation was developed to estimate production from one spring inspection (McMinn, 1982). By 1989, enough data were available to determine whether the accuracy of nest box checks is season dependent.

Since the nesting data for 1980-1982 were gathered during the spring/summer, it could be contrasted with that information collected in the winter between 1983-1989. Additionally, a sample of 33 boxes was monitored during the spring of 1989; the results of the spring inspection were later compared to a "blind" follow-up winter check. A Chi square statistical analysis of the data sets between 1980-1989 was used to assess whether successful or unsuccessful nest classifications were independent of the time of year when boxes were checked. A similar test was applied to the 1989 sample survey data. In both cases, no relationship was demonstrated to exist between the time of year when boxes were checked and data reliability. The tests were performed at the 95 percent confidence level. In a further comparison of the sample spring nest box check with the winter inspection of 1989, it was found that 82 percent of the winter checks conformed correctly with the spring observations (Table 5). Although the Chi square test did not account for the possibility of a trend through the years, the comparative rate of success for all years appeared to discount it (Figure 7).

Discussion

Program Success and Failure

It is evident that the program has been a qualified success since its institution in 1970. The initial program, however, probably only served to reinforce the fidelity and strengthen the existing local population. Aerial waterfowl surveys of Back Bay and Currituck Sound conducted during early fall months and mid-winter periods have essentially confirmed the presence of breeding and wintering Wood ducks prior to 1970 (Sincock, 1966). Under normal conditions, aerial censuses would be less than reliable for this species, thereby further suggesting that an unknown segment of the population was discounted altogether.

Although the program is considered to be successful, it can only be rated as such within the parameters of the program. For instance, as the program has evolved, minimal time has been expended toward assessing the extent of intraspecific brood parasitism or dump nesting on the overall productive efficiency of the program. Only from 1980- 1982 was any reliable measurement of dump nesting recorded. During that period, it was found that approximately 30 percent of all nests checked were dump nests (McMinn, 1982). Additionally, 24 percent of the sample survey in the spring of 1989 were dump nests. A thorough assessment of dump nesting would necessitate monitoring all boxes each spring for several years. In view of recent research on brood parasitism and nest box placement (Semel, Sherman, and Byers, 1988.), however, it may be more cost effective to relocate single/paired boxes from open marshes to more compatible enclosed, wooded habitats on the refuge.

Effects of Nest Parasitism by Starlings

The factors influencing the prevalence of starlings in southeastern Virginia/northeastern North Carolina are variable. Agricultural practices, however, likely contribute to their presence. These practices are intensive and crop rotations are systematic. Two of three crops in standard rotations are grain crops. In fact, refuge croplands incorporate these same cropping practices. So long as these systematic and intensive cropping practices continue, some associated level of starling use will be present.

Thus far, interspecific competition by starlings has been profound, even where grain crop acreage has declined. It is clearly the most serious detraction to the continued success of the program. Research that addresses starling control techniques in managed Wood duck nest box programs supports the use of nesting structures that permit greater light into the cavity. The limited application of the modified design at Mackay Island has demonstrated parallel results.

In view of these considerations, any further expansion of the program, beyond the present number of boxes, should employ the use of the modified nesting box (Figure 5). Replacement boxes should also be of the modified type until data otherwise refutes their effectiveness.

Effect of Habitat and Nest Box Type on Starling Use

Habitat was notably not an independent influence on the success or failure of nesting Wood ducks. The absence of any clear preference for nest boxes in any one habitat type suggests 1) an absence of suitable natural cavities and/or 2) the presence of a high population density and/or 3) no truly significant difference in the visibility of boxes in each habitat type. Indeed, most timber on the refuge has been cut several times prior to its establishment. The latest logging occurred in the 1950's.

Since 1980, very few existing nesting boxes have been relocated to different habitat types within the refuge. The relative greater use of standard nest boxes by starlings in open marsh habitat would indicate that nest box manipulation is warranted.

Experimental manipulation of nest box proximity and visibility have met with success in reducing Wood duck brood parasitism. Similarly, it has been reported that nest box visibility may increase the frequency of parasitism among hole nesting passerines (Semel, Sherman, and Byers, 1988). This would further support the advisability of relocating and converting a segment of the standard nest boxes now located in open marshes.

Effect of Season on the Reliability of Nest Box Inspection Data

The season that nest boxes are checked at Mackay Island NWR appears to only affect the level of exactness in the production estimate derived. This is due to the fact that other seasonal and non-seasonal related factors, such as box conditions, predator control/population(s), diversity of cavity nesting avian species, and observer skill have been previously considered and accounted for during nest box inspections. Since 1980, the program at Mackay Island NWR has sought to evaluate and address most of these factors which limit the accuracy of nest box inspection data.

Without exception, all nest boxes have been maintained annually including structural predator controls. Mammalian predators, primarily raccoons, were found to have a negligible impact on Wood duck nests; Black rat snakes (*Elaphe obsoleta*) were considered to be the principal nest predator; five species of birds (excluding starlings) and grey squirrels were also identified during box checks, however none were deemed significant nest box competitors (McMinn, 1982). Lastly, observer error has been minimized since 1984 by employing knowledgeable and experienced, full-time refuge staff members to conduct the inspections. Unless significant fluctuations of nest box predator populations occur, it seems unlikely that the season of inspection will influence the reliability of the production estimate.

Conclusion

The presence of a strong local nesting Wood duck population at Mackay Island NWR is evident. The presence of local nesting and wintering Wood ducks across the broader area of the Back Bay-North Landing River-Currituck Sound watershed can also be presumed to exist. The implications of incorporating expanded nesting box programs within this larger area, however, are not clear. At Mackay Island NWR, the program has been closely managed to generally insure that production is sustained. Brood habitat quality and proximity has been improved by diversifying waterfowl management areas. It is obvious that an equivalent approach cannot be applied over such a large area, therefore program scale, habitat needs and a reasonable assurance that boxes will be maintained annually are primary considerations.

Areas should be viewed as to whether: 1) artificial nesting structures are necessary, 2) habitat provides the necessary components for Wood duck production, and 3) box designs will be used by Wood ducks; but deter local predators/competitors (Souliere, 1985); additional consideration should focus on program effectiveness rather than size. At Mattamuskeet NWR, for example, the program encompasses 175 nest boxes. Even though Wood duck nesting is evident, only a small percentage (+/- 20 percent) of it is actually estimated to occur in boxes (Davis, 1990). In view of these considerations and the results at Mackay Island NWR, a prudent approach to the institution of broader program within the Back Bay-North Landing River-Currituck Sound watershed would seem to enhance the overall status of this species.

Acknowledgements

Gratitude is expressed to J. Conomy, graduate student and J. Fleming, Unit Leader at the U.S. Fish and Wildlife Service Cooperative Wildlife Research Unit, North Carolina State University, Raleigh, NC for their assistance with data analysis; Ms. Susan Dixon, Mackay Island NWR for graphics preparation; J. Munson, Assistant Manager, Mackay Island NWR for technical review; and O. Florschutz, Biologist, USFWS for review and consultation.

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Table 1. Summary of Wood Duck Nesting Success at Mackay Island NWR 1980-1989

Year	80	81	82	83	84	85	86	87	88	89
Available Boxes	70	73	80	81	77	80	103	107	112	121
Boxes Used/Nest Starts	57	46	45	51	68	78	68	90	96	97
(%)	(81)	(63)	(56)	(63)	(88)	(98)	(66)	(84)	(86)	(80)
								10 Year Average = 77%		
Successful Nests	44	39	38	49	65	52	62	75	60	79
(%)	(77)	(85)	(84)	(96)	(96)	(67)	(91)	(83)	(63)	(81)
								10 Year Average = 81%		
Est. # Ducklings Leaving Nest	495*	371*	386*	490	650	520	620	750	600	790

* Actual count by summer inspection

Table 2. Mean Rate of Starling Use for Standard Nesting Boxes - 1983-1989

Year	Total Standard Boxes	Boxes With Use	Percent
1983	81	18	22%
1984	77	22	29%
1985	80	32	40%
1986	103	34	33%
1987	105	53	50%
1988	97	26	27%
1989	93	9	10%
Total	**636**	**194**	**30%**

Mean Rate of Starling Use for Short Nesting Boxes - 1987-1989

Year	Total Standard Boxes	Boxes With Use	Percent
1987	2	1	50%
1988	15	4	27%
1989	28	0	0%
Total	**45**	**5**	**11%**

Table 3. Nest Box Apportionment by Habitat Type

Year	Marsh	(%)	Wooded/ Semi-Enclosed	(%)	Marsh/Wood Edge	(%)	Total Boxes
1980	37	(53)	19	(27)	14	(20)	70
1981	38	(52)	19	(26)	16	(22)	73
1982	39	(49)	24	(30)	17	(21)	80
1983	39	(48)	25	(31)	17	(21)	81
1984	38	(49)	24	(31)	15	(20)	77
1985	40	(50)	25	(31)	15	(19)	80
1986	41	(40)	25	(24)	37	(36)	103
1987	41	(38)	27	(25)	39	(37)	107
1988	42	(38)	33	(29)	37	(33)	112
1989	43	(36)	32	(26)	46	(38)	121

Table 4. Habitat Distribution for Standard Nesting Boxes with Starling Use - 1983-1989

	Marsh			Wooded/Semi-Enclosed			Marsh/Wood Edge		
Year	Total Boxes	Use Rate	(%)	Total Boxes	Use Rate	(%)	Total Boxes	Use Rate	(%)
1983	39	13	(33)	25	1	(4)	17	4	(24)
1984	38	14	(37)	24	5	(21)	15	3	(20)
1985	40	25	(63)	25	5	(20)	15	2	(13)
1986	41	17	(41)	25	4	(16)	37	13	(35)
1987	41	29	(71)	27	13	(48)	39	11	(28)
1988	42	8	(19)	33	11	(33)	37	7	(19)
1989	43	3	(7)	32	5	(16)	46	1	(2)
Totals	**284 (42)**	**109**	**(38)**	**191 (28)**	**44**	**(23)**	**206 (30)**	**41**	**(20)**

Habitat Distribution for Short Nesting Boxes with Starling Use - 1987-1989

	Marsh			Wooded/Semi-Enclosed			Marsh/Wood Edge		
Year	Total Boxes	Use Rate	(%)	Total Boxes	Use Rate	(%)	Total Boxes	Use Rate	(%)
1987	0	0	(—)		No Boxes		2	1	(50)
1988	10	2	(20)		No Boxes		5	2	(40)
1989	15	0	(—)		No Boxes		13	0	(0)
Totals	**25 (56)**	**2**	**(8)**		———		**20 (44)**	**3**	**(15)**

Table 5. Comparison of Spring Nest Box Observations with Winter Box Inspections - 1989

Season	Number	Successful	(%)	Unsuccessful	(%)	Correct Observations	(%)
Spring	33	18	(55)	15	(45)	N/A	
Winter	33	20	(61)	13	(39)	27	(82)

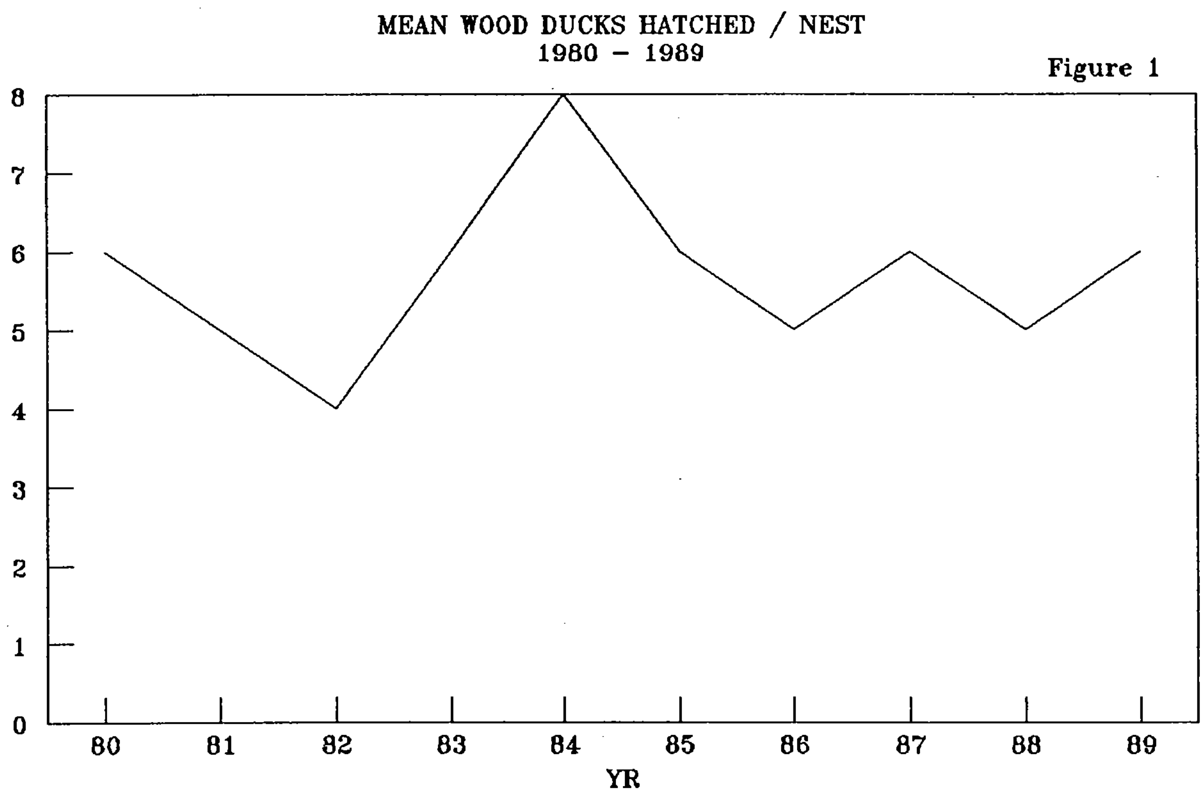
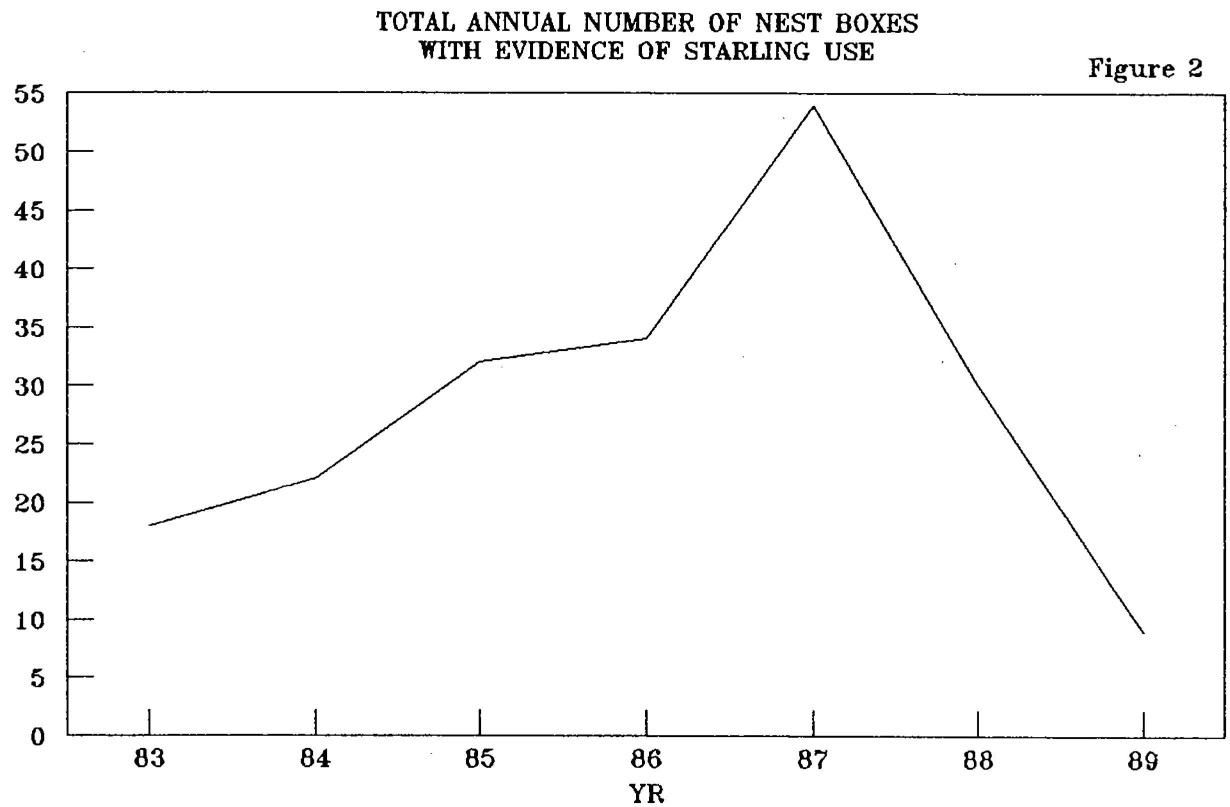


Figure 1. Mean Wood Ducks Hatched/Nest, 1980-1989. William Hegge

Figure 2



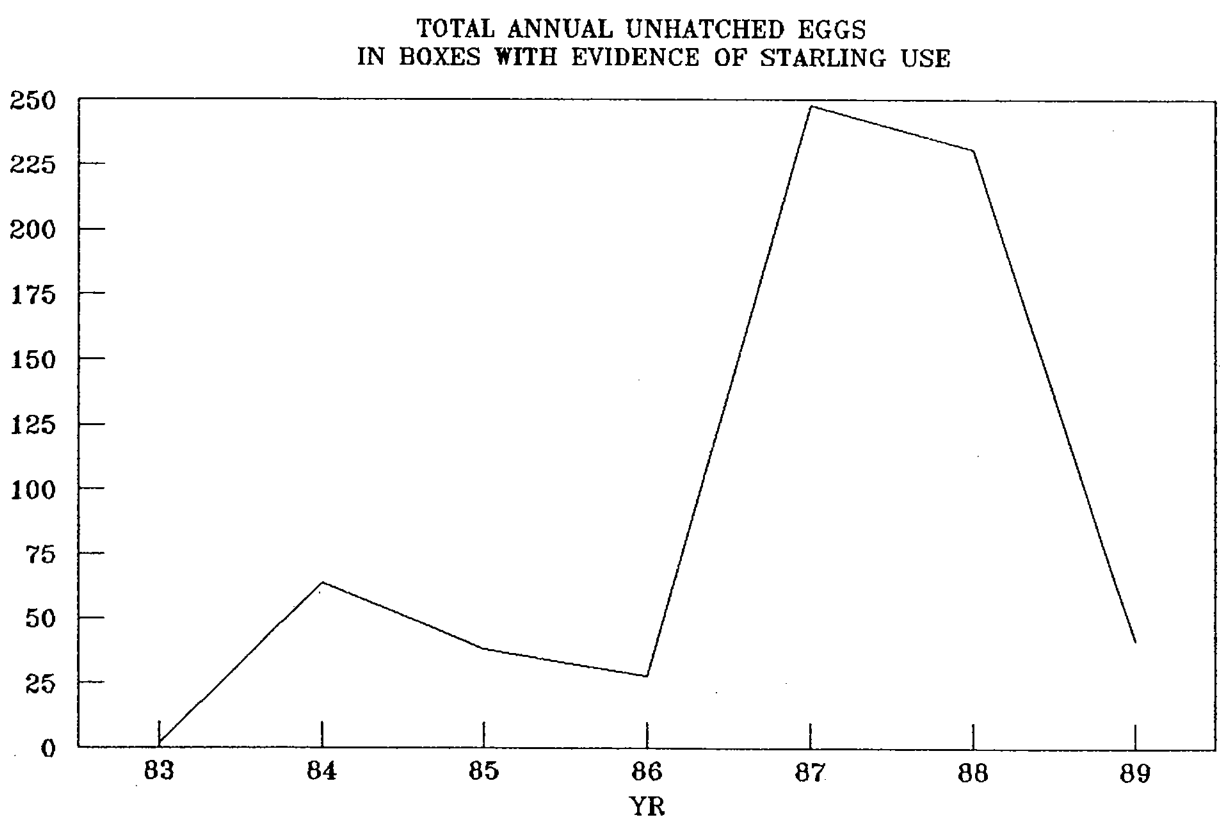
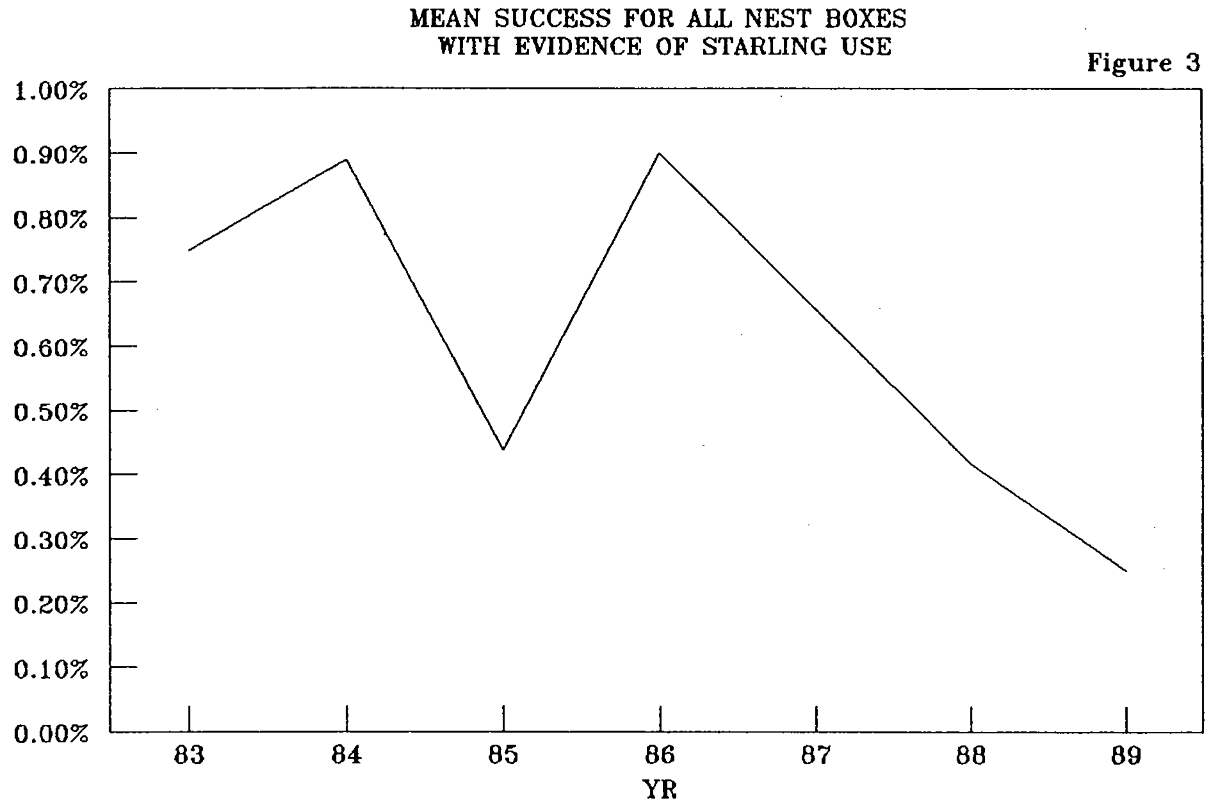


Figure 2. Total Annual Number of Nest Boxes with Evidence of Starling Use.
Total Annual Unhatched Eggs in boxes with Evidence of Starling Use. William Hegge



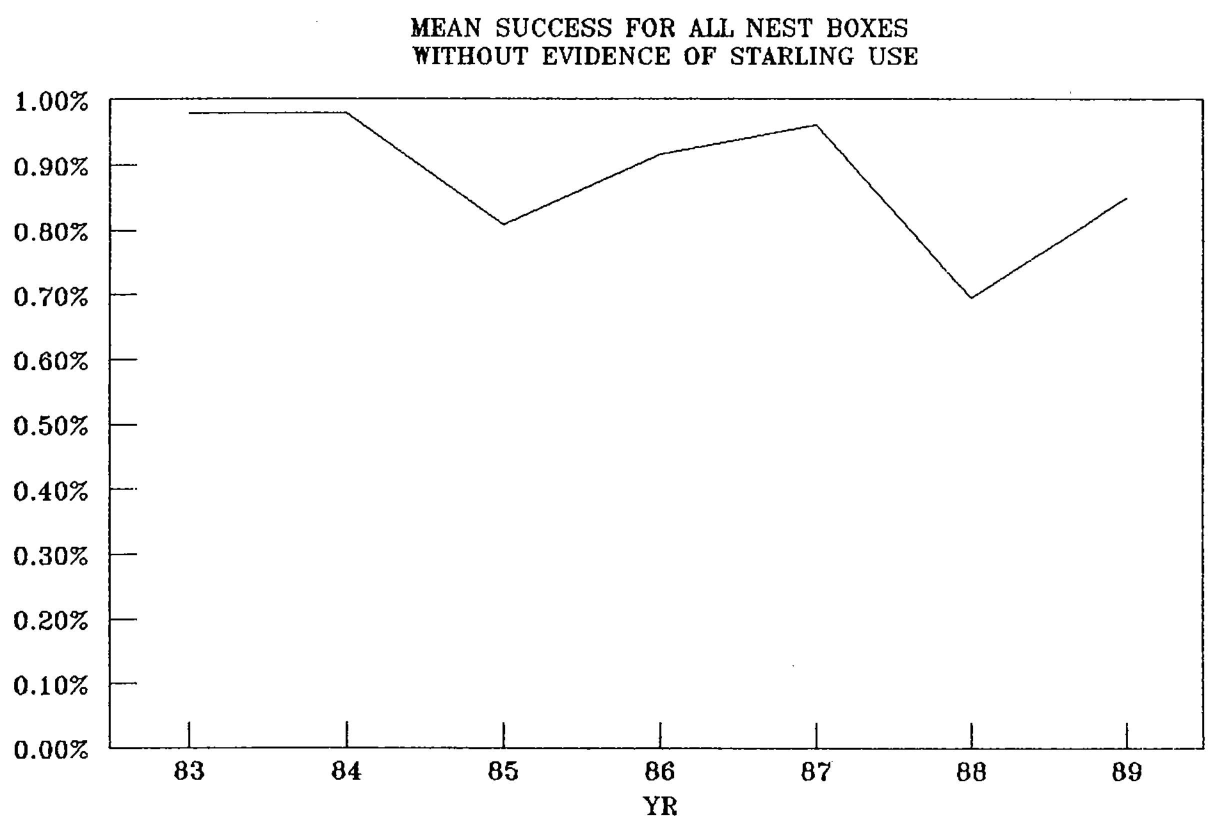


Figure 3. Mean Success for All Nest Boxes with Evidence of Starling Use.
Mean Success for All Nest Boxes without Evidence of Starling Use. William Hegge

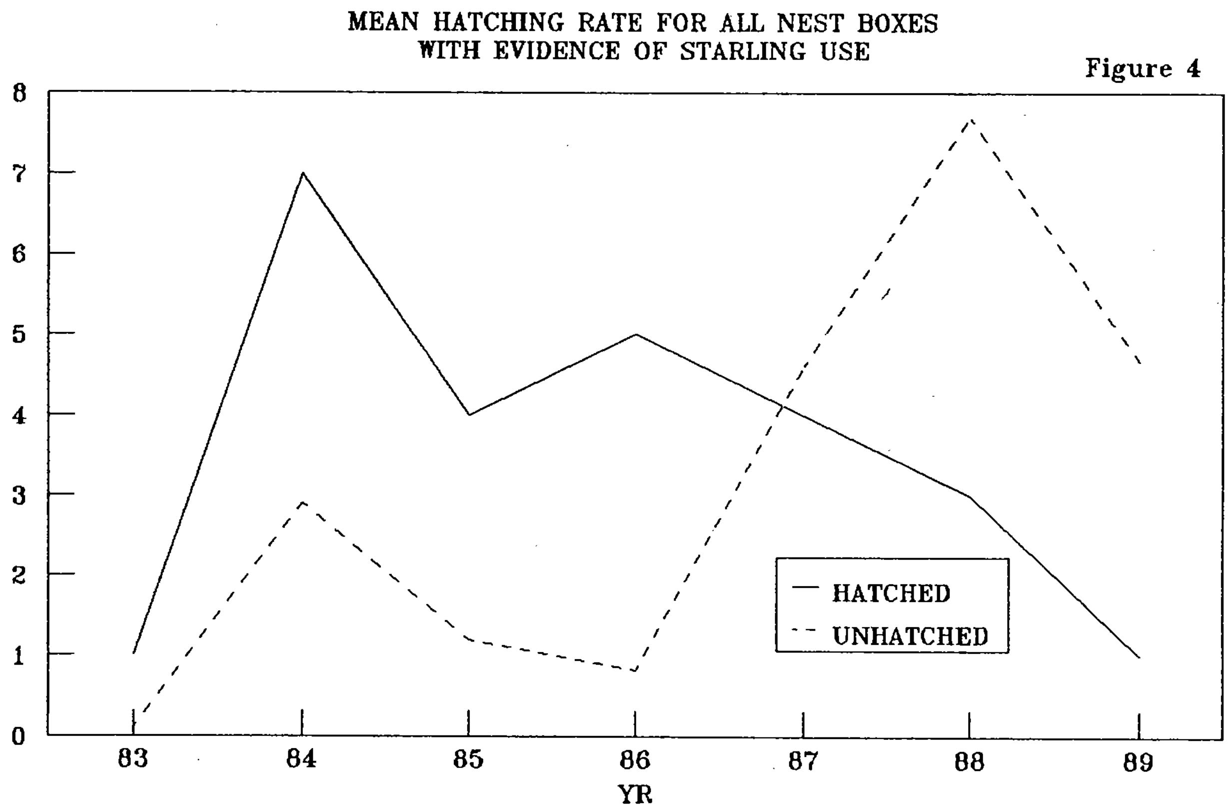


Figure 4. Mean Hatching Rate for All Nest Boxes with Evidence of Starling Use. William Hegge

Figure 5.

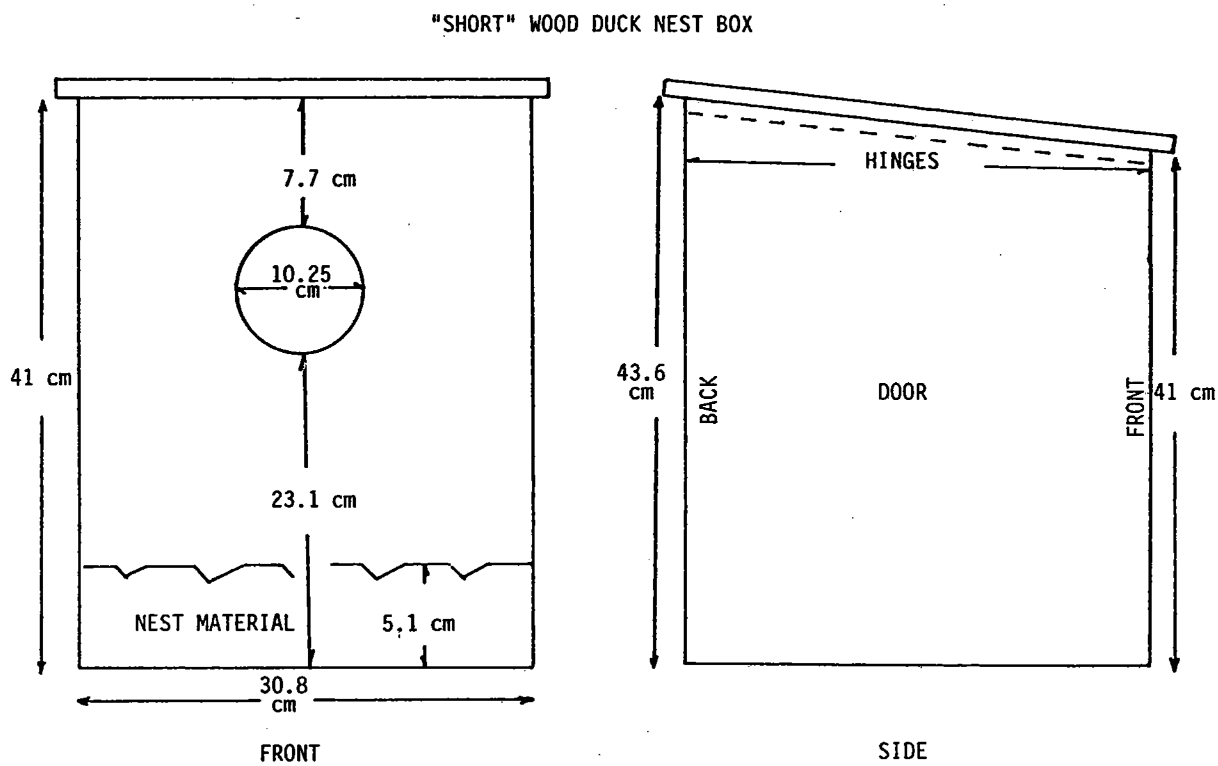


Figure 5. Short Wood Duck Nest Box. William Hegge

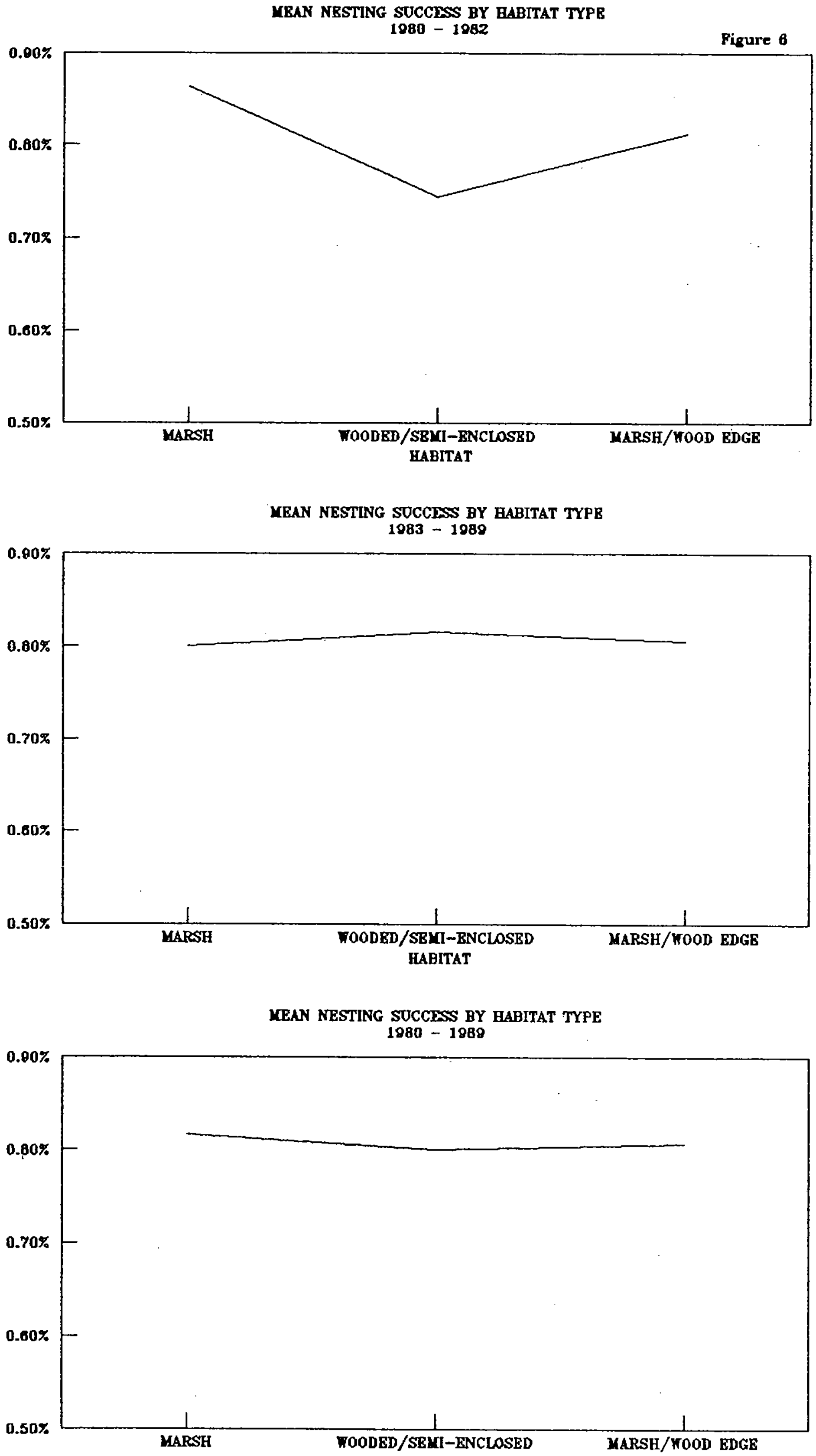


Figure 6. Mean Nesting Success by Habitat Type, 1980-82, 1983-89 and 1980-89. William Hegge

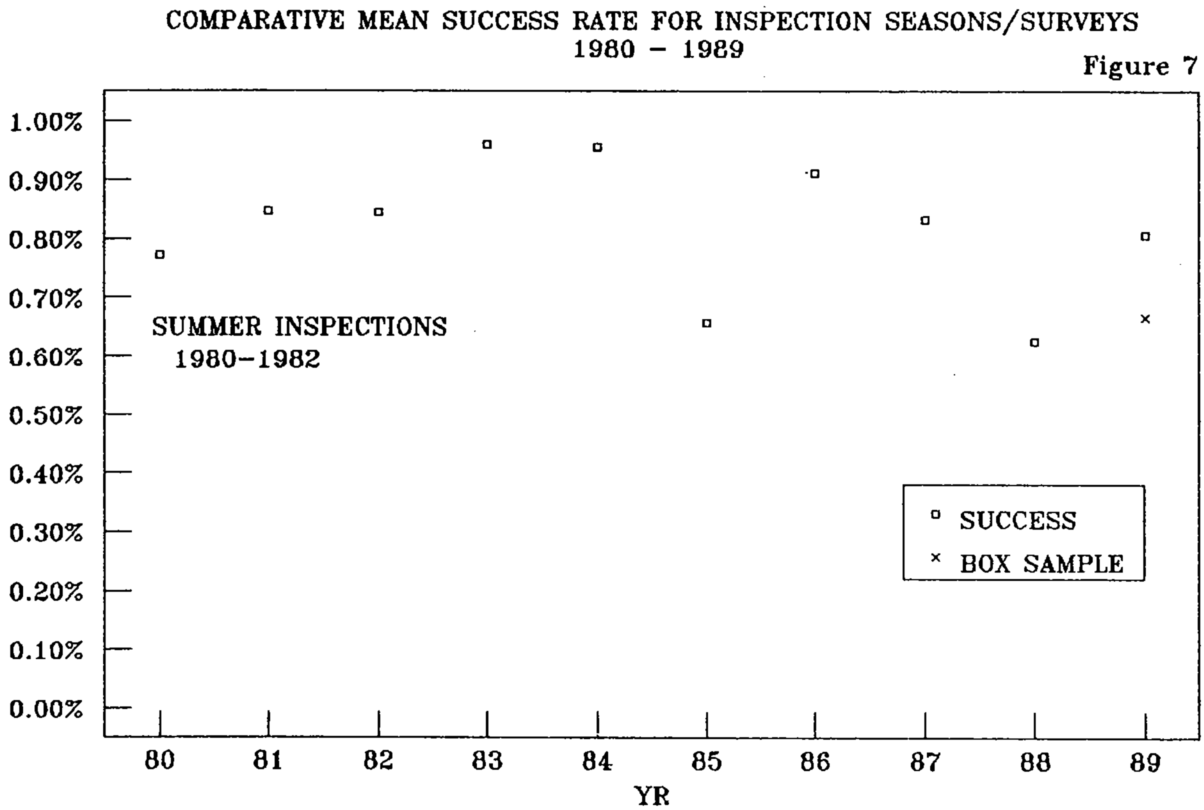


Figure 7. Comparative Mean Success Rate for Inspection Seasons/Surveys, 1980-89. William Hegge

Ecology of Freshwater Turtles in Back Bay, Virginia

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Abstract: The freshwater turtle community of Back Bay National Wildlife Refuge and False Cape State Park is comprised of seven species: *Clemmys guttata, Chrysemys picta, Chelydra serpentina, Kinosternon subrubrum, Pseudemys rubriventris, Terrapene carolina,* and *Trachemys scripta*. Resource partitioning in this community is accomplished by habitat selection and dietary differences. Three species exhibit strong female biased sexual size dimorphism and one species strong male biased sexual size dimorphism; three species do not exhibit strong size dimorphism. Nesting occurs from about late-May through June and probably longer. Clutch size ranges from a low of three in the smallest species (*Kinosternon subrubrum*) to a high of 55 in the largest species (*Chelydra serpentina*). Trapping success varied seasonally and annually. Freshwater turtles play important ecological roles in wetland ecosystems and every effort should be made to insure the continued viability of all populations.

Introduction

Turtles are conspicuous animals in most wetlands in southeastern North America. In Virginia there are from one to nine species syntopic in the same habitat (Mitchell and Pague, unpublished). Species richness varies depending on the type of wetland and its geographic location. Because of their abundance and positions in food webs, freshwater turtles play essential, although largely unstudied, roles in energy transfer in wetland ecosystems, despite the fact that their standing crop biomass is orders of magnitude less than that of plants (Congdon and Gibbons, 1990).

As many as nine species of freshwater turtles occur in southeastern Virginia. One of these, the chicken turtle (*Deirochelys reticularia*), is found only at the northern end of Virginia Beach and is a state endangered species (Mitchell and Buhlmann, in press). The remaining eight are found throughout much of the area in various syntopic combinations. Our objectives in this paper are to summarize information on various aspects of the ecology of the freshwater turtles in the vicinity of Back Bay, Virginia. We describe community composition, sexual size dimorphism, reproductive attributes of selected species, and effectiveness of trapping techniques.

Materials and Methods

We conducted a census of the freshwater turtle populations periodically in 1980-1983 and in 1986 and 1989. Traps were set in ditches lining waterfowl impoundments in Back Bay National Wildlife Refuge and in the ditches and shallow water marshes in False Cape State Park. Both of these areas are on the Currituck Spit, a coastal barrier ecosystem. Most turtles were caught in funnel traps made of 1 inch mesh chickenwire (Iverson, 1979), although 2.5 foot diameter hoop traps made of 1 inch netting without leads and fyke nets with leads (often called fish traps) were used on several occasions. Funnel traps and hoop traps were baited with sardines; holes were punched in the cans so consumption of the bait would not occur and alter natural growth rates. Fyke nets were unbaited. All traps were set with the top portion at or above the surface of the water so that turtles could reach air. Traps were checked at least once daily during each trapping period. Some of the captures were made by hand and with a dipnet. Nesting females were often found on dirt roads during the day and night.

All turtles were processed within 24 h of capture and most were returned to the exact location of capture. All measurements (to the nearest 0.1 mm) of carapace length (CL) and plastron length (PL) were made by one of us (JCM) with dial calipers to reduce investigator-induced error. We used Pesola scales to determine body mass to the nearest gram. Additional notes were taken on injuries, abnormalities, and ectoparasites.

Each turtle was assigned a unique number by filing notches in the carapacial margin. The coding system used the first four carapacial marginals on both sides of the cervical scute anteriorly and midline posteriorly. Numbers 1, 2, 4, and 7 were assigned in sequence (midline outward) as ones on the anterior left, tens on the anterior right, hundreds on the posterior left, and thousands on the posterior right. Up to 9999 individuals of each species can be uniquely marked with this coding system.

Males and females of each species were considered mature when they exceeded minimal sizes known for other populations (Mitchell, 1988; Mitchell and Pague, unpublished) or if the smallest known adult exhibited secondary sex characteristics (males) or contained oviductal eggs. Possession of elongated foreclaws upon maturation in male emydid turtles (*Chrysemys, Pseudemys, Trachemys*) provided additional information on whether sexual maturity had been achieved.

Reproductive data were derived from females in two ways. Some of the females found nesting were sacrificed for other studies. Others were examined for eggs during the nesting season by palping the inguinal area.

Results

Community structure - Seven species were trapped and/or collected during the the study (Table 1). Of these, six were were found within the first year of field work (1980). The seventh, *Clemmys guttata*, was not discovered until 21 May 1983.

Resource partitioning in Back Bay is accomplished in two ways, habitat preference and diet. Four species are basking turtles, two are bottom-walkers (Berry and Shine, 1980), and one is terrestrial (Table 1). Two of these turtles are carnivorous, three are omnivorous, and two are herbivorous, at least as adults (Table 1). Juveniles of *Pseudemys rubriventris* and *Trachemys scripta* are carnivorous, but as adults consume almost entirely plant material (Ernst and Barbour, 1972; Parmenter, 1980). Of the aquatic turtles, three are known to use Back Bay in their movement patterns (*Chelydra serpentina, Pseudemys rubrventris*, and *Trachemys scripta*). We presume the remaining species at least occasionally enter the bay but we have no reports or observations to confirm this assumption. Several slider turtles (*Trachemys scripta*) were found to harbor one or more barnacles (Mitchell and Pague, unpublished), indicating that either these ectoparasites lived in the bay durign times of high salinity or these turtles spent a substantial amount of time in the Atlantic Ocean.

Sexual size dimorphism - Adult males averaged smaller than adult females in three species (carapace length in mm): *Chrysemys picta* males - 134.1, n = 47, females - 137.5, n = 31; *Pseudemys rubriventris males* - 222.1, n = 10, females - 272.6, n = 9; *Trachemys scripta* males - 158.4, n = 20, females - 248.2, n = 21 (Mitchell and Pague, 1990). The largest male *Chelydra serpentina* measured was 396 mm CL and the largest female was 281 mm CL. Sexual size dimorphism was not apparent in *Kinosternon subrubrum* (male average 92.0, n = 62; female average 93.1, n = 25). Two species were represented by a single sex. Four adult female *Terrapene carolina* averaged 136.2 mm CL and the single male spotted turtle, *Clemmys guttata*, was 108.9 mm CL.

Sexual dimorphism in turtles is often more pronounced in body mass. For example, in three species the females had substantially greater maximum body mass than males (*Chrysemys picta* males 430 g, females 545 g; *Pseudemys rubriventris* males 2120 g, females 3530 g; *Trachemys scripta* males 1350 g, females 3200 g). The largest male *Chelydra serpentina* weighed 14.3 kg and the largest females 5.3 kg. The largest male *Kinosternon subrubrum* in Back Bay (206 g) was only slightly heavier than the largest female (196 g). The largest female *Terrapene carolina* weighed 591 g and the single male *Clemmys guttata* weighed 148 g.

Reproduction - With the exception of *Trachemys scripta*, we observed few nesting female turtles. Observed nesting occurred between late May and late June for *T. scripta* and *Pseudemys rubriventris*. A clutch of four *Kinosternon subrubrum* eggs was found in a sand bank.

One *Chrysemys picta* contained four oviductal eggs averaging 29.6 × 15.9 mm in size. One *Chelydra serpentina* contained 55 oviductal eggs (average diameter = 27.7 mm, average wet mass = 12.6 g). Three *Kinosternon subrubrum* contained an average of 3.0 (2-4) oviductal eggs (26.5 × 15.6 mm, 4.5 g). A single *Pseudemys rubriventris* contained 29 oviductal eggs (29.8 × 19.7 mm, 6.8 g). Clutch size in four *Terrapene carolina* averaged 3.5 (2-5) eggs (38.9 × 22.3 mm, 12.0 g). Mitchell and Pague (1990) reported an average clutch size of 9.7 (6-14) eggs for 21 *Trachemys scripta* from Back Bay. These averaged 34.2 × 23.1 mm in size and 10.8 g wet mass.

Trapping success - Trapping success varied among sessions on a seasonal and annual basis (Table 2). *Chrysemys picta, Kinosternon subrubrum, and Trachemys scripta* were caught more often than any other species during all but the 1989 trapping period.

Trapping success data were kept for each trap type during the 1989 trapping session (Table 2), allowing the following observations. *Chelydra serpentina, Pseudemys rubriventris*, and *Trachemys scripta* were captured more often in fyke nets with leads than in chicken wire traps. The opposite result was obtained for *Chrysemys picta* and *Kinosternon subrubrum*.

Discussion

Barrier islands and coastal spits of southeastern North America harbor variously diverse freshwater turtle communities. Gibbons and Coker (1978) listed from one to five species of freshwater turtles on nine Atlantic coast barrier islands. Six islands had three, or fewer, one had four, and two had five species. Braswell (1988) found four species in the ponds of Nags Head Woods, Bodie Island, North Carolina. Few of the Virginia barrier islands harbor freshwater turtles. Assateague Island has five species, Smith Island has three species, Hog Island had populations of two species, and Fisherman Island contains one species (Conant et al., 1990). In contrast, nine species occur on mainland southeastern Virginia. Thus, the freshwater turtle community of the Currituck Spit more closely resembles the mainland fauna than other barrier ecosystems. The only conspicuously absent freshwater turtle is *Sternotherus odoratus* (stinkpot), a species that cannot tolerate even low levels of salinity (Dunson, 1986). We presume the varying salinity in Back Bay has prevented the stinkpot from colonizing Currituck Spit, although it has had little apparent affect on the other species in the vicinity.

Gibbons and Lovich (1990) demonstrated that sexual size dimorphism exhibits geographic variation and is closely tied to localized environmental conditions. For comparisons they suggested a standard sexual dimorphism index (SDI): the mean shell length of the sample containing the larger sex divided by the mean shell length of the sample with the smaller sex. When SDI is positive the female is the larger sex, when negative the male is larger.

Our data set allows us to compare SDI among four species in Back Bay and the SDI for each species with other populations listed in Gibbons and Lovich (1990). The *Chrysemys picta* population in Back Bay has a SDI of 1.03, *Pseudemys rubriventris* a SDI of 1.23, *Kinosternon subrubrum* a SDI of 1.01, and *Trachemys scripta* a SDI of 1.57. SDI for 12 populations of painted turtles ranges from 1.13 to 1.58 (Gibbons and Lovich, 1990). Thus, our Back Bay sample is the least sexually dimorphic population of those reported. SDI has been reported for only a Massachusetts population of red-bellied turtles (1.12: Graham, 1971; Gibbons and Lovich, 1990). Our results for this species in Back Bay suggest that populations at the southern end of the range exhibit more pronounced sexual size dimorphism than at the northern end of the range. Because the population biology of this species has been little studied, this conclusion must be regarded as tenuous. SDI for 10 populations of the eastern mud turtle, including th one in Back Bay, range from -1.07 to 1.18, witl most close to 1.00 (Gibbons and Lovich, 1990).

Sexual size dimorphism is best known fo *Trachemys scripta*. Known SDI values range fron 1.09 to 1.61 (Gibbons and Lovich, 1990). The SD for yellow-bellied sliders in Back Bay is substantially higher than SDI's reported for other barrie ecosystem populations (Caper's Island [1.35] Kiawah Island [1.28] in South Carolina, Gibbon and Lovich, 1990). This may be due to samplin bias. Our sample consisted largely of female found nesting and males caught in traps. W cannot determine without further study whethe this result is a sampling artifact, or if sexual siz dimorphism is truly pronounced at the northeastern edge of the range of this species.

With one exception, all of our information o reproduction in the freshwater turtles of Bacl Bay is anecdotal and the values reported abov are within the ranges reported for other populations (Ernst and Barbour, 1972; Mitchell, 1985a 1985b, 1988). Mitchell and Pague (1990) compared the reproductive ecology of *Trachemys script* between populations from Back Bay and Disma Swamp. They found no significant differences i body size, clutch size, and egg size relationship between the Back Bay population and the Disma Swamp population. In both populations female are as large as those populations from thermall enhanced aquatic systems, with no significan relationship of clutch size to body size, but eg length, width, and wet mass are significantl correlated with body size. Annual growth o juveniles 1-6 years old in Back Bay is 13.1 mm.

The ecological and energetic relationships o freshwater turtles in wetland ecosystems ar undoubtedly greater than now realized. Turtle utilize both the aquatic and terrestrial habitat for different parts of their life histories. Th diversity of foraging modes in freshwater turtle (carnivory, herbivory, and omnivory), couplec with their ubiquity and numbers, suggests tha they play complex, but crucial roles in th maintanence of wetland energy dynamics. Egg are laid on land and their energetic content ha great consequence for terrestrial food webs anc energy flow. Eggs in turtle nests are usually eater by terrestrial predators, such as foxes anc raccoons. Congdon and Gibbons (1990 anc references therein) list nest predation rates o 41% to 95% and demonstrate that nest predatior can be as high as 100% in some years. The averag annual energy gained by predators from turtl eggs in a Michigan wetland was 2.3 kg/ha o marsh (Congdon and Gibbons, 1990). The redistribution of nutrients by turtles alone in wetlanc ecosystems makes these animals valuabl participants.

The conservation of freshwater turtles in wetlands has taken a back seat to the conservation of plants, fish, and birds. Freshwater turtles in the Back Bay region have no legal protection and could be exploited at will. This has already been the case with snapping turtles. Prolonged harvesting of these animals is likely to be detrimental to them and the Back Bay ecosystem. How alteration of wetland habitats affect freshwater turtle populations is unknown and should be studied. Are freshwater impoundments that are created for waterfowl appropriate habitats for these animals? What affect does the wet and dry cycles of these impoundments have on the ecology and survival of freshwater turtles? How will the changing salinity of Back Bay affect their local distribution and population sizes? What are the actual dietary components of the freshwater turtles in the Back Bay region? What are the ecological relationships of these animals to fish and waterfowl? Answering these questions could greatly improve our understanding of the role of freshwater turtles in wetlands ecosystems.

Acknowledgments
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Table 1. Species diversity and community structure of freshwater turtles in Back Bay, Virginia. Abbreviations: BA = basking turtle, BW = bottom walker, C = carnivore, H = herbivore, O = omnivore, TR = terrestrial.

Clemmys guttata	Spotted Turtle	C, BA
Chrysemys picta picta	Eastern Painted Turtle	O, BA
Chelydra serpentina serpentina	Snapping Turtle	O, BW
Kinosternon subrubrum subrubrum	Eastern Mud Turtle	C, BW
Pseudemys rubriventris rubriventris	Red-bellied Turtle	H, BA
Terrapene carolina carolina	Eastern Box Turtle	O, TR
Trachemys scripta scripta	Yellow-bellied Slider	H, BA

Table 2. Freshwater turtle trapping success in Back Bay National Wildlife Refuge, Virginia. Three trapping sessions are reported: May 1983 (22 chickenwire funnel traps), June 1983 (25 chickenwire funnel traps and 2 fyke nets), and August 1989 (23 chickenwire funnel traps and 5 fyke nets). The number represents the number of captures per trap day.

Species	May 1983	June 1983	August 1989	
			Chickenwire	Fyke nets
C. picta	0.36	0.19	0.15	0.10
C. serpentina	0.04	0.06	0.02	0.40
K. subrubrum	0.32	0.24	0.11	0.00
P. rubriventris	0.00	0.02	0.00	2.40
T. scripta	0.77	0.20	0.15	3.00
C. guttata	0.05	0.00	0.00	0.00
No. of trap days	**22**	**54**	**46**	**10**

Waterfowl Trends in Back Bay, Virginia from 1954 to 1990

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Introduction

Back Bay, Virginia and Currituck Sound, North Carolina have long been noted and highly acclaimed as prime waterfowl wintering and migration areas. Although no formal waterfowl surveys were conducted prior to 1937, some gauge of waterfowl abundance can be obtained from harvest record examination. Harvest estimates based on "extraordinarily well kept and recorded data" of ten major waterfowl hunting clubs in Back Bay and Currituck Sound between 1872 and 1962 (Sincock, 1966) suggest that five million (5,000,000) ducks and 560,000 Canada geese were taken by hunting during that 90-year period. Waterfowl population trends in Back Bay for the 37-year period 1954-90 are the subject of this paper.

Methods

Independent periodic waterfowl surveys have been conducted by personnel of Back Bay National Wildlife Refuge and the Virginia Department of Game and Inland Fisheries. Data from these surveys were not used in this analysis because of limited geographic coverage, surveys omitted some years, and the high rate of turnover of survey personnel and variability in experience and ability to census waterfowl populations.

Usable data sets were narrowed to Audubon Christmas Bird Counts and Mid-Winter Waterfowl Inventories. The former counts have been conducted by qualified volunteers of the Audubon Society annually for fifty years during the week between Christmas and New Year's in conjunction with similar counts nationwide. The Back Bay Circle, the sampled area, is a 15-mile diameter circle with its center located approximately 1 1/2 mile east of Back Bay Station in the City of Virginia Beach. The counts are made primarily from the ground by vehicle or walking, however boats and aircraft augment the ground survey some years.

Mid-Winter Inventories (MWI) are annual waterfowl surveys conducted by U. S. Fish and Wildlife Service and/or state wildlife agency personnel. These surveys are coordinated nationwide and are scheduled during the first week of January but occasionally continue into the second week. The Back Bay survey unit, Virginia Zone 4, Segment 14, extends from Dam Neck west to U. S. Route 17, south to the North Carolina state line, east along the state line to the Atlantic Ocean, then north to Dam Neck. The Back Bay survey is aerial and is coordinated with personnel in North Carolina so that Currituck Sound and Back Bay can be surveyed the same day, usually by the same personnel. Such coordination is done to minimize and hopefully eliminate duplication or omission errors of cohorts of birds utilizing habitats on both sides of the state line.

Although Mid-Winter Inventories in the Back Bay survey unit date back to 1937, the waterfowl trends in this presentation will begin with the 1954 survey because data is missing for the years 1941, 1946, 1948, 1952 and 1953 (Sincock, 1966).

Back Bay waterfowl counts from both Audubon Christmas Bird Counts and Mid-Winter Inventories were compared for the 37-year period, 1954-90. Both surveys showed similar fluctuations in waterfowl numbers. The Mid-Winter Inventory data are used in this paper because of the complete aerial coverage of the survey unit, the coordination of survey timing with North Carolina and the ability to relate to Virginia and Atlantic Flyway data for comparable periods.

Linear regression analysis was made on certain waterfowl species or groups of species for the entire 37-year period 1954-90 as well as for the last 10-year period 1981-90.

As a note of interest, the trend in presence of submerged aquatic vegetation (SAV) in Back Bay was graphed and compared to certain species groups and to total waterfowl. Since the annual SAV surveys were conducted in late summer or early fall, the wild bird populations that utilized a summer or fall standing crop were the birds surveyed during the MWI in January of the following calendar year. Thus the SAV percent frequency values appearing in Figures 9-12 are included in the next calendar year to correspond to the correct generation of birds which utilized the plants.

Trends

Dabbling ducks (also known as puddle or tip-up ducks) in Back Bay show highly variable numbers over the 37-year period under consideration. The dabbling ducks have exhibited a statistically significant decline over the last 10-year period ($P<0.04$); however the 37- year decline barely misses being statistically significant ($P = 0.0532$) (Figure 1). Dabbling duck trends declined but at a much slower rate over the last 10-year period in Virginia and in the Atlantic Flyway (FWS-OMBM files).

Figure 2 graphically shows Back Bay population trends in gadwall and American wigeon, two dabbling duck species highly dependent on SAV food production in the bay habitat (Sincock, 1966).

Diving duck species in Back Bay (Figure 3) have shown a statistically significant dramatically declining trend since 1954 ($P<0.001$) as contrasted to a stable or only slightly declining trend at the Virginia and Flyway levels (FWS-OMBM files).

The greater snow goose (Figure 4) has exhibited a significant decline since 1954 in Back Bay ($P<0.03$) while Flyway numbers of this species have increased from an annual average of 47,000 in 1954-59 to 163,000 in 1986-90 (FWS-OMBM files).

The Canada goose (Figure 5) has shown a statistically significant decline in Back Bay since 1954 ($P<0.001$) while Virginia and Atlantic Flyway populations have increased during the same period (FWS-OMBM files).

The Back Bay population of tundra swan (Figure 6) has declined significantly since 1954 ($P<0.03$) while the Atlantic Flyway population has steadily increased (FWS-OMBM files).

Although the American coot is a member of the family Rallidae and not a true waterfowl species, it is included here because of its close association with waterfowl groups addressed in this paper and because of coot dependence on submerged aquatic vegetation. Although the declining trend in Back Bay coot numbers is not statistically significant, Figure 7 shows the dramatic variations. No coots have been counted during the mid-winter inventory in Back Bay since 1980. Audubon Christmas Bird Counts show a very similar trend. Coot populations in the Atlantic Flyway have remained stable since 1954 (FWS-OMBM files).

Total waterfowl numbers in the Back Bay survey unit (Figure 8) have exhibited a statistically significant declining trend between 1954 and 1990 ($P<0.001$) (FWS-OMBM files).

Many factors influence waterfowl populations (a) natural and hunting mortality, (b) production affected by breeding populations and nesting, brood habitat conditions, and (c) distribution which can be affected by all of the preceding factors plus the condition and abundance of migration and wintering habitat. The declining trend of many waterfowl species or species groups in Back Bay are contrary to Virginia or Atlantic Flyway trends. Such evidence suggests the declines are not entirely a result of mortality or production functions. Extreme care must be exercised not to over simplify cause and effect relationships in dynamic wild natural systems. The following data are presented for your interpretation. Figure 9 shows the percent frequency of submerged aquatic vegetation 1959-1990 (actually sampled early fall 1958-early fall 1989). (Coggin, 1966 and 1968; Schwab, 1985, et al. 1988; Settle and Coggin, 1975 and 1976; and Settle and Taylor, 1979). Two periods of abundant SAV occur from 1959 to 1964 and again from 1972 to 1981 where percent frequency of SAV equalled or exceeded 50. The periods of low SAV abundance below 50% frequency were 1965 to 1971 and from 1982 to 1990. The last six consecutive years, 1985-1990, have averaged below 10% SAV frequency in Back Bay. The 1 to 8 percent frequency of SAV noted in recent years is the lowest recorded in the 32 years of SAV monitoring.

The graphs shown in Figures 10-12 show SAV abundance superimposed on dabbling ducks, bay feeding dabbling ducks (gadwall and wigeon) and total waterfowl numbers from Back Bay Mid-Winter Inventories. With few exceptions, it appears that when SAV is abundant in Back Bay waterfowl numbers increase; when SAV is scarce waterfowl numbers decrease.

Sincock (1966) suggested that waterfowl distribution in Back Bay, Virginia was more influenced by SAV than in Currituck Sound, North

Carolina during his 1958-63 investigations. He also inferred that because many waterfowl species are relatively short lived, migratory patterns and habits could be negatively influenced by several years of poor food production on the wintering grounds.

Summary

Thirty seven (37) years of Mid-Winter Waterfowl Inventories of Back Bay, Virginia, 1954-90, indicate statistically significant declines in numbers of many waterfowl species or groups of species such as diving ducks, greater snow goose, Canada goose, tundra swan, American coot and total waterfowl. Dabbling duck numbers showed a significant decline over the past 10-year period. (Figures 1-8).

Comparison of submerged aquatic vegetation abundance and waterfowl trends in Back Bay, Virginia is shown graphically in Figures 9 - 12. The graphs generally suggest a direct relationship between SAV abundance and waterfowl numbers.

Acknowledgement

Appreciation is expressed to David Steffen, wildlife biologist, Virginia Department of Game and Inland Fisheries, for performing the statistical computations and analysis used with this presentation.

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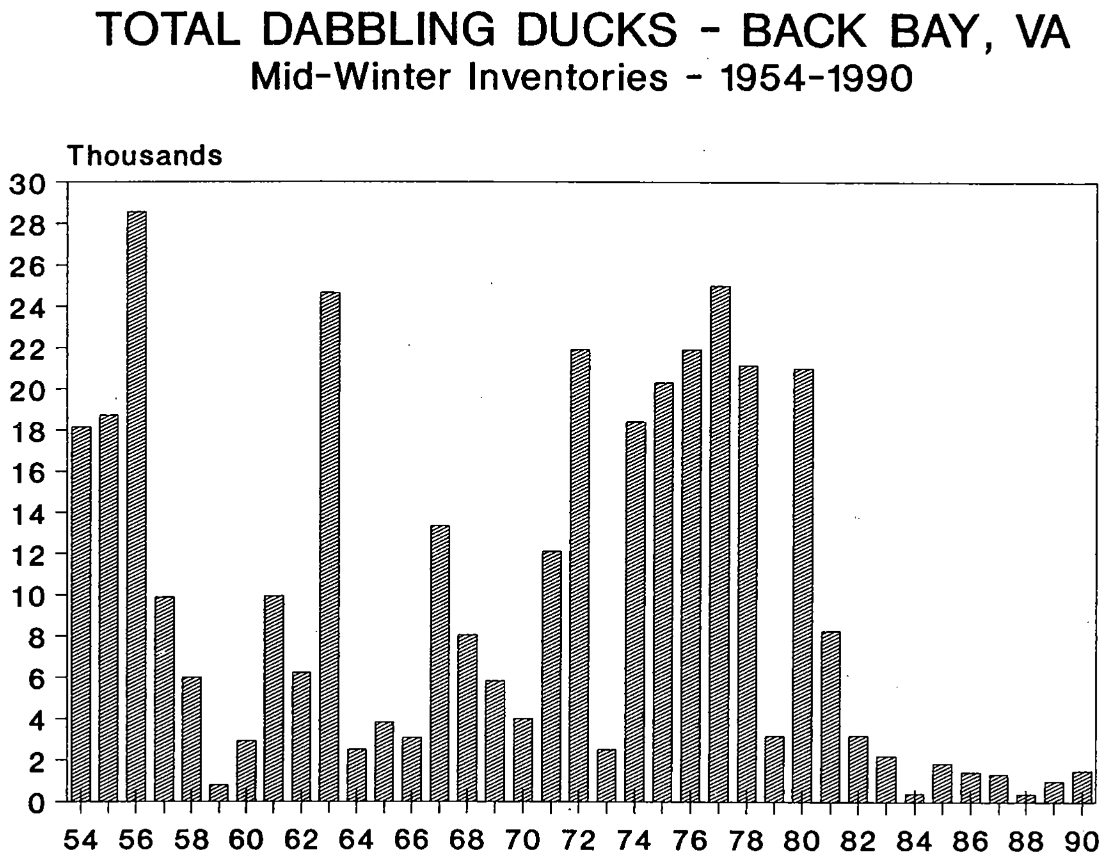

Figure 1. Total Dabbling Ducks - Back Bay, VA

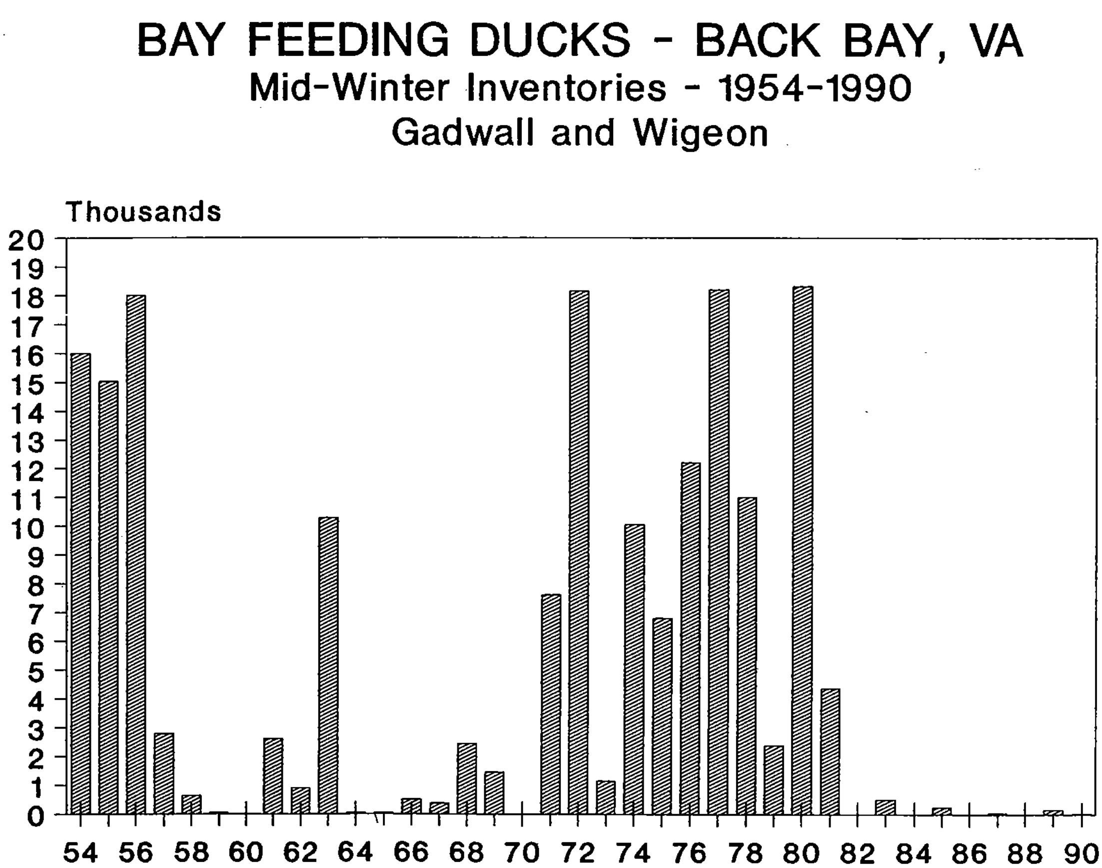

Figure 2. Bay Feeding Ducks - Back Bay, VA

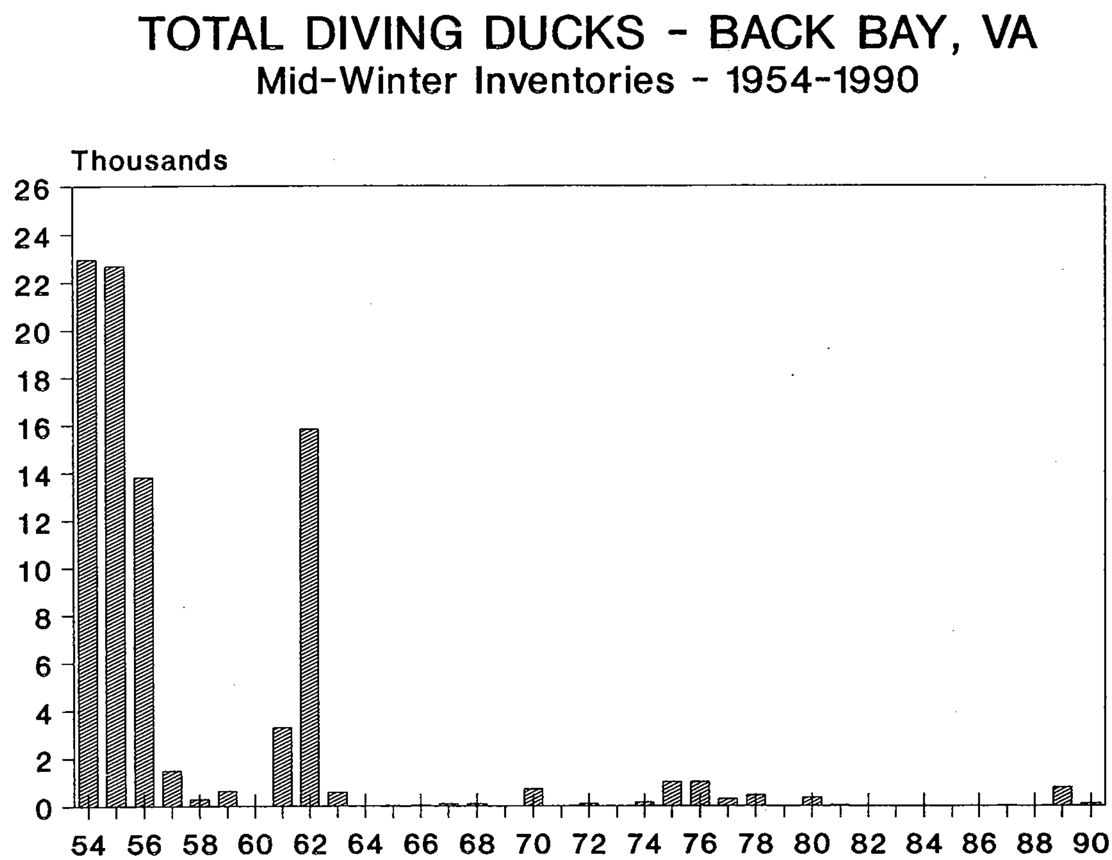

Figure 3. Total Diving Ducks - Back Bay, VA

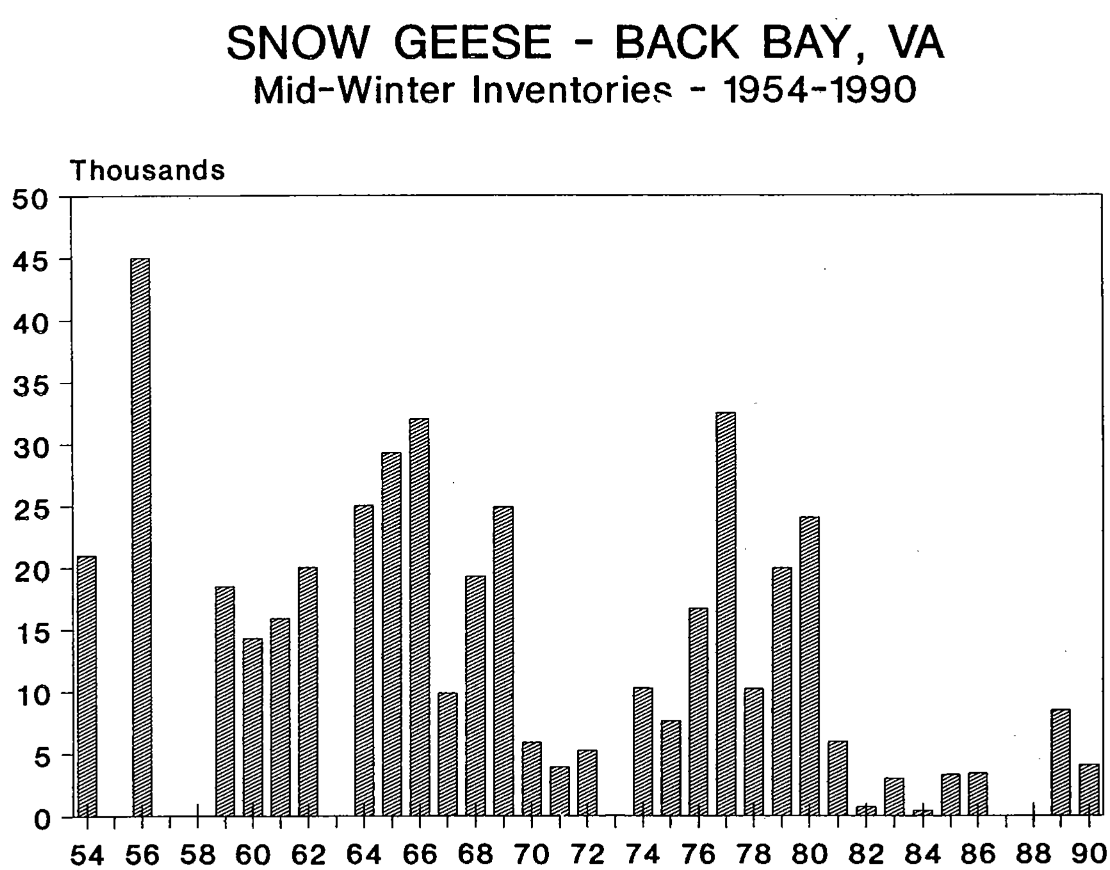

Figure 4. Snow Geese - Back Bay, VA

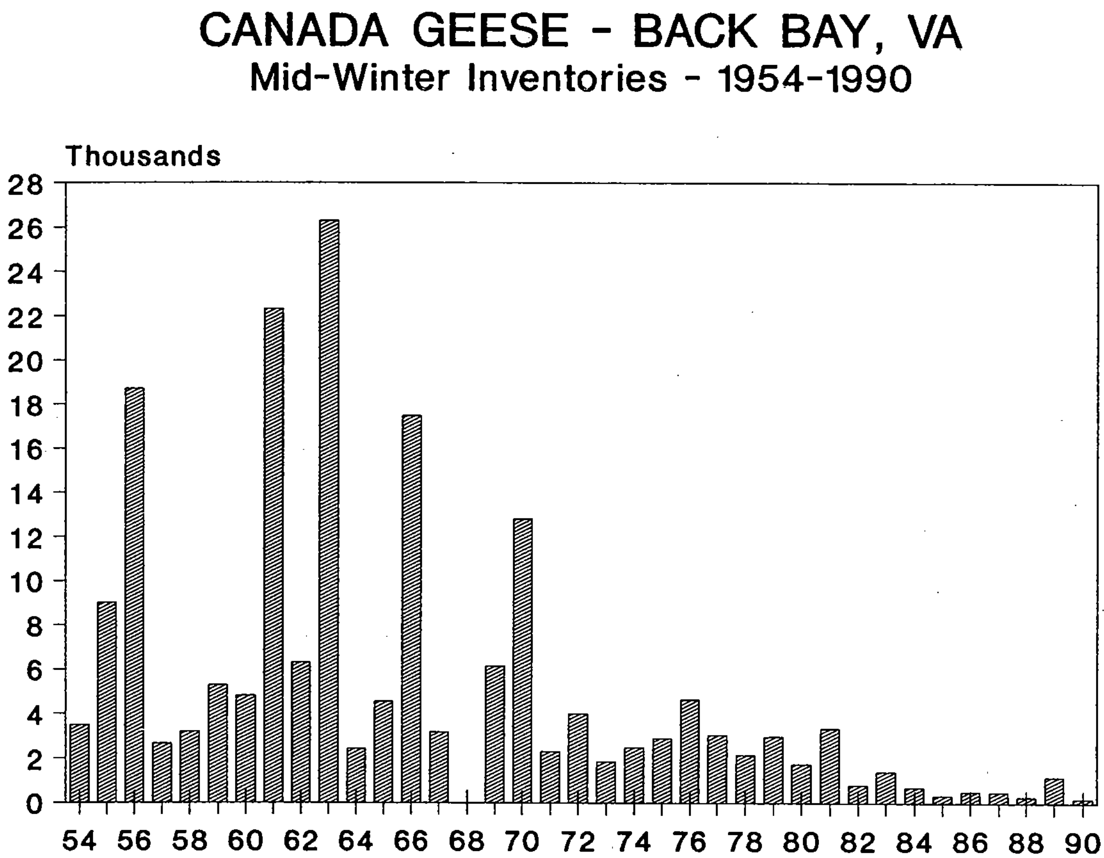

Figure 5. Canada Geese - Back Bay, VA

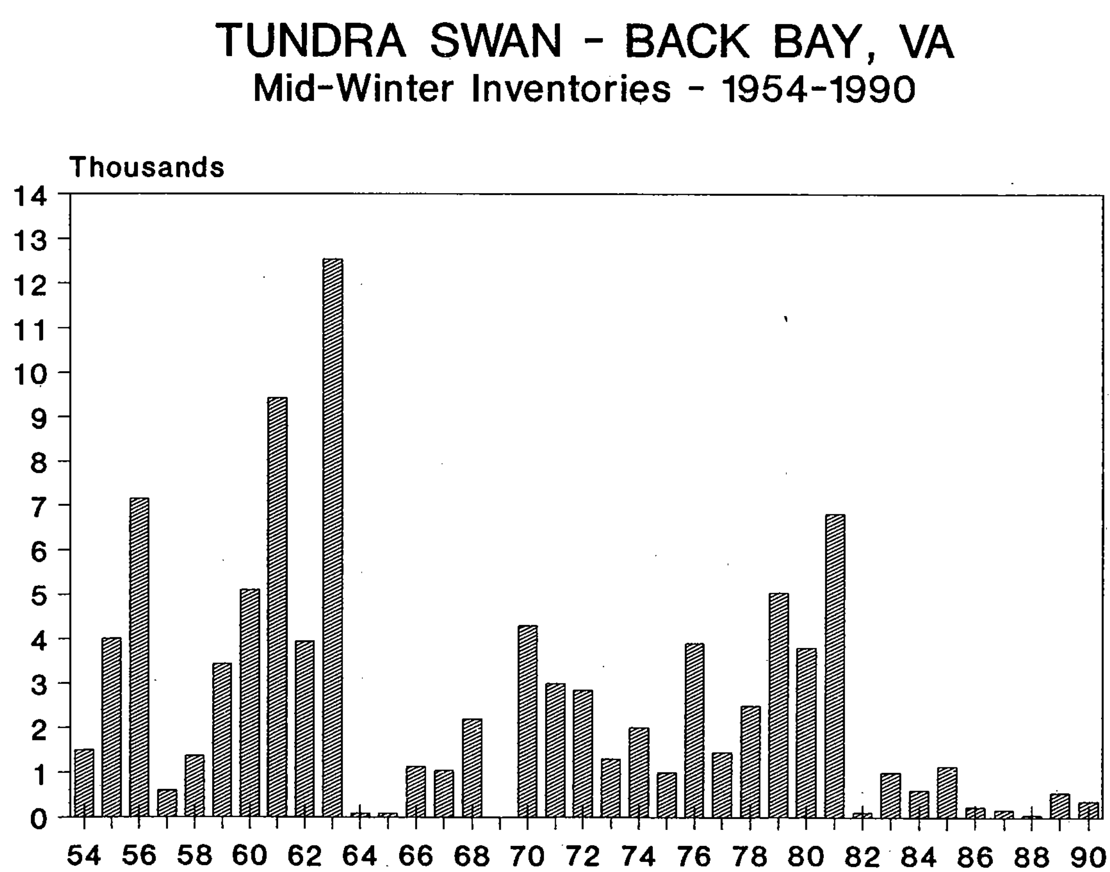

Figure 6. Tundra Swan - Back Bay, VA

COOTS - BACK BAY, VA
Mid-Winter Inventories - 1954-1990

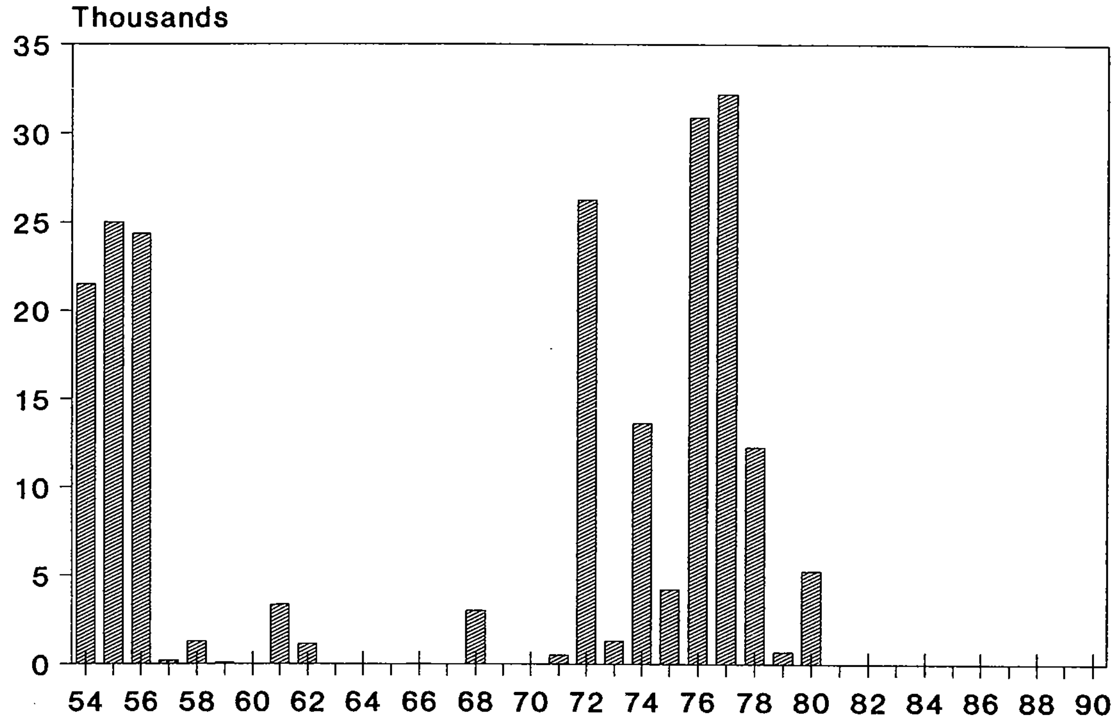

Figure 7. Coots - Back Bay, VA

TOTAL WATERFOWL - BACK BAY, VA
Mid-Winter Inventories - 1954-1990

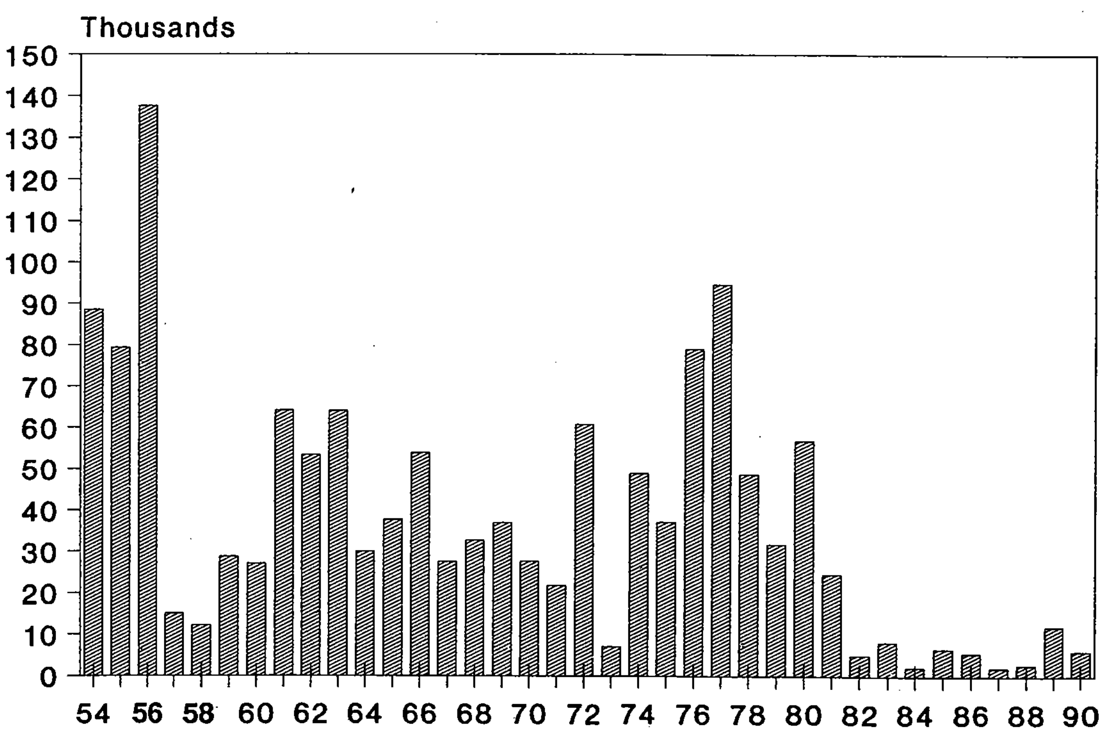

Figure 8. Total Waterfowl - Back Bay, VA

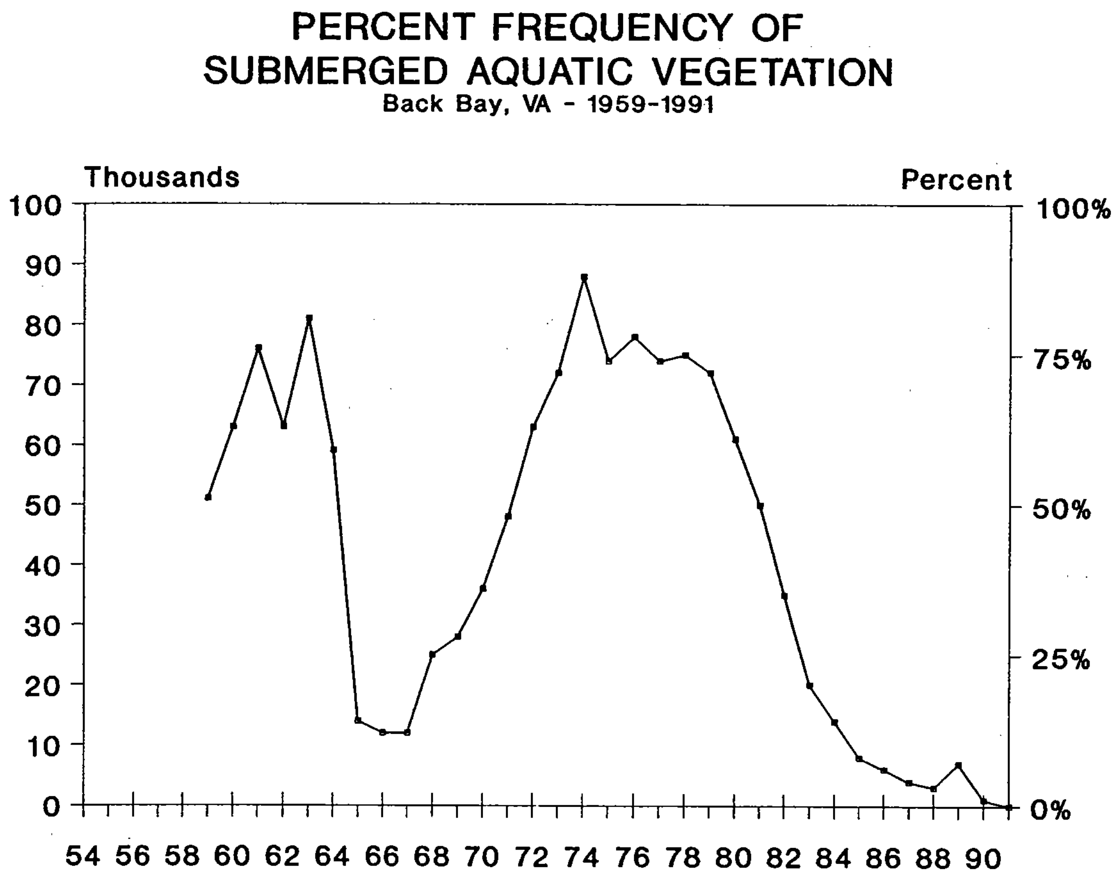

Figure 9. Percent Frequency of Submerged Aquatic Vegetation.

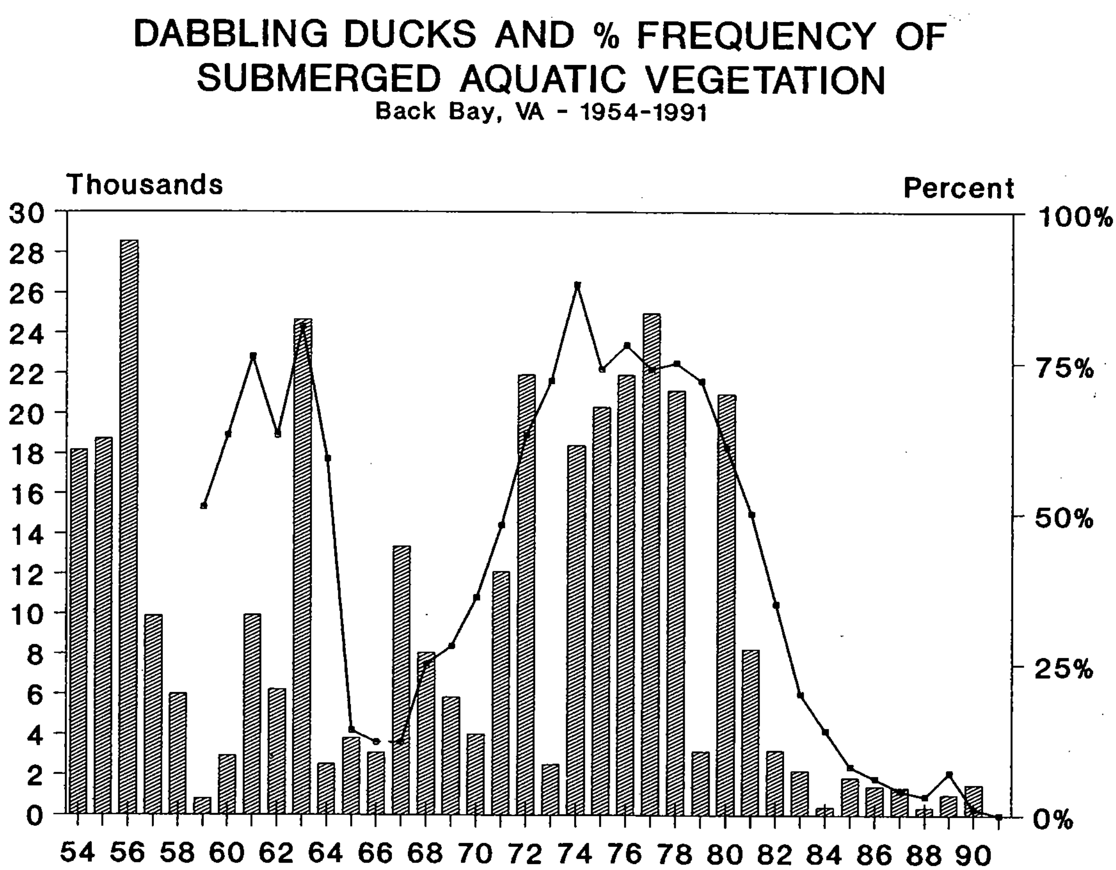

Figure 10. Dabbling Ducks and Percent Frequency of Submerged Aquatic Vegetation.

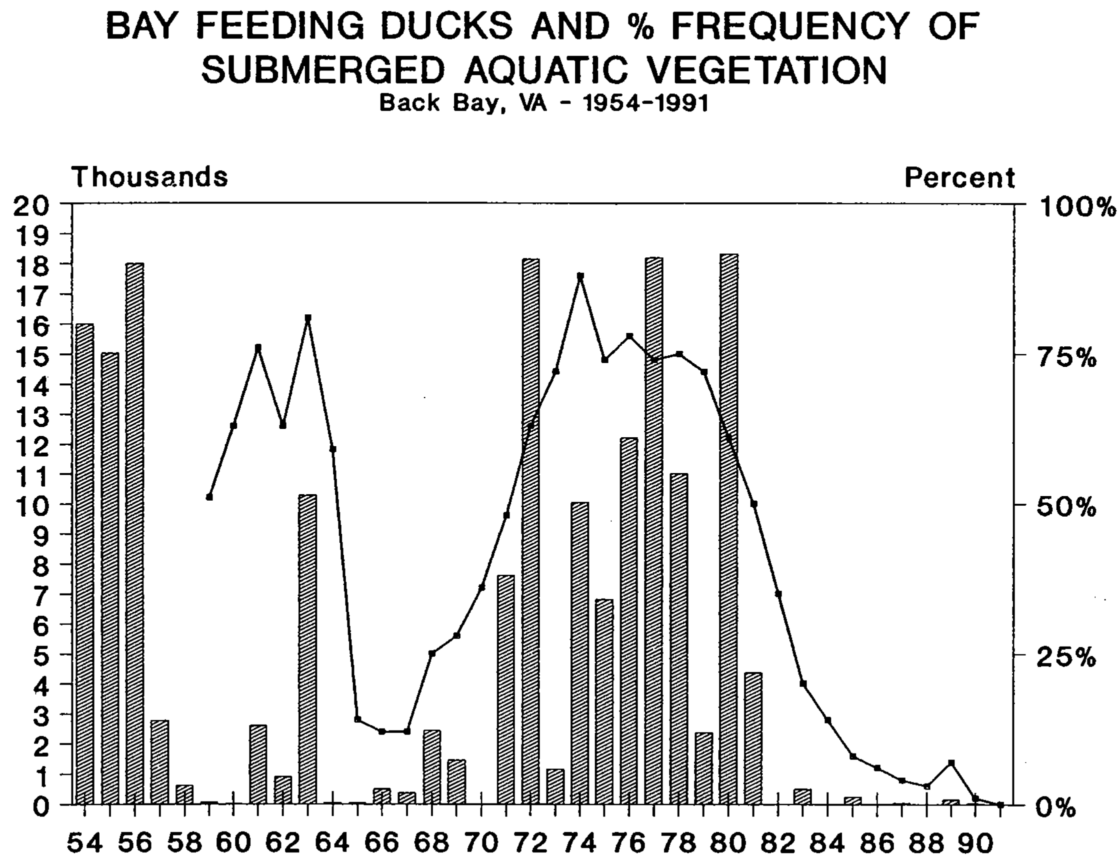

Figure 11. Bay Feeding Ducks and Percent Frequency of Submerged Aquatic Vegetation.

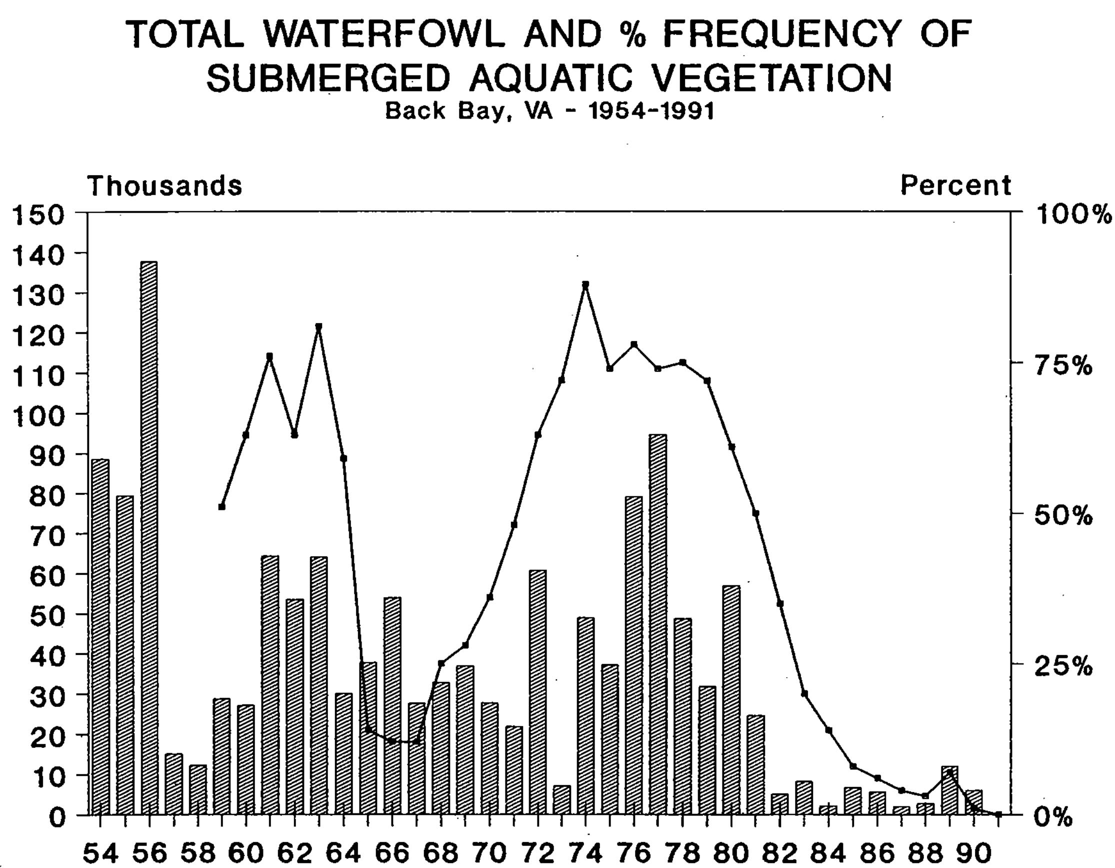

Figure 12. Total Waterfowl and Percent Frequency of Submerged Aquatic Vegetation.

III. Flora

Phytoplankton Populations in Back Bay, Virginia

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Abstract: Cyanobacteria, diatoms and chlorophyceans dominated the seasonal assemblages of phytoplankton in a two year study of Back Bay, Virginia. Seasonal differences in composition and development were found between the two years, with highest concentrations occurring in summer and early fall when a pico-nanoplankton assemblage of cells was dominant.

Introduction

Back Bay is a shallow, oligohaline habitat of approximately 77.7 km^2. Lunar tides are not significant, but wind driven saline waters from Currituck Sound will enter the Bay, coming from the Pamlico Sound estuary located to the south. A pycnocline and stratification are rare because of the prevailing wind patterns that are present and the shallow nature (<2m) of Back Bay. Land drainage into the Bay also comes from several creeks and irrigation ditches. This area was once part of the Great Dismal Swamp and drainage through this system continues to contain tannin stained waters that are slightly acidic. Oaks *et al.* (1979) have discussed the geological history of this region and the relationship between Back Bay, the Great Dismal Swamp and the Pamlico Sound estuarine complex. Comegys (1977) described the phytoplankton in Back Bay as predominantly freshwater species dominated by cyanophyceans in summer, with chlorophyceans the major component of other times. He noted spring to fall production maxima, with the annual salinity range between 0.89 and 3.77 o/oo and a pH range from 6.3 to 9.2. The desmids were a common component, with diatoms having minor significance. Other regional phytoplankton studies have included those in the lower Chesapeake Bay, Elizabeth River and Nansemond River (Marshall, 1967; Marshall and Lacouture, 1986; Shomers, 1988). Flora from these sites are predominantly neritic and estuarine in composition, but differ significantly from assemblages in Back Bay. There are also different associations and dominant species in the freshwater phytoplankton of Lake Drummond, located within nearby Dismal Swamp. These lake species are dominated by diatoms and desmids, with cyanobacteria rare (Marshall, 1976, 1979).

The purpose of this study was to evaluate the seasonal composition and abundance of phytoplankton in Back Bay and to compare these populations to those reported by Comegys over a decade ago. During this period Back Bay has undergone major changes, which include the loss of its submerged vegetation, reduction in its freshwater fishery, increased turbidity and an intermittent policy where saltwater was being pumped into Back Bay.

Methods

Water samples for phytoplankton analysis were taken twice a month from March through October and once a month November through February from February 1986 to March 1988 at six stations in Back Bay (Fig. 1). A 500 ml sample was collected within the upper 0.5 meter at each station and preserved immediately with Lugol's solution. A settling and siphoning procedure followed to obtain a 20 ml concentrate that was placed in a settling chamber and later analyzed with an inverted plankton microscope. The entire concentrate was scanned at 125x for net phytoplankton. A random field-minimum count basis was used at 315x for microplankton (20-200 μ m), and at 500x for pico-nanoplankton (1.5-2.0 microns). Unidentified cells less than 1.5 microns in size were not counted since clear distinction could not be made between autotrophic and heterotrophic cells with the microscope used in this study. This analysis produced an 85% accuracy estimate for the species concentrations within these size ranges. Cell volume measurements were obtained by corresponding each phytoplankter to one or more geometric shapes and determining the cell volume in μ m^3. Salinity and temperature readings were obtained using a portable induction salinometer.

Results

The mean station temperatures for the two year period are given in Figure 2. The major difference between the two years was the timing of the spring temperature rise and subsequent decline into winter. The warming trend came earlier in 1986, with lowest surface water temperatures in January 1988 (0.5°C) and highest in July 1987 (32.1°C). The salinity range for this period was 1.9 to 4.9 o/oo for 1986 and 1.4 to 3.8 o/oo in 1987. Highest salinities were associated with summer and fall, with lowest values generally in late winter and spring, and in 1987 (Figure 2). This decrease was related to the regional precipitation totals for 1986 and 1987. The period for 1986 was considered a "dry" year, with a total precipitation of 26.4 inches compared to 44.6 inches for 1987. The salinity range in 1974-1975, noted by Comegys (1977) was 0.89 to 3.77 o/oo. The 1986 spring-summer temperature rise was associated with increased salinities. However, the temperature drop in 1986 preceded by two months lower salinity records for the station. In contrast, the temperatures and salinity patterns for 1987 and early 1988 were similar. These results indicated basic environmental differences were present over the two periods of study.

A total of 158 phytoplankton were identified (Table 1). These were represented by cyanobacteria (36), Chlorophyceae (35), Bacillariophyceae (49), Dinophyceae (14), Cryptophyceae (4), Euglenophyceae (10), Chrysophyceae (5), Xanthophyceae (3), and Prasinophyceae (2). In addition, several forms were placed under broader generic categories, with other unidentified cells placed in size categories of 1.5-3.0, 3-5 and 5-10 µ m, that included both picoplankton (0.2-2.0 microns) and nanoplankton (2.0-20.0 microns) size groups. The majority of the cells in these three size categories were cyanobacteria, chlorophyceans and microflagellates. The seasonal pattern for the total phytoplankton was a unimodal abundance period occurring in late summer-early fall for both 1986 and 1987, with winter lows each year (Fig. 3). There was greater abundance in the 1987 summer maximum due to increased numbers of cyanobacteria cells. In contrast, many of the other taxonomic groups were more abundant in 1986, and due to their larger cell sizes produced a greater biomass (cell volume) at this time (Fig. 3). Refer to Marshall (1988) for the monthly concentration patterns for the dominant species.

Cyanobacteria

The most abundant and characteristic phytoplankters in Back Bay were cyanobacteria. This group was divided into identifiable species composed of isolated cells, filaments or colonial forms and were included within the cyanobacteria category, and a second assemblage that was within the pico-nanoplankton category. The cyanobacteria were the major component in the size group 1.5-3 µ m, with most of the cells generally 1.5 to 2.0 µ m in size. Additional autotrophic cells, mainly cyanobacteria, within the picoplankton category were not counted because distinction between these and heterotrophic bacteria was not feasible with the light microscope. Thus, the counts given for picoplankton concentrations are considered underestimates of the pico-cyanobacteria component. Random samples taken over the study period and prepared for epifluorescent microscopic examination verified the vast majority of autotrophic cells in this category were cyanobacteria. Similar verification was noted in the 3-5 µ m cell size category, but the proportion of cyanobacteria cells to others was not as great as in the <3 µ m component. The larger cyanobacteria had one major pulse each year (Fig. 4). The cells in the < 3 µ m category were ubiquitous and abundant each year, but were more numerous in 1987 when a more distinct spring-summer pulse developed (Fig. 4). The greater diversity in composition of the 3-5 µ m cell size component produced larger numbers of cells throughout 1986, in comparison to 1987, which resulted in larger numbers of cyanobacteria.

With the exception of the pico-nanoplankton cells, the most abundant cyanobacteria in Back Bay were *Lyngbya limnetica, Lyngbya contorta, Chroococcus limneticus, Merismopedia elegans, Merismopedia tenuissima, Merismopedia glauca,* and *Gomphosphaeria aponina*. *Lyngbya limnetica* and *L. contorta* had peak production in mid-summer and fall, with a winter low (Table 1). These growth patterns were of shorter duration in 1987, with the decline more rapid and the peak production limited to summer. *Merismopedia glauca* and *M. tenuissima* had similar patterns, but *M. elegans* was generally a background species, with the exception of a spring 1986 pulse. *Gomphosphaeria aponina* and *Chroococcus limneticus* were also common, with a decline in winter.

Other Phytoplankton Categories

The Bacillariophyceae consisted of predominantly freshwater (e.g. *Melosira distans*) and to a lesser degree estuarine species (e.g. *Rhizosolenia setigera, Thalassiosira eccentrica*). *Cyclotella striata, Cyclotella meneghiania,* and *Cyclotella caspia* were dominant species throughout the year (Table 1), with their peak concentrations occurring during spring-summer months (Marshall, 1988). Higher numbers occurred in 1987 (than in 1986) when an early spring bloom began in late winter with a peak in January, followed by a decline, then a greater pulse in April, before dropping again into May (Fig. 3). There was no fall pulse, nor did any of the estuarine species reach high concentrations. These cells were more common at Station 22, the southern most site nearest to Currituck Sound. A diverse group of chlorophyceans were in the samples and in contrast to the diatoms had much higher concentrations during 1986 than in 1987. However, their greatest abundance occurred in spring and fall in 1986 and spring in 1987 and 1988 (Fig. 5). The group was mainly represented by desmids which included *Cosmarium costatum, Scenedesmus bijuga, S. dimorphus* and *S. quadricauda*. In addition, *Ankistrodesmus falcatus, Crucigenia tetrapedia,* and *Tetraedron regulare* were also common. Although not specifically recognized in the pico-nanoplankton category, there were also chlorophycean cells in these size groups. They often consisted of "chlorella like" cells, so their addition from that category would augment the significance of chlorophyceans in this habitat. Highest concentrations of chlorophyceans were consistently noted at Station 9, the most northern and least saline station sampled.

The cryptophyceans represented a major component within Back Bay with several generic groups common. These included *Cryptomonas, Chroomonas* and *Hemiselmis*, with *Cryptomonas* spp. most abundant. The greatest concentrations were in fall 1986 with other scattered pulses noted over the study period (Fig. 5). These cells were also common to the lower Chesapeake Bay and the regional sections of estuarine rivers (Marshall and Lacouture, 1986). These varied seasonal growth patterns indicated growth responses from several different components within the group. The dinophyceans consisted mainly of estuarine species, e.g. *Gymnodinium danicans, Katodinium rotundatum* and *Prorocentrum minimum*. Concentration levels were generally low, with the exceptions of pulses during winter 1986, summer 1987 and spring 1988 (Fig. 5). The spring 1988 pulse was limited to two northern stations (Stations 5, 9) and was dominated by *Gymnodinium danicans*. The different pulses of dinoflagellates were growth responses by an individual species, rather than a general growth response by numerous species. The dominant species were not unique for the region, but common constituents of local estuarine habitats (Marshall and Lacouture, 1988). Another prominent phytoflagellate category in Back Bay was the Euglenophyceae. Although never found in high concentrations the euglenophyceans were common at all stations. Representative species included *Euglena acus, E. proxima, E. pumila,* and *Eutreptia lanowii*. More rare were several *Phacus* spp. and *Trachelomonas hispida*, however, these genera were often noted at Station 9 and to a lesser degree at other stations. This group was most common in summer, with lowest concentrations during winter (Fig. 4).

In addition to the phytoplankton categories mentioned above, several other groups provided low concentrations and low diversity of species during the sampling period. These background species included chrysophyceans, prasinophyceans and xanthophyceans. The chrysophyceans are common estuarine species that were divided into two categories: 1) the silicoflagellates and 2) the other chrysophytes. The silicoflagellates included *Dictyocha fibula* and *Distephanus speculum*. They were generally rare but produced a small summer 1986 pulse. The other chrysophyceans consisted of *Calycomonas wulffie, Mallomonas* sp. and *Ochromonas* sp. The entry of these and other estuarine species into Back Bay was influenced by local wind patterns. Strong and prevailing winds from the southeast (or ESE, SSE) bring the more saline Currituck Sound water into the Bay. Depending upon wind direction, its duration and velocity, this water may move either into the entire lower portion of the Bay, or along the eastern margin. Other estuarine categories included the prasinophyceans which were represented by *Pyramimonas* sp. and *Tetraselmis* sp. and the xanthophyceans containing *Nephrochloris salina, Nephrochloris* sp. and *Olisthodisaus* sp. None of these three groups were major components of the Bay flora, but they produced several pulses over the two year period.

Discussion

Comegys (1977) described the phytoplankton flora of Back Bay as predominantly cyanobacteria (blue green algae) and chlorophycean, with diatoms, cryptomonads and others as non-dominant components. The results of this present study indicate the cyanobacteria remain the dominant flora, but show a changing contribution to the total assemblage by the chlorophyceans and the greater significance of diatoms and the cryptomonads. In addition, there were interannual differences in the seasonal abundance of the various phylogenetic groups and total phytoplankton concentrations between 1986 and 1987.

There have been major environmental events that have impacted Back Bay since Comegys's study in 1974-1975, which represent only a portion of the total changes that have taken place within this drainage basin. Their total scope is too vast to discuss in this report. However, they include: 1) the intermittent pumping of salt water into Back Bay; 2) the changing land use patterns bordering Back Bay, which includes the transition of woodland and marsh sites to agriculture and housing developments; 3) increased turbidity levels; 4) the loss of submerged vegetation; and 5) the reduction of the freshwater fishery. In addition, there are likely seasonal and annual deviations of algae growth patterns that cannot be fully identified in short-term studies. Normal ranges of seasonal fluctuations need to be identified before many of the algal responses to "normal" and/or adverse environmental conditions can be fully recognized.

Alden and Ewing (1990) have also reviewed water quality data for Back Bay over the past two decades and identified several concerns. One involves the tributaries along the western border that are major sources for nutrients into the Bay. In addition, the main Bay waters have a high suspended solid load, with high TKN concentrations. Their data infers a reduction in productivity (based on pH and oxygen levels), with elevated TKN values indicating a positive trend, going from means of 1.14 to 1.97 mg/l over this period. They associate a reduced productivity with the loss of submerged aquatic vegetation, increased suspended solids and a change in the phytoplankton population. A significant feature of the TKN is that they are above the 0.9 mg/1 level "used as a benchmark for nitrogen over-enrichment." It should be noted the present phytoplankton populations contain potential bloom producers among its procaryote and eucaryote species. Greater development, or bloom production is considered imminent if nutrient levels, specially phosphates, were to increase in the Bay waters. Sites most vulnerable for increased growth would be those located near, or along the western margin of the Bay. With a submerged vegetation practically absent in the Bay, there would be little competition for increased nutrient loadings, resulting in rapid uptake by the phytoplankton community. However, a major deterrent to this utilization and growth, may be the high suspended solid load within the Bay waters and the possible impact this has on reducing light availability to the cells.

The present algal assemblages in Back Bay are unique among regional habitats. The nearby estuaries of the Elizabeth and Nansemond Rivers have predominantly an estuarine-neritic flora dominated by diatoms and a pico-nanoplankton component (Marshall, 1967; Shomers, 1988). These assemblages are comparable to those in the lower James River (Hampton Roads) and the lower Chesapeake Bay (Marshall and Lacouture, 1986). Common components that were dominant in these different habitats was the diatom *Cyclotella striata* and the ubiquitous pico-nanoplankton cells. However, other diatoms such as *Skeletonema costatum, Leptocylindrus minimus* and *Asterionella glacialis* were major dominants and these were not common in Back Bay. The acidic, brown water Lake Drummond, located in nearby Dismal Swamp, has a floral assemblage that is dominated by another diatom group consisting of *Asterionella formosa, Melosira granulata* and *Melosira herzogii* (Marshall, 1976).

The phytoplankton flora at Back Bay is characterized as predominantly composed of cyanobacteria, bacillariophyceans and chlorophyceans. A very prominent pico-nanoplankton community of cells is ubiquitous and composed of mainly cyanobacteria, with chlorophyceans in less abundance. The major period of algal growth is summer, when each of these categories obtained maximum development. The dominant species within each category are small cells. Even *Cyclotella striata*, or *Cyclotella caspia* are represented by a cell size of less than 10 μ m. The cryptomonads are also prominent, but to a lesser degree. The other taxonomic groups were not major contributors to the local productivity. However, within each of the taxonomic categories individual pulses of growth were common, with a larger number of background species intermittently present, but in lower concentrations during the sampling period.

In summary, the phytoplankton assemblages have changed since 1974-75 when they were evaluated by Comegys (1977). Comegys considered Back Bay was in an advanced mesotrophic or eutrophic stage. The present species composition in Back Bay would be considered more mesotrophic than eutrophic, with the changes in species compositon that have occurred over the past decade due to modified water quality conditions that favored the presence and growth of the existing assemblages. The return to a lower salinity range, increased nutrient input and reduced salt water entry (from either pumping activities, or its natural entry from the south) would enhance eutrophication and initiate another composition change of future phytoplankton assemblages.

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Table 1. Phytoplankton species observed in Back Bay. Mean annual cell concentrations and mean annual volume measurements are given for each species. Less than 1 values are indicated by a zero. Cell concentrations given in no.'s per liter, cell volume in cubic microns per microliter.

Species	Cell Concentration	Cell Volume
BACILLARIOPHYCEAE		
Achnanthes clevei Grunow	270	0
Achnanthes longipes Agardh	234	6
Achnanthes sp.	270	1
Amphiprora alata (Ehrenberg) Kutzing	590	43
Amphiprora costata (W. Smith) Hustedt	284	7
Amphiprora sp.	234	14
Amphora proteus Gregory	0	0
Amphora sp.	248	5
Bacteriastrum hyalinum Lauder	12194	63
Biddulphia longicruris Greville	2144	19
Centric diatoms (Unid.) <20u diameter	5920	5
Centric diatoms (Unid.) 20u-100u diameter	53980	1831
Chaetoceros sp.	3	0
Cocconeis sp.	9923	60
Coscinodiscus centralis Ehrenberg	35	28
Cyclotella glomerata Bachmann	41182	23
Cyclotella meneghiniana Kutzing	578509	909
Cyclotella sp.	250125	85
Cyclotella sp. *I*	27909	1
Cyclotella caspia Grunow	35753	2
Cyclotella striata (Kutzing) Grunow	743306	2627
Cymbella sp.	2698	1
Diploneis crabro Ehrenberg	625	15
Diploneis gruendleri (Schmidt) Cleve	270	1
Fragilaria sp.	7836	2
Frustulia rhomboides (Ehrenberg) deToni	0	0
Frustulia sp.	248	2
Gomphonema sp.	866	8
Gyrosigma hippocampus (Ehrenberg) Hassall	319	4
Licmophora paradoxa (Lyngbye) Agard	319	5
Licmophora flabellata (Carmichael) Agardh	0	0
Melosira distans (Ehrenberg) Kutzing	26411	72
Melosira granulata (Ehrengerg) Ralfs	11783	64
Melosira nummuloides (Dillwyn) Agardh	1	0
Melosira sp.	16843	331
Navicula arenaria Donkin	0	0
Navicula sp.	2314	17
Nitzschia angularis var. *affinis* Grunow	10292	100
Nitzschia clausii Hantzsch	319	0
Nitzschia sigma (Kutzing) W. Smith	951	36
Nitzschia sp.	5636	51
Nitzschia vermicularia (Kutzing) Hantzsch	0	0
Pennate Diatoms (Unid.) <20u apical axis	53611	10
Plagiogramma staurophorum (Gregory) Heilberg	27228	3
Pleurosigma sp.	271	10
Pleurosigma strigosum W. Smith	468	30
Porosira gracialis (Gran) Jorgensen	1774	94
Rhizosolenia setigera Brightwell	319	15
Striatella sp.	248	5
Surirella fastuosa Ehrenberg	319	28
Surirella striatula Turpin	2	0
Thalassiosira eccentrica (Ehrenberg) Cleve	3	0

Species	Cell Concentration	Cell Volume
DINOPHYCEAE		
Amphidinium sp.	1107	4
Amphisolenia bidentata Schroeder	539	90
Ceratium sp.	248	7
Dinoflagellate cysts (Unid.)	589	25
Glenodinium sp.	1455	10
Gymnodinium danicans Campbell	22659	33
Gymnodinium nelsonii Martin	284	11
Gymnodinium sp.	1810	142
Gyrodinium aureolum Hulburt	1704	10
Gyrodinium sp.	284	10
Katodinium asymmetricum (Massart) Loeblich III	305	0
Katodinium rotundatum (Lohmann) Loeblich III	2456	2
Oblea rotunda (Lebour) Balech	0	0
Prorocentrum minimum (Pavillard) Schiller	2371	1
Protoperidinium sp.	1604	23
CYANOBACTERIA		
Agmenellum quadruplicatum (Heneghini) Brebisson	3407	0
Anabaena confervoides Reinsch	298	0
Anabaena sp.	6445	0
Anacystis cyanea (Kutzing) Drouet & Dailey	468	0
Blue Green single cells (Unid.)	19768	1
Blue Green trichomes (Unid.)	539	1
Calothrix sp.	327	0
Chroococcus dispersus (Keissler) Lemmerman	11321	0
Chroococcus limneticus Lemmerman	5799735	655
Chroococcus sp.	13969	3
Chroococcus turgidus (Kutzing) Naegeli	78546	932
Dactylococcopsis fascicularis Lemmerman	639	0
Gomphosphaeria aponina Kutzing	3081428	1384
Gomphosphaeria sp.	213	0
Johannesbaptistia pellucida (Dickie) Taylor & Drouet	2002	0
Lyngbya contorta Lemmerman	1114301	309
Lyngbya limnetica Lemmerman	15446130	9468
Lyngbya sp.	497	0
Merismopedia elegans Braun	3121613	28728
Merismopedia v. *major* G. Smith	6090	4
Merismopedia glauca (Ehrenberg) Naegeli	6390852	217
Merismopedia punctata Meyen	453107	546
Merismopedia sp.	5494	3
Merismopedia tenuissima Lemmerman	3531559	32
Microcystis aeruginosa Kutzing	7354521	2809
Microcystis incerta Lemmerman	1740863	2
Nodularia sp.	270	0
Nostoc commune Vaucher	454143	30
Nostoc sp.	47344	3099
Oscillatoria limnetica Lemmerman	479205	158
Oscillatoria sp.	3024	35
Oscillatoria tenuis Agardh	51702	69
Raphidiopsis curvata Fritsch & Rich	573872	1333
Rhabdoderma lineare Schmidle & Lauterborn	5196	0
Rhabdoderma sigmoidea f. *minor* Moore & Carter	60588	0
Rhabdoderma sp.	1164	0
Schizothrix sp.	284	0
Spirulina subsalsa Oersted	284	0

Species	Cell Concentration	Cell Volume
EUGLENOPHYCEAE		
Euglena acus Ehrenberg	2472	82
Euglena ehrenbergii Klebs	319	12
Euglena proxima Dangeard	2633	73
Euglena pumila Campbell	2243	88
Euglena sp.	13025	177
Eutreptia lanowii Steuer	319	0
Eutreptia sp.	284	2
Phacus sp.	355	0
Trachelomonas hispida (Perty) Stein	589	130
Trachelomonas sp.	958	197
CHLOROPHYCEAE		
Ankistrodesmus falcatus Beijerinck	66515	130
Ankistrodesmus sp.	7204	197
Botryoccus protuberans West & West	3577	0
Chlamydomonas sp.	365256	164
Chlorella sp.	355	0
Cosmarium costatum West & West	1682	24
Cosmarium sp.	9916	143
Crucegenia sp.	20570	2
Crucegenia quadrata Morren	3549	0
Crucegenia tetrapedia (Kirchner) West & West	17773	2
Dictyophaerium planctonicum Tiffany & Ahlstrom	3748	2
Dictyophaerium pulchellum Wood	1874	0
Euastrum sp.	355	4
Kirchneriella lunaris (Kirchner) Moebius	50147	2
Kirchneriella obesa major (Bernard) G. Smith	6118	1
Kirchneriella sp.	31898	
Microasterias sp.	234	30
Pediastrum boryanum (Turpin) Meneghini	4863	69
Pediastrum duplex Meyen	2023	1059
Pediastrum duplex var. *rotundatum* Meyen	3	1715
Pediastrum simplex (Meyen) Lemmerman	319	167
Scenedesmus abundans (Kirchner) Chodat	3407	0
Scenedesmus bernardii G. Smith	3975	1
Scenedesmus bijuga (Turpin) Lagerheim	115498	125
Scenedesmus dimorphus (Turpin) Kutzing	88355	4
Scenedesmus hystrix Lagerheim	3407	1
Scenedesmus quadricauda (Turpin) Brebisson	253633	431
Scenedesmus sp.	6558	9
Staurastrum grande Bulnheim	7098	21
Staurastrum sp.	3159	15
Tetraedron lobulatum (Naegeli) Hansgirg	284	3
Tetraedron minimum (Braun) Hansgirg	10008	20
Tetraedron muticum (Braun) Hansgirg	284	1
Tetraedron regulare Kutzing	1519	28
Tetraedron sp.	5728	8
CRYPTOPHYCEAE		
Chroomonas sp.	8979	2
Cryptomonas sp.	394197	253
Cryptomonas sp. 2	44767	12
Hemiselmis sp.	132283	2

Species	Cell Concentration	Cell Volume
XANTHOPHYCEAE		
Nephrochloris salina Carter	9029	1
Nephrochloris sp.	710	0
Olisthodiscus sp.	1363	0
CHRYSOPHYCEAE		
Calycomonas wulffii Conrad & Kufferath	355	0
Mallomonas sp.	270	0
Ochromonas sp.	81527	7628
CHRYSOPHYCEAE: SILICOFLAGELLATES		
Dictyocha fibula Ehrenberg	270	2
Distephanus speculum (Ehrenberg) Haekel	41253	314
PRASINOPHYCEAE		
Pyramimonas sp.	3748	0
Tetraselmis sp.	4827	1
OTHER TAXA		
Micro-phytoflagellates (Unid.) <10 Microns	11186	0
Micro-phytoflagellates (Unid.) >10 Microns	72300	10
Green cells (1.5-3 microns)	61664095	123
Green cells (3-5 microns)	6505887	221

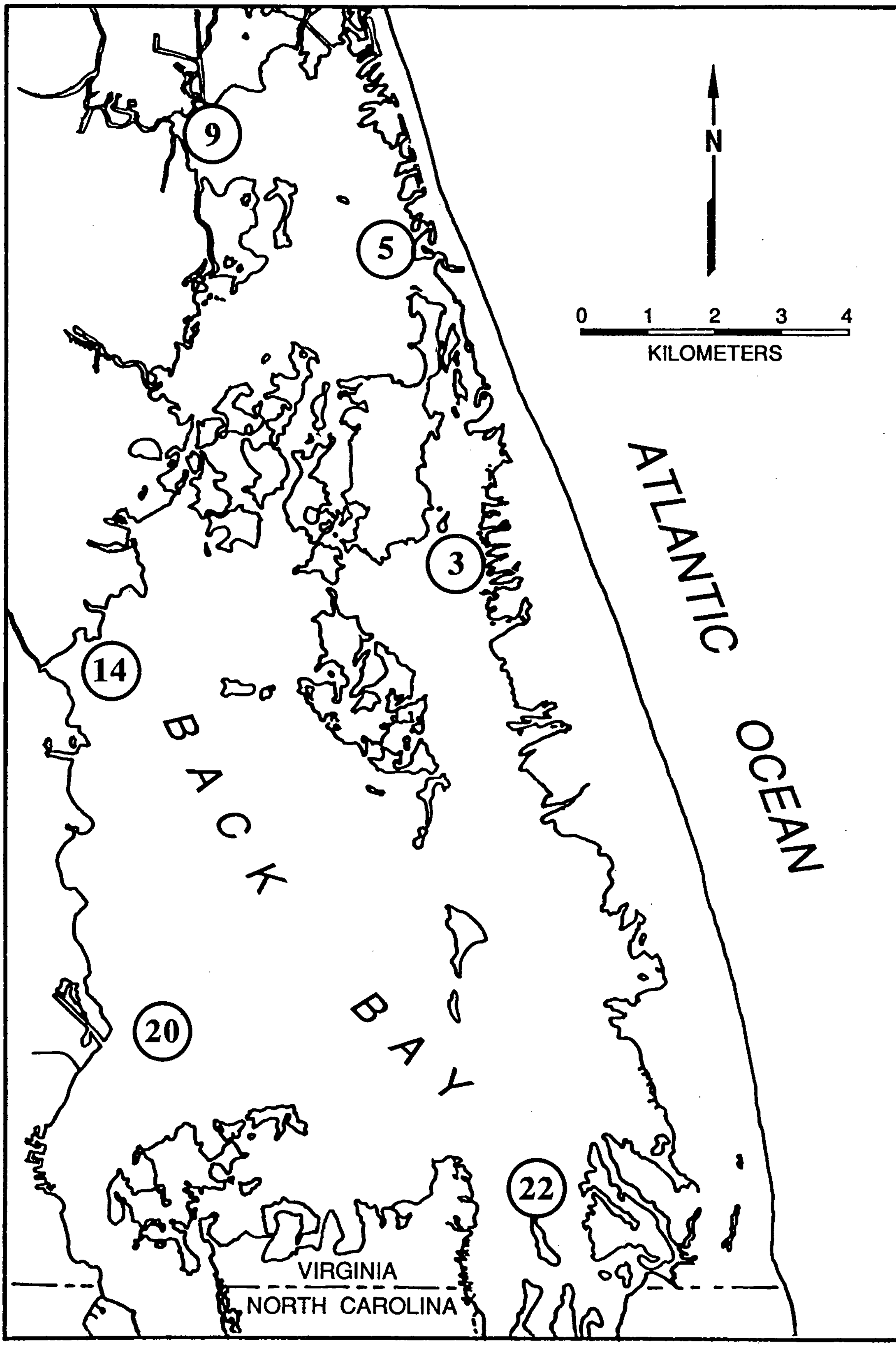

Figure 1. Station locations in the Back Bay collection area.

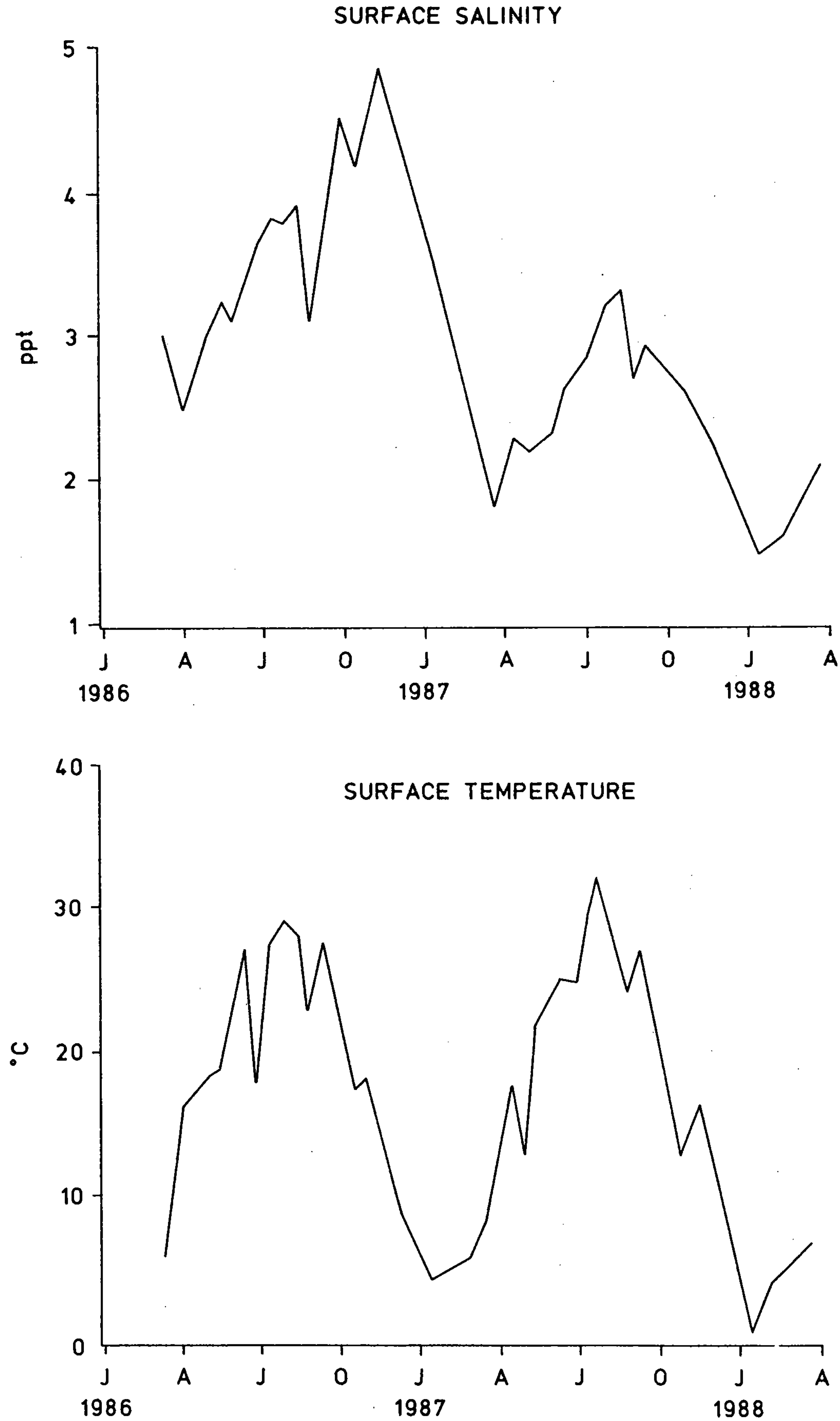

Figure 2. Mean surface salinity and temperature records from all stations in the Back Bay collections from February 1986 through March 1988.

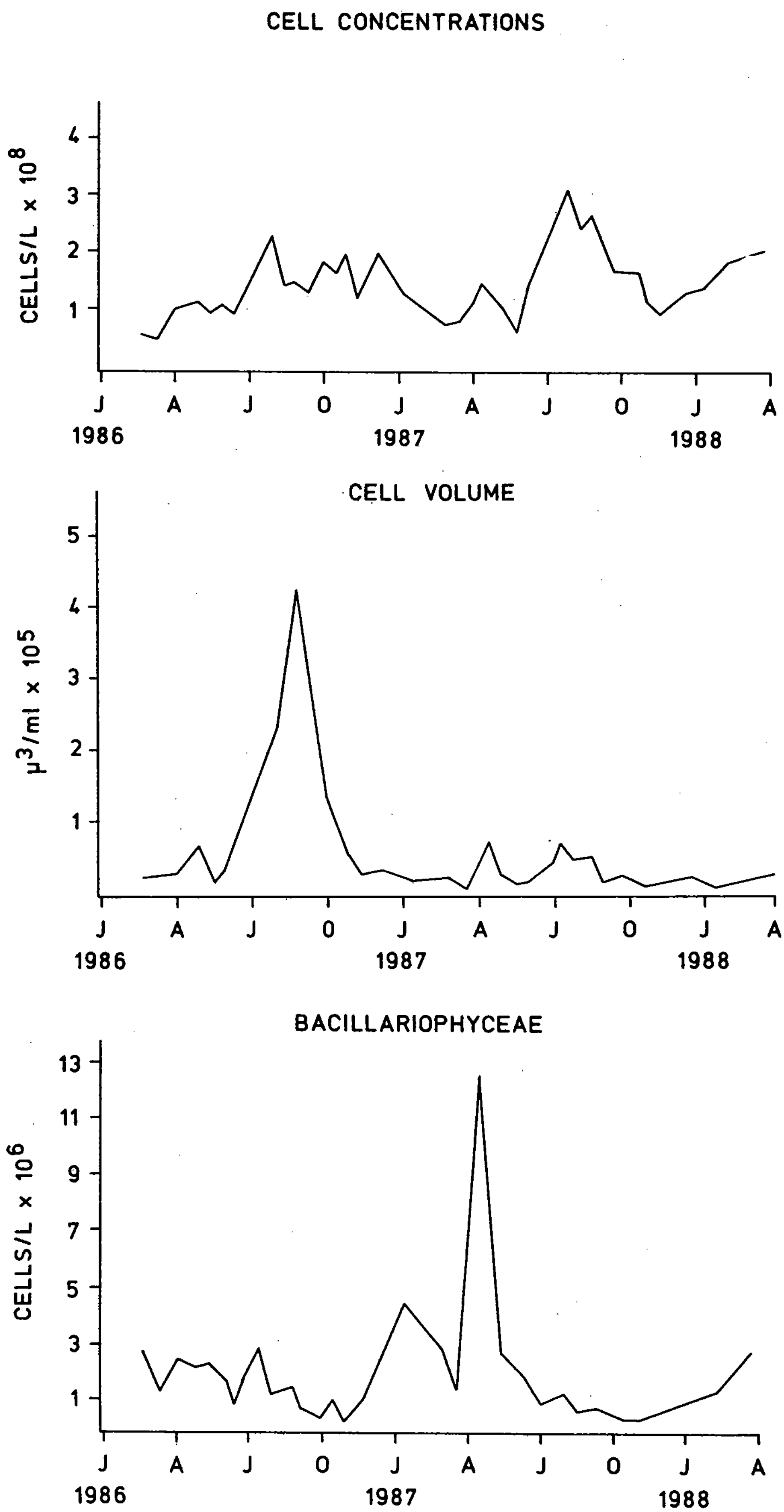

Figure 3. Mean values for total cell concentrations, total cell volume and concentrations of diatoms (Bacillariophyceae) from all stations in the Back Bay collections from Feburary 1986 through March 1988.

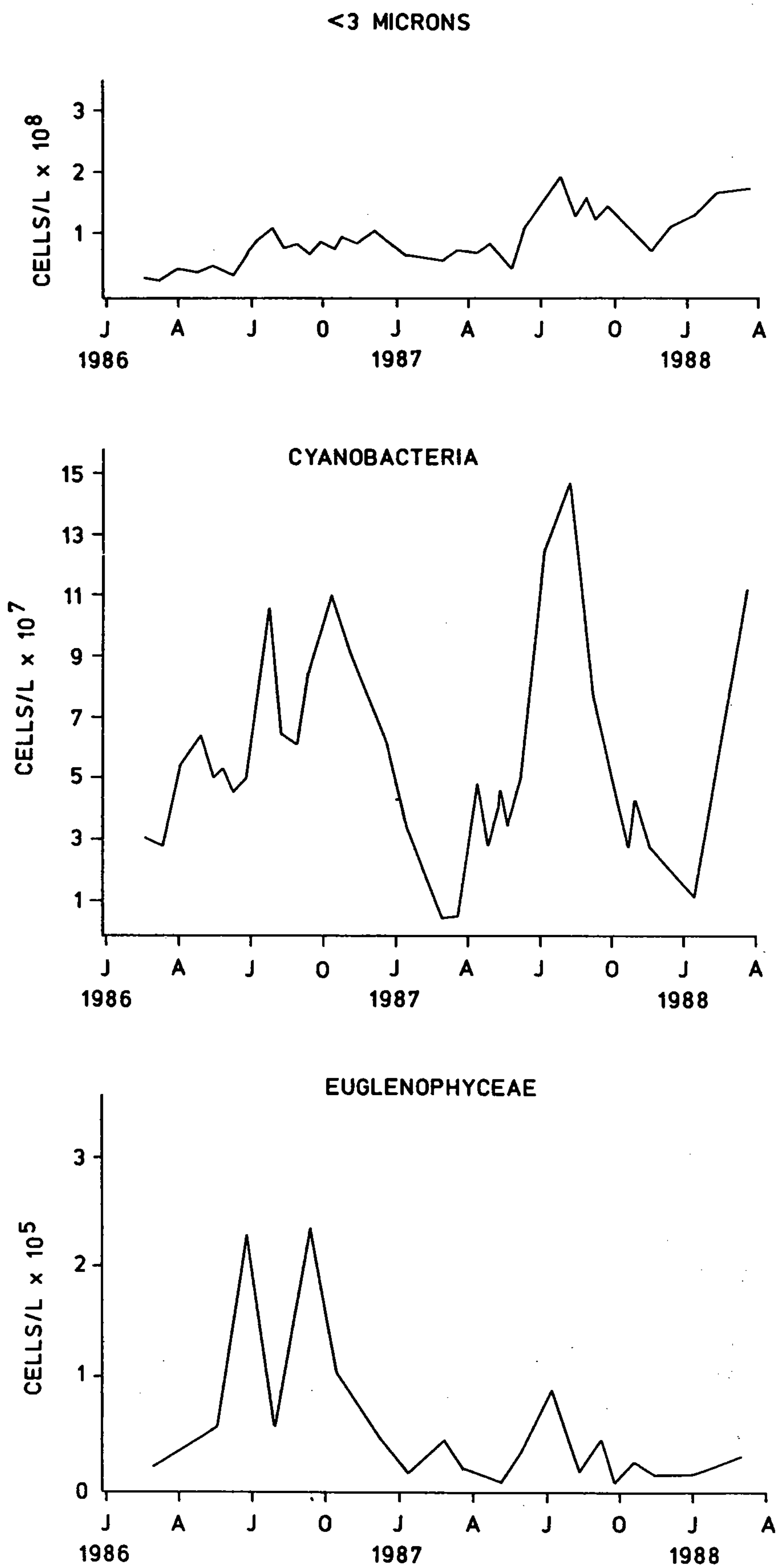

Figure 4. Mean cell concentrations for pico-nanoplankton cells less than 3 microns, cyanobacteria and euglenophyceans from all stations in the Back Bay collections from Feburary 1986 through March 1988.

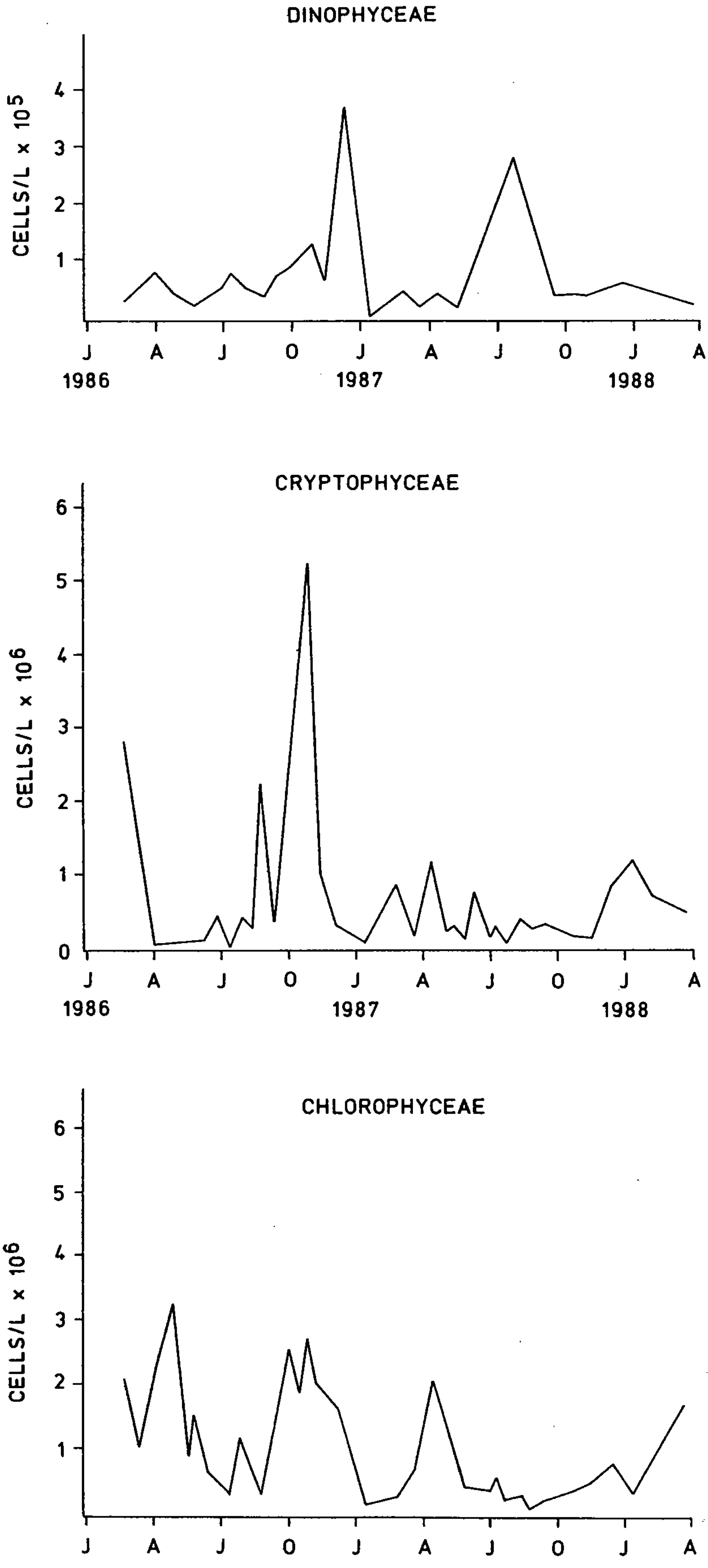

Figure 5. Mean cell concentrations for dinophyceans, cryptophyceans and chlorophyceans from all stations in the Back Bay collections from Feburary 1986 through March 1988.

The Phytogeographical Significance of Some Rare Plants at Back Bay

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Abstract: The Back Bay region has long been recognized for its many species which reach either their northern or southern limits there. The eminent Harvard botanist M.L. Fernald collected extensively in the Back Bay region during the late 1930's and early 1940's. He postulated the Back Bay area provided a unique opportunity for the migration of fresh and brackish water species through a series of interconnected or neighboring marshes and pools. His collections document the presence of several species which we now consider extirpated.

Of especial interest are genera with vicarious species pairs, that is, one area of overlap between wide-ranging species and southern species is at Back Bay. We present information on two such pairs: *Lilaeopsis carolinensis* (southern) and *Lilaeopsis chinensis* (wide-ranging); and *Lippia nodiflora* (southern) and *Lippia lanceolata* (wide-ranging). In addition we discuss species which reach their northern or southern limits at Back Bay. Examples include: *Limosella subulata* (Scrophulariaceae), a northern species which apparently has been extirpated, and *Juncus megacephalus* (Juncaceae), an endemic of the southeastern United States which is abundan near its northern limit at Back Bay.

Introduction

In 1856 the range of the second edition of *Gray's Manual of Botany* was extended to include all of Virginia (Fernald, 1950). This seemingly trivial event led to some of the most intense botanical exploration of the state by the irrepressible Harvard botanist, Merritt Lyndon Fernald.

The majority of Fernald's fieldwork in Virginia was focused on the coastal plain of the southeastern portion of the state. The flora of this botanically rich and interesting area was described by Fernald (1937) as follows:

> ...the species making up the indigenous flora of the coastal plain in southeastern Virginia are by no means of uniform occurrence. Many are almost ubiquitous types.... The majority, however, are restricted in occurrence, their restrictions varying from local abundance in one or few small areas to single tiny colonies or individuals. In other words, a considerable proportion of the flora has the characteristics of either a relic-flora, left over but not dominating in an area from which it has largely been destroyed, or a pioneering flora which has not succeeded in competition with more aggressive and dominating species.

The botanical uniqueness of the area is further supported by the fact that the City of Virginia Beach (formerly Princess Anne County) has 15 plant species which are found nowhere else in the state (Harvill et al, 1986). This is the highest number of species known from only one county in Virginia, the second highest being nine, from Lee County. Of the 15 species known in Virginia only from the City of Virginia Beach, at least six of these are currently found, or were historically collected from Back Bay: *Eleocharis radicans* (Poiret Kunth., *Lilaeopsis carolinensis* C. & R., *Arenaria lanuginosa* (Michx.) Rohrback, *Limosella subulata* Ives, *Physalis viscosa* L., and *Lippia nodiflora* (L. Michaux.

This paper discusses some general geographic patterns and the significance of some rare plants of Back Bay.

Materials and Methods

This paper heavily relies on the work of Fernald (1937 and 1940) as it applies to the Back Bay region. The phytogeographical history of the Atlantic coastal plain follows the recent work by Delcourt and Delcourt (1981; 1986). The present status of many of these uncommon plants stems from a current inventory of the Back Bay region by the second author (Wright, these proceedings)

Study Area

Back Bay is located in the southeastern corner of the City of Virginia Beach. For the purposes of this paper, the "Back Bay region" refers to the maximum Back Bay land acquisition boundary recently proposed by the U.S. Fish and Wildlife Service (U.S. Department of the Interior USF&WS, 1989). This same report gives a helpful summary of the climate, geology, topography and soils of the region.

Regional Phytogeographical Patterns

Recent studies on the flora of southeastern Virginia's coastal plain have emphasized that it is a region where many boreal and austral plant species are at the extreme limits of their ranges (Frost and Musselman, 1987; Wright et al, 1990). This same pattern holds true for the Back Bay region, and was recognized by Fernald over 50 years ago (Fernald, 1937). Table 1 lists some rare plants of Back Bay which can be generally classified as northern or southern elements.

Because of the number of novelties found in the Back Bay region and the unique environmental conditions, Fernald had a keen interest in the phytogeography of Back Bay. He stated that the more characteristic Back Bay plants are

> ...intolerant of much salinity in the waters and confine themselves to the fresh to but slightly brackish reaches of streams, pools, and inlets. This group is, then, of peculiar interest, since the plants have apparently mostly attained their present habitats and extreme isolation in the past, at periods when they could migrate from river to river along fresh or brackish (not strongly saline) shores. (Fernald, 1940)

One of these fresh to brackish tidal plants of northern distribution is *Limosella subulata*. Figure 1 shows the range of this species (adapted from Pennell, 1935). It was historically reported from the Back Bay region (Fernald, 1935), however, recent attempts to locate it by the authors have been fruitless. Increased water turbidity may be to blame, for Fernald (1940) states the "water of shallow Back Bay was so very clear that we could see the white sandy bottom only a few feet below, except where *Potamogeton bupleuroides*, *Vallisneria americana* and other aquatics made solid growth." Any recent visitor to Back Bay knows that Fernald's (1940) description of the water quality is sorely dated (see Norman and Southwick, these proceedings).

Juncus megacephalus is an endemic rush of fresh to brackish estuaries of the southeastern United States (see Figure 2) and is found near its northernmost limit at Back Bay (Fernald, 1940; Harvill et al, 1986). Fernald (1940) often cited this species in his discussions of the flora of fresh tidal estuaries and shores. He described it as

> ...not a plant of the saline outer coast but rather of the fresh to barely brackish inner margin of the coast, sometimes in fresh inland habitats. With great stretches of fresh to slightly brackish inner shore, now extending from below Cape Henry to Cape Fear and, formerly, doubtless more continuously to Florida, it has been able to follow more or less without interruption its most favorable habitats; but it does not follow north along the saline outer coast. (Fernald, 1940)

The genus *Lilaeopsis* is represented at Back Bay by two species: *Lilaeopsis chinensis* and *L. carolinensis*. *Lilaeopsis chinensis* is found all along the Atlantic coast of North America, and at Back Bay is often associated with *Spartina cynosuroides* on firm, exposed mud. *Lilaeopsis carolinensis*, however, "has its chief center on the lower reaches of La Plata River in temperate eastern South America, but with four remote stations known in North America: near New Orleans; shallow water near Mrytle Beach, South Carolina; an unidentified station (presumably near Wilmington), North Carolina; and this pond on Long Island [Back Bay]" (Fernald, 1940; see Figure 3). Since Fernald's time, more stations for *L. carolinensis* have been found along the Gulf and Atlantic coastal plains between New Orleans and Back Bay (Ludwig, personal communication). Unlike *L. chinensis*, *L. carolinensis* is found in more protected coves on unconsolidated peat flats often in association with *Triglochin striata*.

Lippia is another genus which is represented at Back Bay by two species: *Lippia lanceolata* and *Lippia nodiflora*. The former species is known from Florida to southern California, north to southern New Jersey and the Great Lakes region. The latter is known from Florida to Texas and north to southeastern Virginia (Fernald, 1950). As stated before, in Virginia *Lippia nodiflora* is known only from the City of Virginia Beach (Harvill et al, 1986).

Although there does seem to be a convergence of northern and southern elements at Back Bay, this is an oversimplification of the phytogeographical patterns for the coastal plain of southeastern Virginia. Fernald (1937) gives a more detailed discussion based on his extensive fieldwork and divides the flora into seven general phytogeographical categories.

Fernald hypothesized that the predominance of pan-tropical and warm-temperate species at Back Bay was a result of a "very ancient dispersal." Recent paleobotanical work, however, indicates that during the Wisconsonian glaciation (mid-Pleistocene epoch), Virginia was dominated by boreal vegetation (Delcourt and Delcourt, 1981; Delcourt and Delcourt, 1986). This condition existed until the early Holocene when the Laurentide ice sheet retreated north out of the Great Lakes basin. The accompanying rise in temperature, sea-level, and other geomorphic changes led to the migration of warm-temperate taxa north, and the retreat of boreal taxa northward and to the higher elevations of Virginia (Delcourt and Delcourt, 1981; Delcourt and Delcourt, 1986; Woodward and Ruska, 1986). If this were the case, then perhaps the North American stations of *Lilaeopsis carolinensis* represent a relatively recent migration.

It should not be inferred, however, that the northern and southern elements found at Back Bay migrated as two distinct groups. The individual species of any flora surely differ in their rates of dispersal, temperature limitations, salinity tolerance, etc.

Of the factors which affect the range of a species, climate is considered to be of chief importance because it not only imposes physiological limitations on plants, but also influences soil development (Good, 1964). It is more than mere coincidence that many of the austral Back Bay species have ranges which closely parallel the mean minimum annual temperature zones as mapped by Cathey (1990). For example, the range of *Lippia nodiflora* closely matches the southeastern portion of zone 8 which has a mean annual minimum temperature of 10-20 F (see Figure 4).

Phytogeographical Significance

Whether the rare plants of Back Bay are representatives of a relic distribution or are the result of recent migration is still subject to debate. This should not, however, detract from the significance of the Back Bay region being the extreme limit (either north or south) of many rare plants' range. Mayr (1963) states that

> The most distinct isolates of a species are nearly always situated along the periphery of the species range. ...They are almost invariably a source of disagreement among taxonomists, some of whom consider them 'still' subspecies, others 'already' species.

The variability of Back Bay's vegetation is nicely documented in the writings of Fernald (1935; 1937; 1940; 1941; 1950). His knowledge of the flora and keen powers of observation led to the addition of many subspecies and varieties considered "new to Virginia."

Many of the species listed in Table 1 are not considered rare throughout their ranges (eg. *Cladium jamaicense*). These plants are given special consideration in Virginia because they are uncommon in the state. The presence of these species, in addition to the true rarities, make the vegetation of the Back Bay region a unique component of the state flora (Harvill et al, 1986; Ludwig et al, these proceedings).

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Table 1: Some Rare Plants of Back Bay

Rare Back Bay Plants with Northern Affinities

Sparganium androcladium (Engelm.) Morong
Potamogeton perfoliatus var *bupleuroides* (Fernald) Farwell
Cyperus engelmanii Steud.
Eleocharis halophila Fernald & Brack.
Limosella subulata Ives

Rare Back Bay Plants with Southern Affinities

Lycopodium appressum (Chapm.) Lloyd & Underw.
Bulbostylis ciliatifolia (Ell.) Clark
Cladium jamaicense Crantz
Cyperus haspan L.
Dichromena colorata (L.) Hitchcock
Tillandsia usneoides L.
Juncus abortivus Chapman
Juncus megacephalus M.A. Curtis
Calopogon pallidus Chapman
Quercus incana Bartram
Arenaria lanuginosa (Michx.) Rohrback
Paronychia riparia Chapman
Lilaeopsis carolinensis C.& R.
Sabatia brachiata Ell.
Lippia nodiflora (L.) Michaux
Verbena scabra Vahl
Physalis viscosa ssp. *maritima* (M.A. Curtis) Waterfall
Bacopa monnieri (L.) Pennell
Aster racemosus Ell.
Erigeron vernus (1.) T.& G.
Heterotheca gossypina (Michx.) Shinners
Iva imbricata Walter

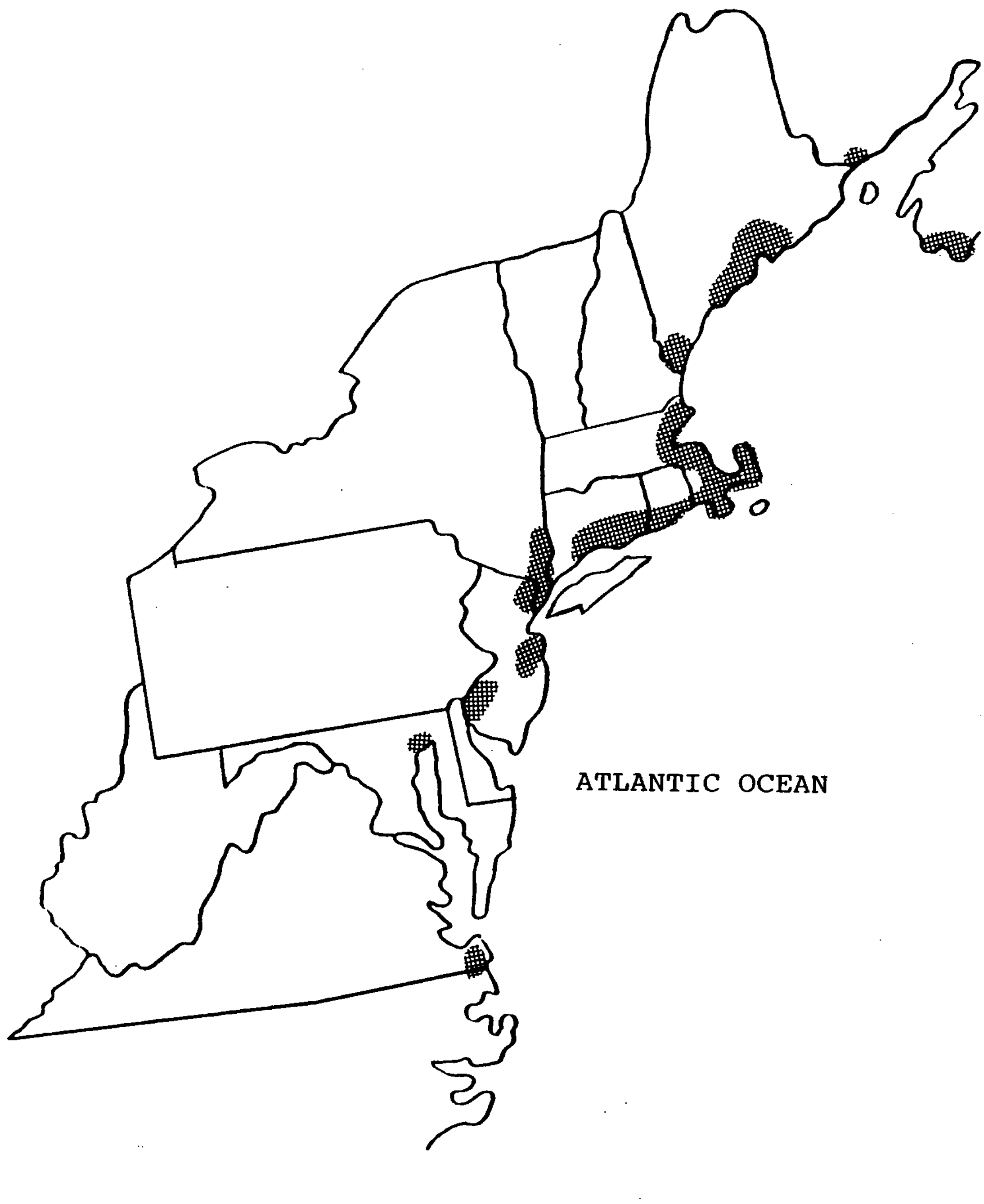

Figure 1. Range of *Limosella subulata* (Pennell, 1935)

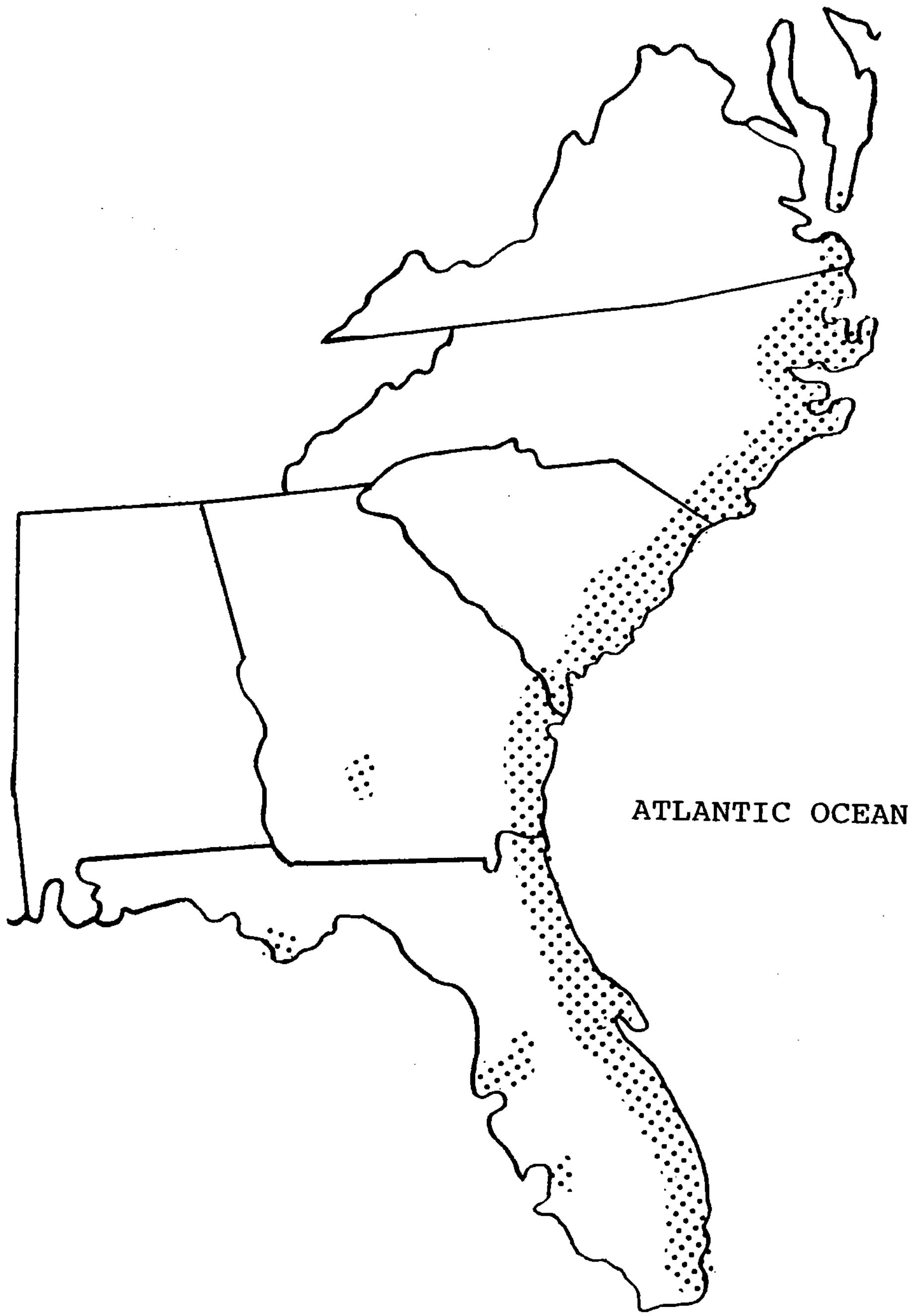

Figure 2. Range of *Juncus megacephalus* (Fernald, 1940)

Figure 3. Range of *Lilaeopsis carolinensis* (Fernald, 1940)

The Marshes of Back Bay, Virginia

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Abstract: An inventory was undertaken to determine the type and extent of the emergent tidal wetlands in Back Bay, which, historically, has ranged from a lunar tidal brackish estuary to a wind tidal freshwater system. The inventory was conducted primarily by boat with visual observations made for each marsh. The configuration and areal extent of each marsh was determined from USGS topographic maps and confirmed with aerial photography where necessary. Approximately 9925 acres of wetlands as defined by the Commonwealth of Virginia were identified within the watershed. These wetlands supported a very diverse flora consisting of over 109 species.

The five dominant species accounted for almost 75% of the wetland acreage. They included: cattails, *Typha* spp., (4004 acres), needlerush, *Juncus roemerianus,* (2371 acres), big cordgrass, *Spartina cynosuroides,* (605 acres), saltmeadow hay, *Spartina patens,* (449 acres) and switchgrass *Panicum virgatum,* (427 acres). The remainder of the species represented a diverse mixture of brackish plants with a significant component of freshwater species.

The emergent tidal wetlands are dominated by plants typically indicative of brackish conditions even though the system now tends toward freshwater conditions under normal circumstances. These brackish species are probably relicts from when Back Bay was directly influenced by the salinity and tides afforded by inlets to the ocean. The brackish communities because of their continued dominance appear to be more adaptable to the periods of freshwater than the freshwater species are to periods of brackish conditions. These historical oscillations between brackish and fresh conditions are probably responsible for much of the plant diversity found. These plant communities are not static either, as evidenced by changes in the coverage of common reed, *Phragmites australis,* which has increased substantially between this inventory done in 1977 and recent (1990) observations.

Introduction

Back Bay has long been a significant aquatic resource in southeastern Virginia. Its vast expanses of emergent wetlands, beds of submerged aquatic vegetation and open water have provided excellent habitat for finfish, shellfish, waterfowl and furbearers. Despite their contribution to the resource value of Back Bay, the emergent tidal wetlands have received comparatively little scientific attention. Among the early works are a number of papers on the phytogeograghy of the plants of the region, including wetland species, which are summarized in Fernald (1940). He found the Back Bay region to be unique in that it represents the northern range limit for many southern plants and the southern limit for a number of northern species.

During the Back Bay-Currituck Sound Cooperative Study (Sincock et al., 1965), a generalized cover map of the Back Bay wetlands was prepared from aerial reconnaissance and photograph interpretation. The dominant species reported included: needlerush, *Juncus roemerianus,* big cordgrass, *Spartina cynosuroides,* cattails, *Typha* spp., wax myrtle, *Myrica* spp., saltgrass, *Distichlis spicata* and a heterogeneous marsh of mixed cattail, *Typha* spp., three-squares, *Scirpus* spp., spikerushes, *Eleocharis* spp., marsh hibiscus, *Hibiscus moscheutos* and smartweeds, *Polygonum* spp.

Sincock et al. (1965) also noted a community succession following disturbance by fire or grazing by geese. Initial dominants were *Cyperus* spp., spikerush, *Eleocharis palustris* and smartweeds, *Polygonum* spp. and were followed by three-squares, *Scirpus olneyi, S. americanus, S. robustus* and *S. validus.* The climax dominants were reported to be cattails, *Typha* spp. and marsh hibiscus, *Hibiscus moscheutos.*

A review of the wetland vegetation in Back Bay and Currituck Sound by Silberhorn (1977) indicated similar community compositions. He also noted as important aspects of plant community succession, the role of oceanic overwashes, changes in salinity and the effects of man.

According to Roy Mann Associates (1984) approximately 22% of the Back Bay watershed was wetlands. Emergent wetland vegetation comprised 11,351 acres or 17% of the watershed. Lowland forest with 2,357 acres and scrub/shrub wetlands with 749 acres made up 4% and

1%, respectively, of the watershed. Much of the emergent vegetation was characterized by relatively homogeneous stands of cattails, *Typha* spp., and needlerush, *Juncus roemerianus*.

The purpose of this inventory was to document the type and areal extent of the tidal wetlands found in Back Bay as defined by the Virginia Wetlands Act. The vegetated wetlands of Back Bay and its tributaries are defined by the Code of Virginia (Chapter 2.1, Section 62.1-13.2(f)) to include:

> "...all marshes subject to flooding by tides including wind tides, provided this shall not include hurricane or tropical storm tides, and upon which one or more of the following vegetation species are growing..." (25 species are listed in the Wetlands Act).

Physical Setting

Back Bay is a barrier spit lagoon isolated from the Atlantic Ocean by Sandbridge and False Cape (Fig. 1). Geologically, the bay and its watershed are part of the sand-ridge and mud-flat complex that consists of a number of roughly parallel sand ridges with intervening areas that were low lying mud flats (Oaks and Coch, 1973). The ridges from west to east include: Pungo Ridge, Dawley Corners Ridge, Charity Neck Ridge and Knotts Island Ridge (Fig. 2). Portions of the Knotts Island Ridge appear as the upland portions of Little Cedar, Cedar, Ragged and Long islands. Much of the emergent wetlands surveyed in this inventory have apparently developed on the lower elevation lagoonal deposits in between these old beach ridges.

The closest direct link of Back Bay to the Atlantic Ocean is now Oregon Inlet, NC, aproximately 60 miles to the south. Historically, though, there have been several inlets along the barrier spit that provided more direct access to the ocean and lunar tides (Fig. 1). Remnants of the flood tide deltas formed by these old inlets are evident in a number of locations along the barrier spit, particularly the Big Bull Island, Horse Island, Deal Creek complex along the North Carolina line. This was the location of the Old Currituck Inlet, which opened around 1650 and closed around 1729 (Hennigar, 1977). Back Bay also received periodic influxes of seawater during washovers prior to the stablization and enhancement of the sand dunes along the barrier spit during the 1930s. Since then overwashes have become more infrequent. The last major overwash occurred in 1962 during the Ash Wednesday storm.

The only other major source of salinity in Back Bay was the Albemarle and Chesapeake Canal that connected the Elizabeth River to the North Landing River. Locks were originally installed on the canal but were left open from 1918 to 1932. During this time the average salinity in lower Back Bay ranged from 2.2 to 2.7 parts per thousand (ppt) (Bourn, 1929).

Seawater began to be pumped from the ocean into Back Bay in 1965 in an effort to improve water quality by helping precipitate suspended silts and clays. It continued until 1974; during which time the salinity was generally less than 3.5 ppt (Norman and Southwick, 1978). Pumping was resumed in 1979 and was formally discontinued in 1986. Salinity during this period was generally greater than 3.5 ppt (Norman and Southwick, 1987). During the hiatus between pumpings from 1974-1979 the salinity in Back Bay was generally less than 1 ppt (Norman and Southwick, 1987). This inventory was conducted in 1977 during the period of freshwater conditions. Since the cessation of pumping the salinity of Back Bay has returned to approximately 1 ppt (Southwick, personal communication).

The existing situation, with the closest oceanic inlet being very remote, virtually eliminates any influence of astronomical tides on water levels in Back Bay (Roy Mann Assoc., 1984). Water level fluctuations are primarily attributable to wind tides. High water levels with a low average tide range usually occur during summer months with the predominantly south and southwest winds. During winter, water levels are generally low with a high average range because of the dominant northerly winds (Roy Mann Associates, 1984). The average water level at the Back Bay National Wildlife Refuge is 1.0 feet above mean sea level (MSL) with a maximum range in tides from -2.0 feet to 3.0 feet MSL during the period 1977 to 1983 (Roy Mann Associates, 1984).

Methods

Wetland locations and wetland boundaries were obtained by consulting USGS topographic maps and aerial photographs. The configuration and areal extent of each marsh was confirmed by observations by boat, on foot or by low level overflights. Individual plant species percentages are quantitative estimates of coverage based on visual inspections of every marsh. The field work was performed during the months of August, September and October, 1977.

In the inventory (Priest and Dewing, 1989), the outline of each marsh as depicted on the topographic map was planimetered to determine its acreage. Marshes 0.25 acres or larger are designated by number. The acreage, plant species percentage and respective acreage, marsh type and other observations are recorded in tabular form for each of these marshes. These tables are not being included in this report; so therefore these marsh numbers have been deleted from the maps in this report for the sake of clarity. Marshes less than 0.25 acres (usually narrow fringing marshes and very small pocket marshes) are indicated by the same shaded symbol as the numbered marshes but are not included in the tabulations for the total acreage.

Areas surveyed included all emergent herbaceous vegetation including adjacent scrub, shrub communities where appropriate. This inventory generally does not include areas of swamp forest because of the difficulty in determining whether these areas met the requirement for periodic inundation contained within the Wetlands Act. This determination is made when necessary on a case-by-case basis when jurisdiction is in question on a particular project. Given the appropriate elevation and vegetation, which are present in many instances, many of these swamp forests would be covered under the Wetlands Act, greatly increasing the acreage of tidal wetlands in Back Bay.

Results

The 1977 inventory identified 9925 acres of emergent tidal wetlands as defined by the State of Virginia. These wetlands supported over 109 species of wetlands plants (Table 1). The dominant species were cattails with 4004 acres (40.3%) and needlerush with 2371 acres (23.9%). The balance of the tidal wetlands was vegetated by a variety of other species (Table 2). The marshes inventoried were divided into five sections along institutional boundaries where possible (Fig. 3).

The wetlands in Section I are contained within False Cape State Park and The Barbours Hill Wildlife Management Area (WMA) (Figs. 4 and 5). They were dominated by black needlerush (492 acres) and cattails (324 acres) with a total area of 1188 acres.

The majority of the wetlands in this section are large marshes that have developed on the landward side of the barrier spit. The marshes in the southern portion of this section have developed on the relicts of the flood tide delta of the Old Currituck Inlet. The remainder have developed as broad fringing marshes on old overwash and inlet features.

Included within this section are 129 acres of impoundments on Barbours Hill WMA, which are managed for moist soil emergent vegetation during spring and summer and flooded during fall and winter for migratory waterfowl.

Section II includes those wetlands included within the boundaries of the Back Bay National Wildlife Refuge (Figs. 6, 7, 8 and 9). They include approximately 3000 acres of marsh that extends from the barrier spit below Sandbridge across Back Bay to the mainland. These wetlands are dominated by cattails, 988 acres; and black needlerush, 699 acres; with large areas of big cordgrass (213 acres) and saltmeadow grasses (241 acres).

Along the barrier spit are approximately 512 acres of moist soil impoundments that have been developed on the old overwash flats. They are drained in spring to encourage emergent vegetation and flooded in fall to provide enhanced wintering habitat for migratory waterfowl. Along the shoreline adjacent to the impoundments are a number of broad fringing marshes that have developed around the extremities of these old overwashes.

The majority of the rest of the marshes in this section, the Long Island and Ragged Island complexes, have developed on a geological formation known as the Sandridge-mudflat complex. It is composed of a series of relict beach ridges interspaced with lower lagoonal or mudflat deposits that formed during recent oscillations in sea level. The upland portion of Long Island as well as Cedar and Little Cedar Islands in Section I are part of the Knotts Island Ridge that once extended up to the vicinity of Sandbridge. In many instances these lagoonal deposits were comparatively low in elevation and supported very diverse wetland floras.

Populations of *Lilaeopsis carolinensis*, a plant species ranked as extremely rare in the state and recommended for threatened status, were observed in several marshes in this section (Virginia Natural Heritage Program, 1990).

Section III extends from the Back Bay National Wildlife Refuge north to roughly the head of the Back Bay watershed (Figs. 10, 11 and 12). It includes the marshes along the developed portion of the barrier spit, the large embayed marshes of North Bay and the more isolated wetlands of the headwaters. There are almost 1500 acres of marsh in this section that are, again, dominated by cattails, 545 acres, and black needlerush, 249 acres. Smartweeds (119 acres), spikerush (97 acres) and big cordgrass (90 acres) also contribute significant areas to the acreage.

The wetlands along the bayside of Sandbridge have been severely impacted and diminished by extensive dredging and filling for the canal developments. North and west of Sandbridge are several somewhat isolated wetlands and water bodies including Black Gut, Lake Tecumseh, Redwing Lake and Lovetts Marsh. They are relicts of the Sandridge-mudflat complex and are hydrologically connected to Back Bay through a complex system of drainage ditches and the channelized Hell Point Creek.

The western shore marshes of Section IV are composed of the extensive marshes of the western bayshore as well as those of the major tributary streams, Asheville Bridge/Muddy Creek, Beggars Bridge Creek and Nawney Creek (Figs. 13, 14, 15 and 16). There are approximately

2848 acres of marsh in this section dominated by cattails, 1420 acres, and black needlerush, 793 acres, with substantial areas of big cordgrass (148 acres) and Olney threesquare (106 acres). Many of these marshes are floristically complex, supporting as many as 28 different species in a relatively small area of habitat.

The marshes of the Trojan Waterfowl Management Area maintained by the Virginia Department of Game and Inland Fisheries are included in this section.

The final section, Section V, includes marshes from several different areas (Figs. 17 and 18). The first part contains the last 166 acres of the western bayshore marshes; portions of which have been impacted by dredging and filling in the past. Typically, these marshes are dominated by cattails, black needlerush and big cordgrass.

Offshore is the Pocahontas Waterfowl Area, which is managed as a public waterfowl hunting area by the Virginia Department of Game and Inland Fisheries. It consists of a number of marsh islands totalling over 500 acres. The vegetation is dominated by cattails and switchgrass.

Immediately adjacent to the Pocahontas Waterfowl Area is the Virginia portion of the Mackay Island National Wildlife Refuge. The majority of the Refuge is located across the border in North Carolina. The Virginia portion consists of a number of marsh islands, some supporting stands of trees, and a large section of marsh west of Knotts Island. The area encompassed 724 acres of predominately cattail and black needlerush with a large number of associated species.

The total marsh area for this section is approximately 1442 acres. Cattails, 727 acres, and switchgrass, 345 acres, dominated the cover with sizeable complements of black needlerush (137 acres) and big cordgrass (85 acres).

Discussion

Since no methodology was provided by Roy Mann Associates (1984), a comparison of the 11,351 acres of emergent wetlands found by that study and the 9925 acres for this inventory is not possible. The difference, however, is probably attributable to differences in wetlands definitions and interpretations. This may be particularly true with respect to some transitional areas between the scrub/shrub and swamp communities, which were not included because of the difficulty in determining whether the periodic inundation criterion of the Wetlands Act was being met. In those instances where both the vegetation requirement and inundation periodicity were met these areas would be wetlands and increase the area of tidal wetlands present in Back Bay. In general, the inventory represents a reasonably conservative interpretation of wetlands, identifying only those clearly meeting the definition in the Wetlands Act.

The USGS topograghic maps used as the base maps for this inventory were prepared in the early 1950s and photo revised in 1970 and 1971. As a consequence, there are a number of physiograghic and cultural changes that have occurred, e. g. considerable shoreline erosion has occurred in many places reducing the existing areas of wetlands including several small marsh islands that have completely eroded away. Additionally, several areas have been filled by dredge and fill operations, further reducing existing wetland acreage.

Species percent cover estimates can be subject to a seasonal bias depending on what time of year the estimates are made. In brackish water marshes if the observations are made in spring many of the late developing annuals, e.g. water hemp, saltmarsh aster, marsh fleabane and orach, are not visible among the earlier developing grasses. In freshwater marshes, spring and early summer dominants, arrow arum, pickerelweed and cattails are often replaced by other dominants like beggars ticks and rice cutgrass during late summer and early fall. Back Bay was particularly well suited to the late summer and early fall time of this inventory because there was a relatively small amount of the early developing freshwater species and there was a sufficient amount of the early grasses remaining to obtain accurate estimates of their cover. There was also a large number of late developing species that were included in this inventory that would have been missed if it had been done during spring and early summer.

The dominant species in the emergent wetlands of Back Bay, cattail, *Typha angustifolia*, needlerush, *Juncus roemerianus*, and big cordgrass, *Spartina cynosuroides* are typically found in brackish marshes (Beal, 1977). These species are probably relicts from when Back Bay was directly influenced by the salinity and tides afforded by inlets to the ocean. The clear dominance of plants typically adapted to brackish conditions appears to indicate they are more suited to the varying salinity regimes of Back Bay than those more typical strictly freshwater systems. An example of this is the disappearance of the American lotus, *Nelumbo lutea*, from the Asheville Bridge Creek/Muddy Creek complex soon after the resumption of seawater pumping.

Another major change in the vegetation of the wetlands of Back Bay is a continuing one involving the dramatic spread of the common reed, *Phragmites australis*. During the period of the inventory the estimated percent cover of this species was 0.9 percent. Observations made during low level overflights in 1990 would indicate a rough estimate of average percent cover at up to 10 percent. The reasons for this spread are not clear. One plausible explanation would be that the large scale dredging and filling projects that occurred during the 1960s and early 1970s provided a sufficient disturbance of the natural flora that common reed had the opportunity to become firmly established. It has since been able to continue spreading by virtue of its aggressive growth habits that allow it to outcompete the native flora.

Summary

An inventory of the tidal wetlands of Back Bay in Virginia Beach, Virginia found a total of 9925 acres that support over 109 species of wetlands vegetation.

The inventory was influenced by two factors that affected the acreage estimates. Some areas were probably underestimated because of the uncertainty of whether the inundation criteria required by the state was being met. Other areas were overestimated because the topographic maps used as the base maps did not accurately reflect changes in marsh areas resulting from shoreline erosion.

The dominant species were typically representative of brackish water conditions. However, there were a large number of freshwater species that were present in smaller numbers.

The inventory was conducted during a period of freshwater dominance in the system that was sandwiched between two periods of brackish conditions occasioned by the pumping of seawater from the Atlantic Ocean.

The common reed, on recent observations appears to be spreading dramatically, increasing its cover from approximately 1 percent to 5-10 percent.

Acknowledgements

I would like to thank Gene Silberhorn and Tom Barnard for their review and comments on this paper.

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Table 1. Marsh Plants (common names and scientific names as found in the data tables of this report).

American Lotus	*Nelumbo lutea* (Willd.) Persoon
Ammannia	*Ammannia teres* Raf.
Arrow Arum	*Peltandra virginica* (L.) Kunth
Arrow Grass	*Triglochin striata* R.& P.
Arrowhead	*Sagittaria latifolia* Willd.
Bald Cypress	*Taxodium distichum* (L.) Rich
Beak-Rush	*Rhynchospora* spp.
Bedstraw	*Galium tinctorium* L.
Beggar's Ticks*	*Bidens coronata* (L.) Britten
Big Cordgrass*	*Spartina cynosuroides* (L.) Roth
Black Willow	*Salix nigra* Marshall
Blue Flag	*Iris virginica* L.
Boneset	*Eupatorium perfoliatum* L.
	Eupatorium serotinum Michaux
Bur-Head	*Echinodorus cordifolius* L. Grisebach
Buttercup	*Ranunculus* Spp.
Button Bush	*Cephalanthus occidentalis* L.
Cane	*Arundinaria gigantea* (Walter) Muhl
Cardinal Flower	*Lobelia cardinalis* L.
Cattails*	*Typha angustifolia* L.
	Typha latifolia L.
Climbing Hempweed	*Mikania scandens* (L.) Willd.
Common Reed	*Phragmites australis* (Cav.) Trin. ex Steud.
Common Threesquare*	*Scirpus americanus* Pers.
Dayflower	*Commelina virginica* L.
Dodder	*Cuscuta* sp.
Duckweed	*Lemna* sp.
Dune Bean	*Strophyostyles helvola* (L.) Ell.
Eclipta	*Eclipta alba* (L.) Hasskarl
Eryngo	*Eryngium aquaticum* L.
False Loosestrife	*Ludwigia decurrens* Walter
False Nettle	*Boehmeria cylindrica* (L.) Swartz
Fireweed	*Erechtites hieracifolia* (L.) Raf.
Foxtail Grass	*Setaria magna* Grisebach
	Setaria glauca (L.) Beauvois
	Setaria geniculata (Lam.) Beauvois
Frogfruit	*Lippia lanceolata* Michx.
Germander	*Teucrium canadense* L.
Groundsel Tree*	*Baccharis halimifolia* L.
Jewelweed	*Impatiens capensis* Meerb
Lilaeopsis	*Lilaeopsis carolinensis* C.&.R.
	Lilaeopsis chinensis (L.) Knutze
Live Oak	*Quercus virginiana* Miller
Lizard's-tail	*Saururus cernuus* L.
Lobelia	*Lobelia elongata* Small
Marsh Elder*	*Iva frutescens* L.
Marsh Fern	*Thelypteris palustris* Schott
Marsh Fimbristylis	*Fimbristylis spadicea* (L.) Vahl
Marsh Fleabane	*Pluchea purpurascens* (Swartz) DC
Marsh Hibiscus*	*Hibiscus moscheutos* L.
Marsh Mallow	*Kosteletskya virginica* Presl.
Marsh Pink	*Sabatia stellaris* Pursh
Meadow-Beauty	*Rhexia virginica* L.
Mermaid-Weed	*Proserpinaca palustris* L.
Mock Bishop's-Weed	*Ptilimnium capillaceum* (Michaux) Raf.
Mud Plantain	*Heteranthera reniformis* R.&P.
Needle Rush*	*Juncus roemerianus* Scheele
Nodding Ladies' Tresses	*Spiranthes cernua* (L.) Richard
Nut Sedge	*Cyperus* spp.
Olney Threesquare*	*Scirpus olneyi* Gray
Panic Grass	*Panicum dichotomiflorum* Michaux
Partridge Pea	*Cassia fasciculata* Michaux
Pennywort	*Hydrocotyle umbellata* L.
	Hydrocotyle verticillata Thunberg

Pickerelweed*	*Pontederia cordata* L.
Plumegrass	*Erianthus giganteus* (Walter) Muhl.
Red Maple	*Acer rubrum* L.
Rice Cutgrass*	*Leersia oryzoides* (L.) Sw.
Royal Fern*	*Osmunda regalis* L.
Rushes	*Juncus acuminatus* Michaux
	Juncus effusus L.
	Juncus scirpoides Lmn.
	Juncus spp.
Sacciolepis	*Sacciolepis striata* (L.) Nash
Saltmarsh Aster	*Aster subulatus* Michaux
	Aster tenuifolius L.
Saltmarsh Bulrush	*Scirpus robustus* Pursh
Saltmarsh Cordgrass*	*Spartina alterniflora* Loisel.
Saltmarsh Loosestrife	*Lythrum lineare* L.
Salt Meadow Hay*	*Spartina patens* (Aiton) Muhl.
Saltwort	*Salicornia* sp.
Seaside Goldenrod	*Solidago sempervirens* L.
Sedge	*Carex* spp.
Smartweed*	*Polygonum punctatum* Ell.
Soft Stem Bulrush	*Scirpus validus* Vahl.
Spikerush*	*Eleocharis fallax* Weatherby
	Eleocharis parvula (R.+S.) Link
Sprangletop	*Leptochloa fasicularis* (Lam.) Gray
Swamp Loosestrife	*Decodon verticillatus* (L.) Ell.
Swamp Milkweed	*Asclepias incarnata* L.
Swamp Rose	*Rosa palustris* Marshall
Sweet Flag	*Acorus calamus* L.
Sweet Gum	*Liquidambar styraciflua* L.
Switch Grass*	*Panicum virgatum* L.
Tearthumb	*Polygonom arifoliuim* L.
	Polygonum sagittatum L.
Water Dock*	*Rumex verticillatus* L.
Water Fern	*Azolla caroliniana* Wind.
Water Hemlock	*Cicuta maculata* L.
Water Hemp*	*Amaranthus cannabinus* (L.) J.D. Sauer
Water Horehound	*Lycopus virginicus* L.
Water Hyssop	*Bacopa caroliniana* (Walt.) Robins
Water Lily	*Nymphaea odorata* Alton
Water Parsnip	*Sium suave* Walter
Wax Myrtle*	*Myrica cerifera* L.
Wild Millet	*Echinochloa walteri* (Pursh) Nash
Wild Rice*	*Zizania aquatica* L.
Wild Rye Grass	*Elymus virginicus* L.
Woolgrass	*Scirpus cyperinus* (L.) Kunth

**Species included in the Wetlands Act of 1972.*

Table 2. Acreage of the dominant wetland plant species in Back Bay, Va.

	Plant Species	Acreage	Percent
1.	Cattail	4004	40.3
2.	Needlerush	2371	23.9
3.	Big cordgrass	605	6.1
4.	Saltmeadow hay	449	4.5
5.	Switchgrass	427	4.3
6.	Olney threesquare	261	2.6
7.	Spikerush	229	2.3
8.	Wild millet	188	1.9
9.	Smartweeds	181	1.8
10.	Marsh hibiscus	139	1.4
11.	Saltmarsh cordgrass	133	1.3
12.	Saltmarsh bulrush	133	1.3
13.	Marsh mallow	102	1.0
14.	Common threesquare	100	1.0
15.	Common reed	85	0.9
16.	Water hemp	79	0.8
17.	Tearthumb	71	0.7
20.	Rice cutgrass	29	0.3
21.	Aster	27	0.3
22.	Nutsedge	23	0.2
23.	Marsh fimbristylis	21	0.2
24.	Soft-stem bulrush	19	0.2
25.	Beggars ticks	19	0.2
26.	Plumegrass	16	0.2
27.	Woolgrass	16	0.2
28.	All other species	198	2.1
	Total	**9925**	**100**

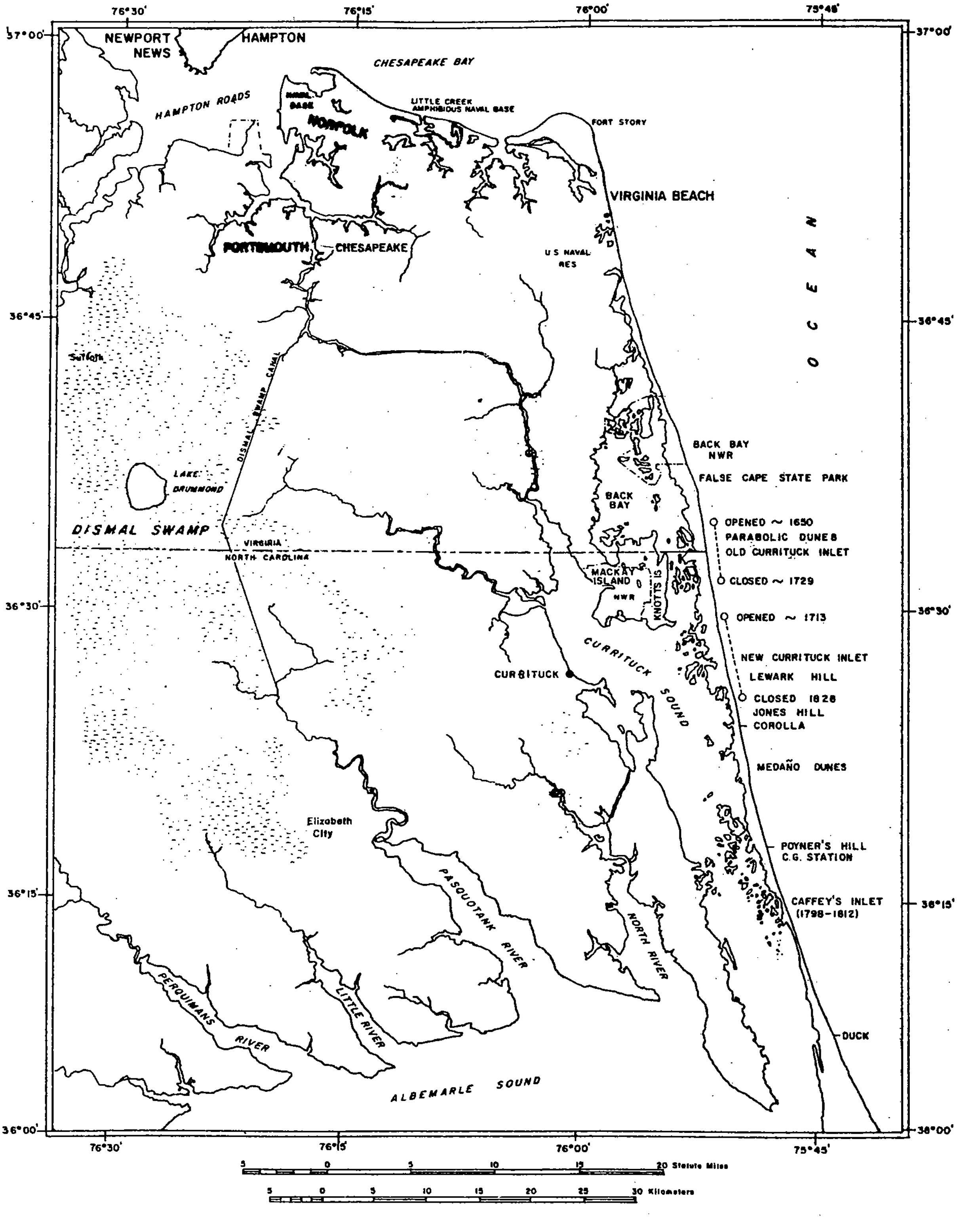

Figure 1. Vicinity map and locations of historical inlets along Currituck Spit (from Goldsmith, 1977).

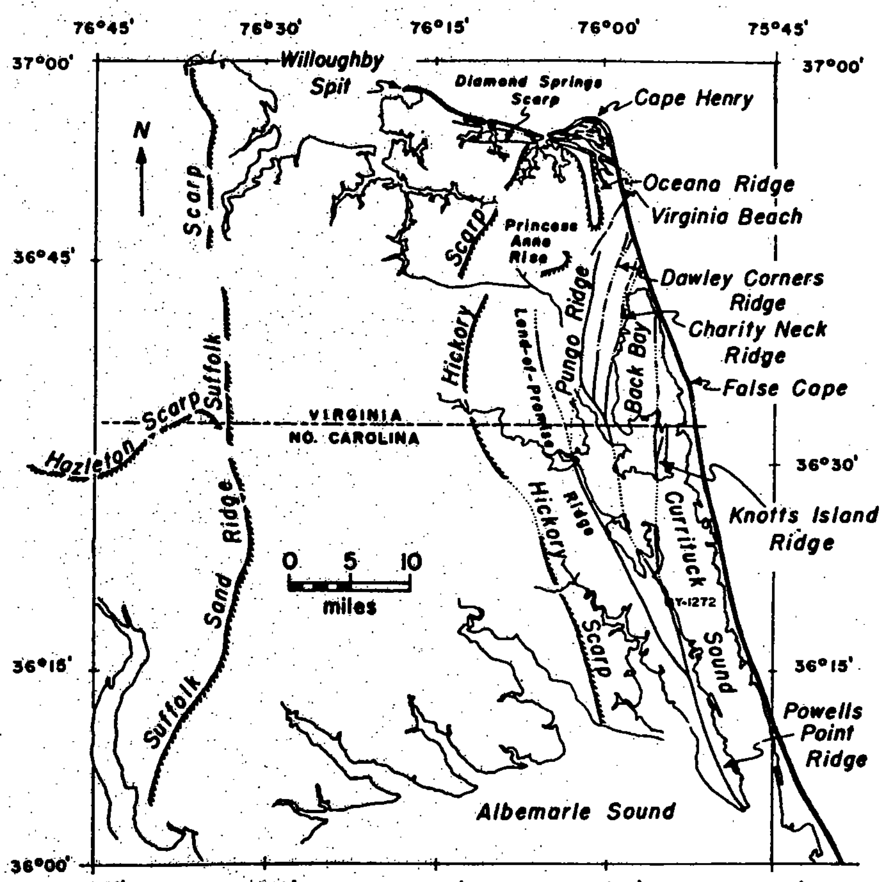

Figure 2. Scarps and ridges in southeastern Virginia and adjacent North Carolina (from Oaks and Coch, 1973).

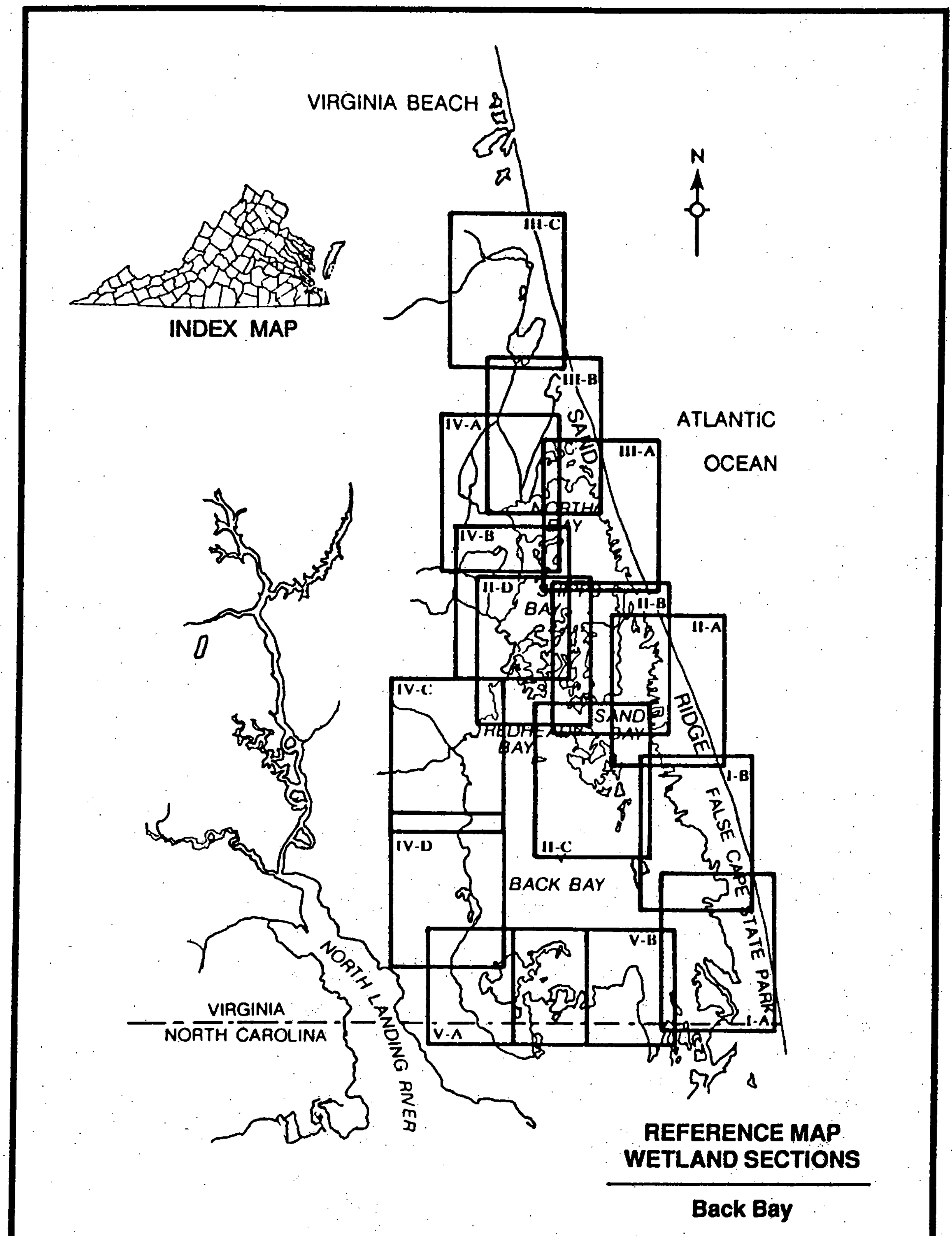

Figure 3. Location of inventory section maps (from Priest and Dewing 1989).

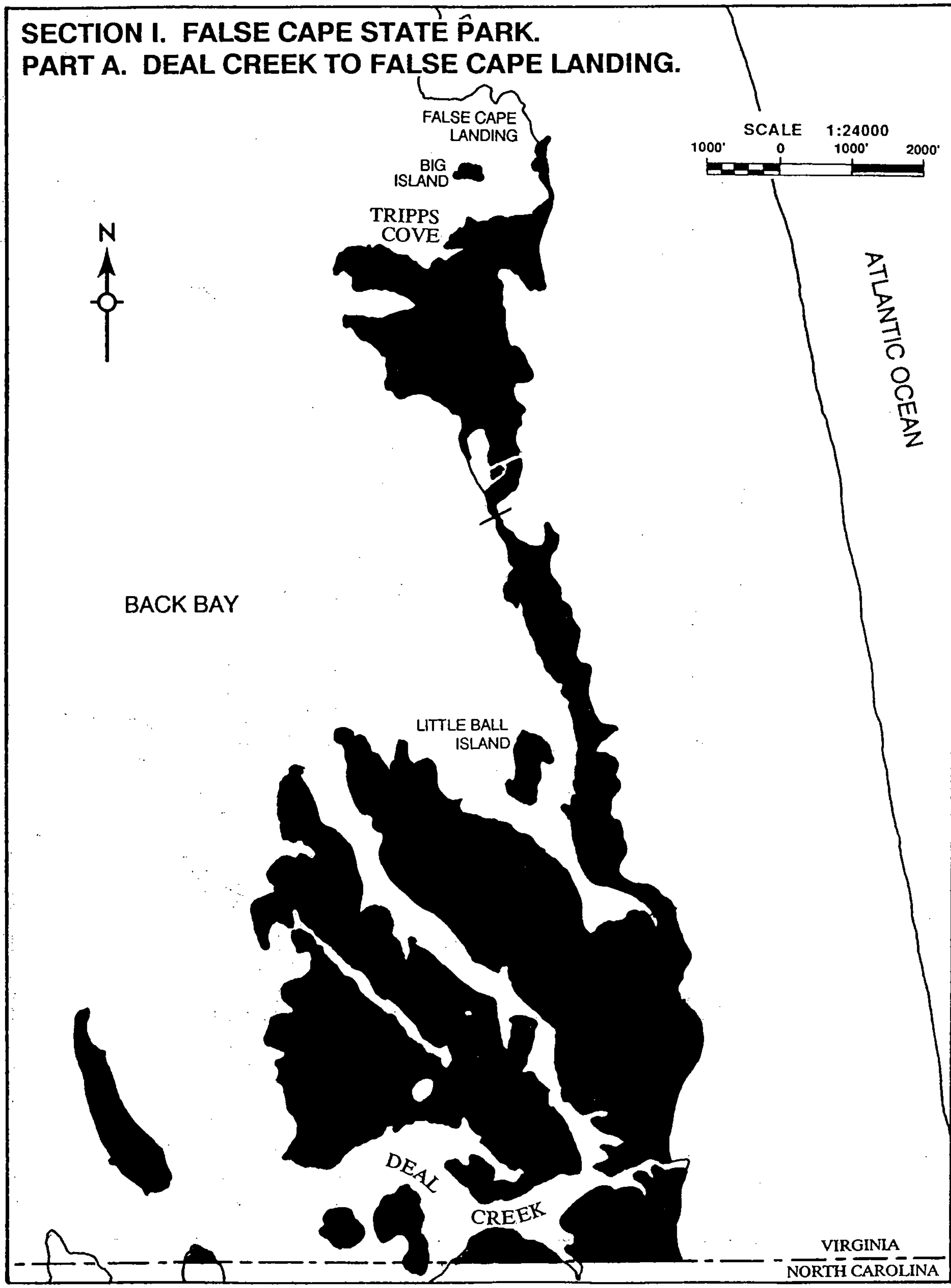

Figure 4. Section I. False Cape State Park. Part A. Deal Creek to False Cape Landing.

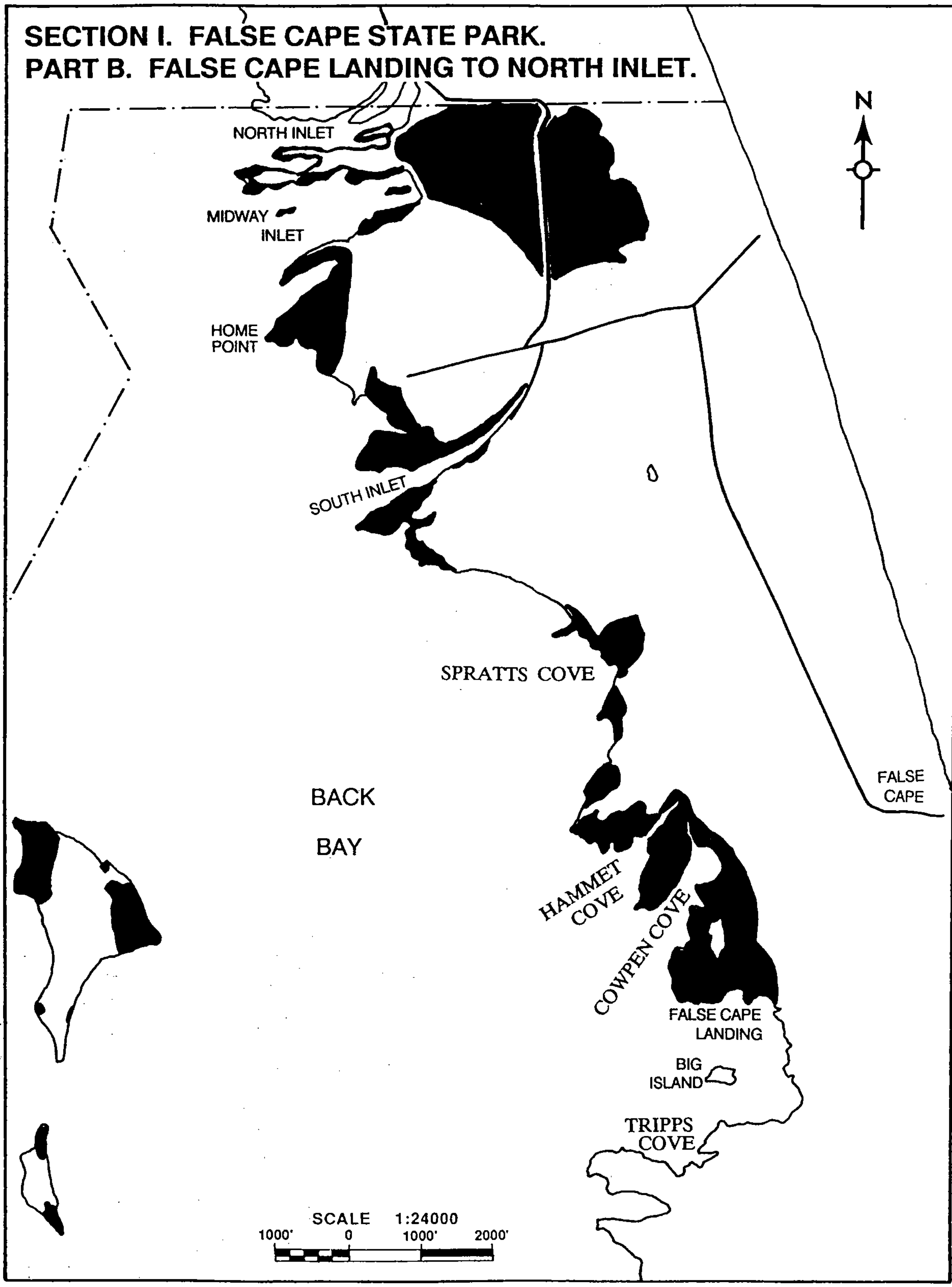

Figure 5. Section I. False Cape State Park. Part B. False Cape Landing to North Inlet.

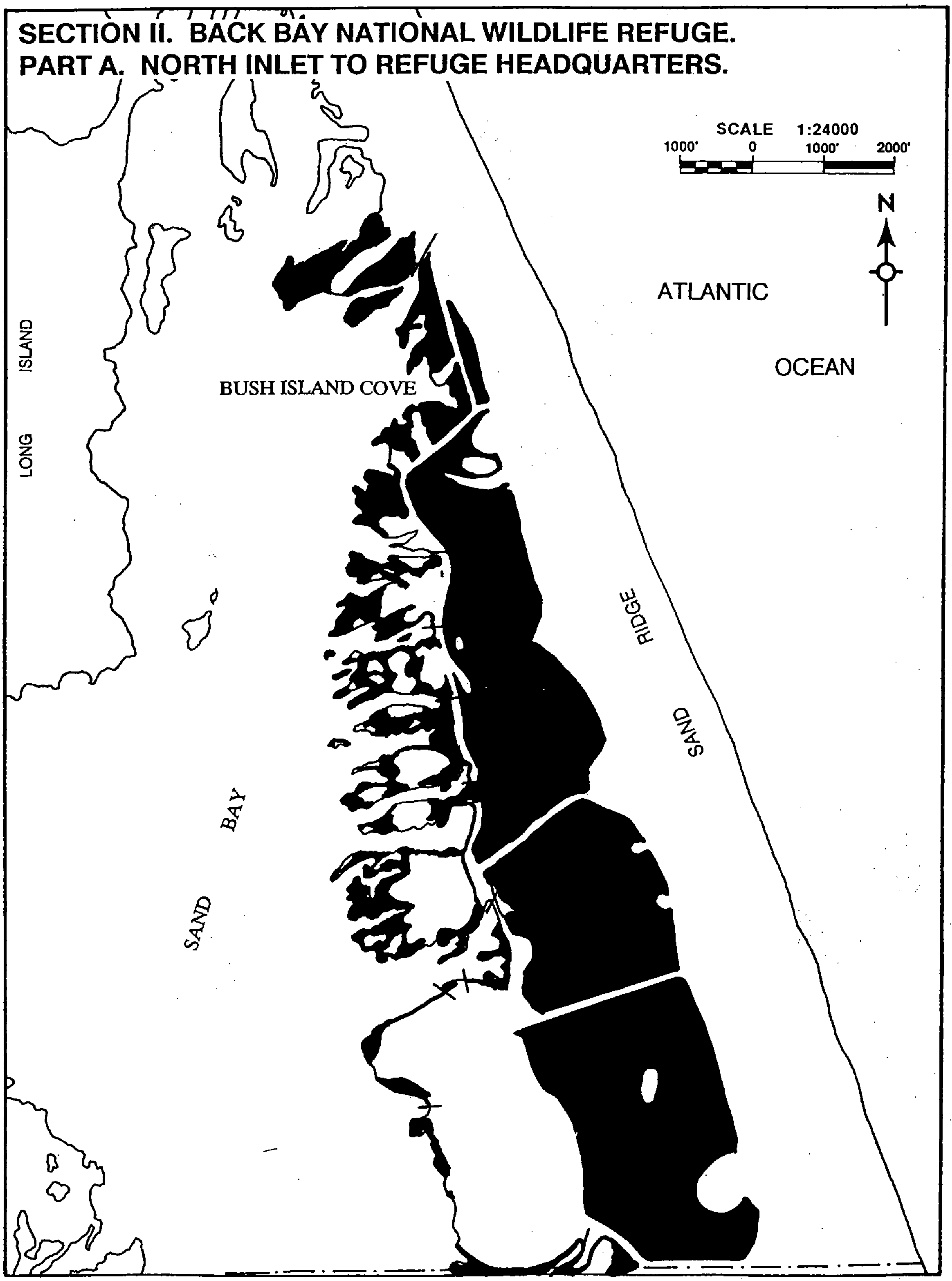

Figure 6. Section II. Back Bay National Wildlife Refuge. Part A. North Inlet to Refuge Headquarters.

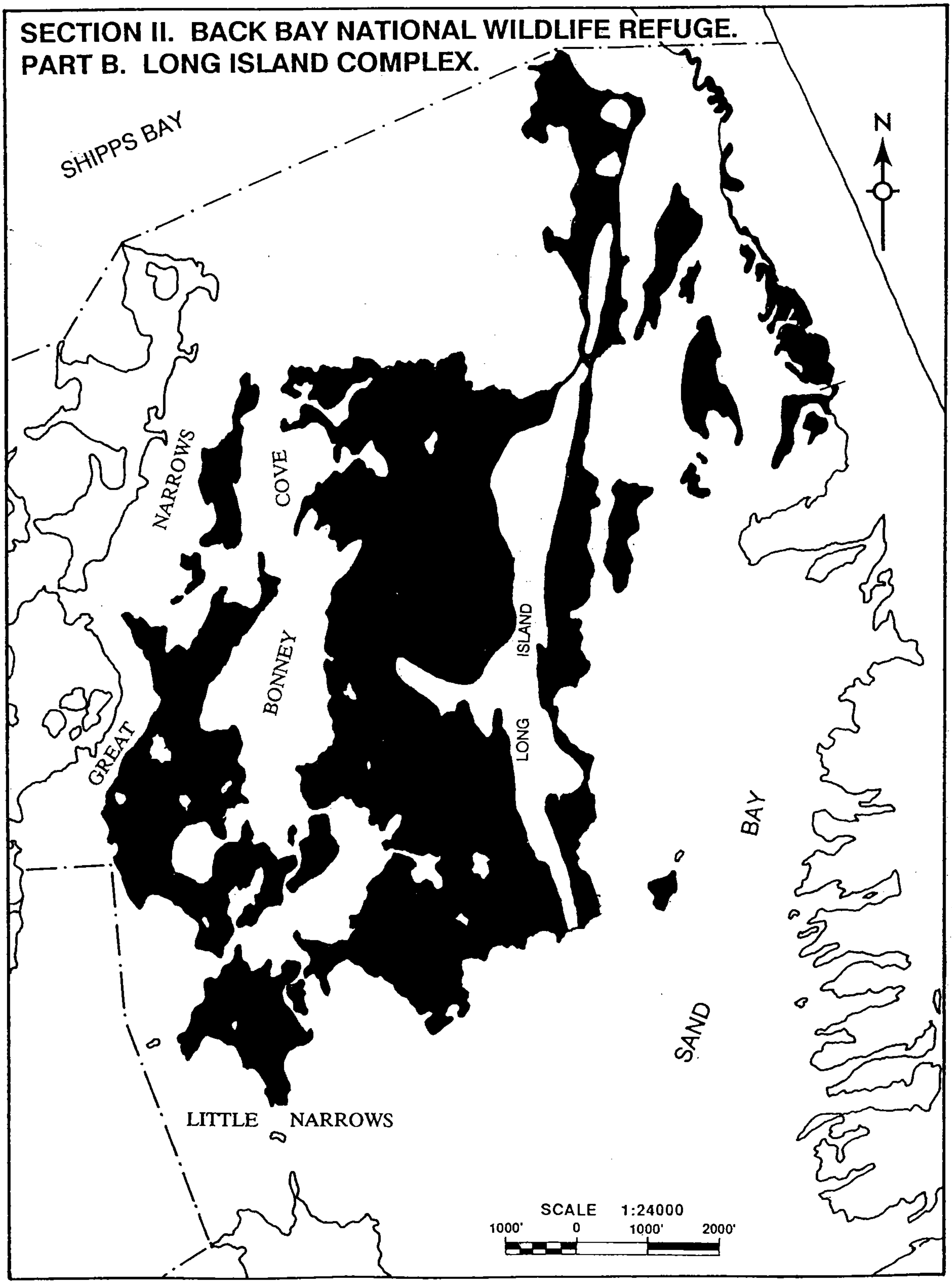

Figure 7. Section II. Back Bay National Wildlife Refuge. Part B. Long Island Complex.

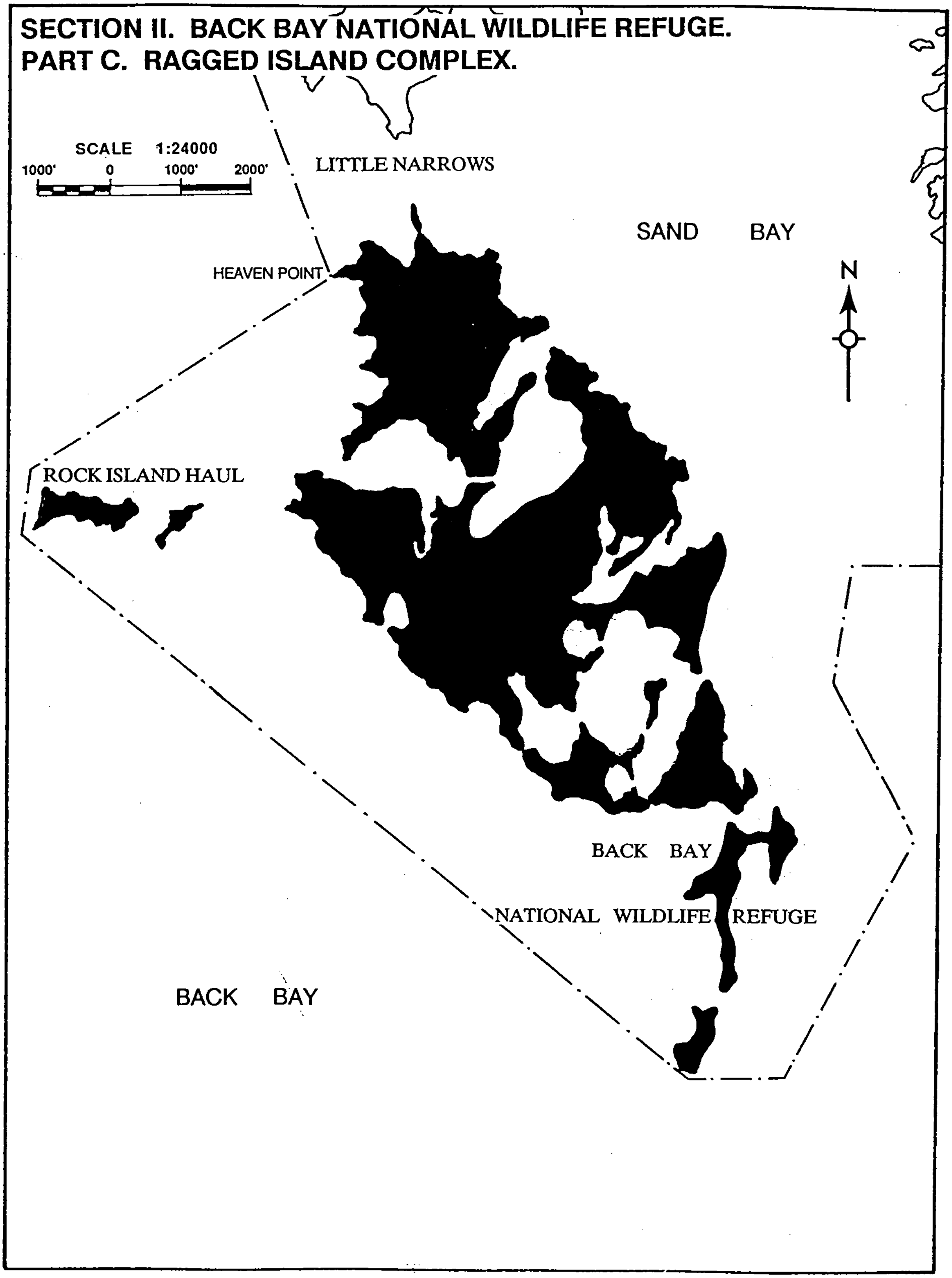

Figure 8. Section II. Back Bay National Wildlife Refuge. Part C. Ragged Island Complex.

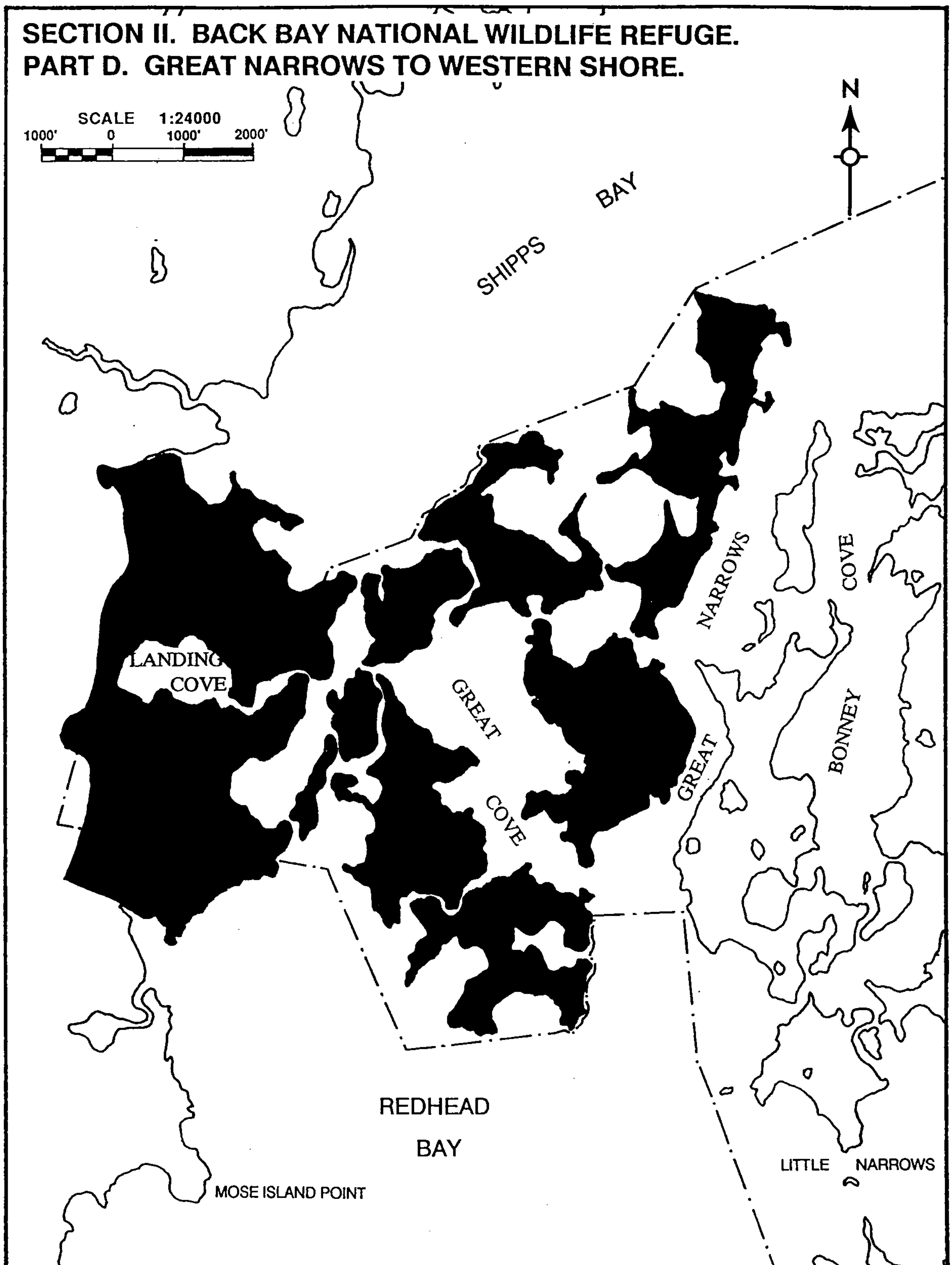

Figure 9. Section II. Back Bay National Wildlife Refuge. Part D. Great Narrows to Western Shore.

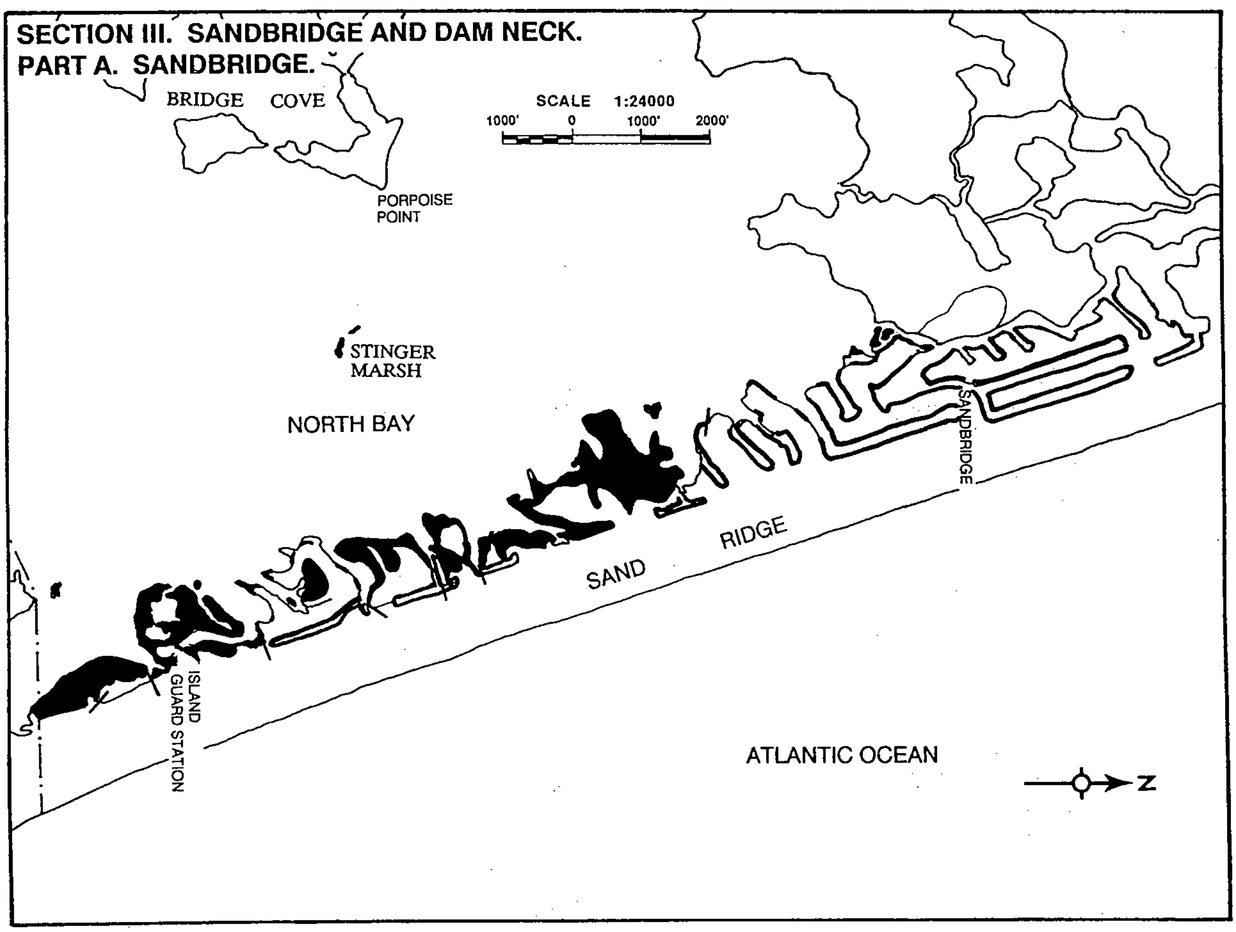

Figure 10. Section III. Sandbridge and Dam Neck. Part A. Sandbridge.

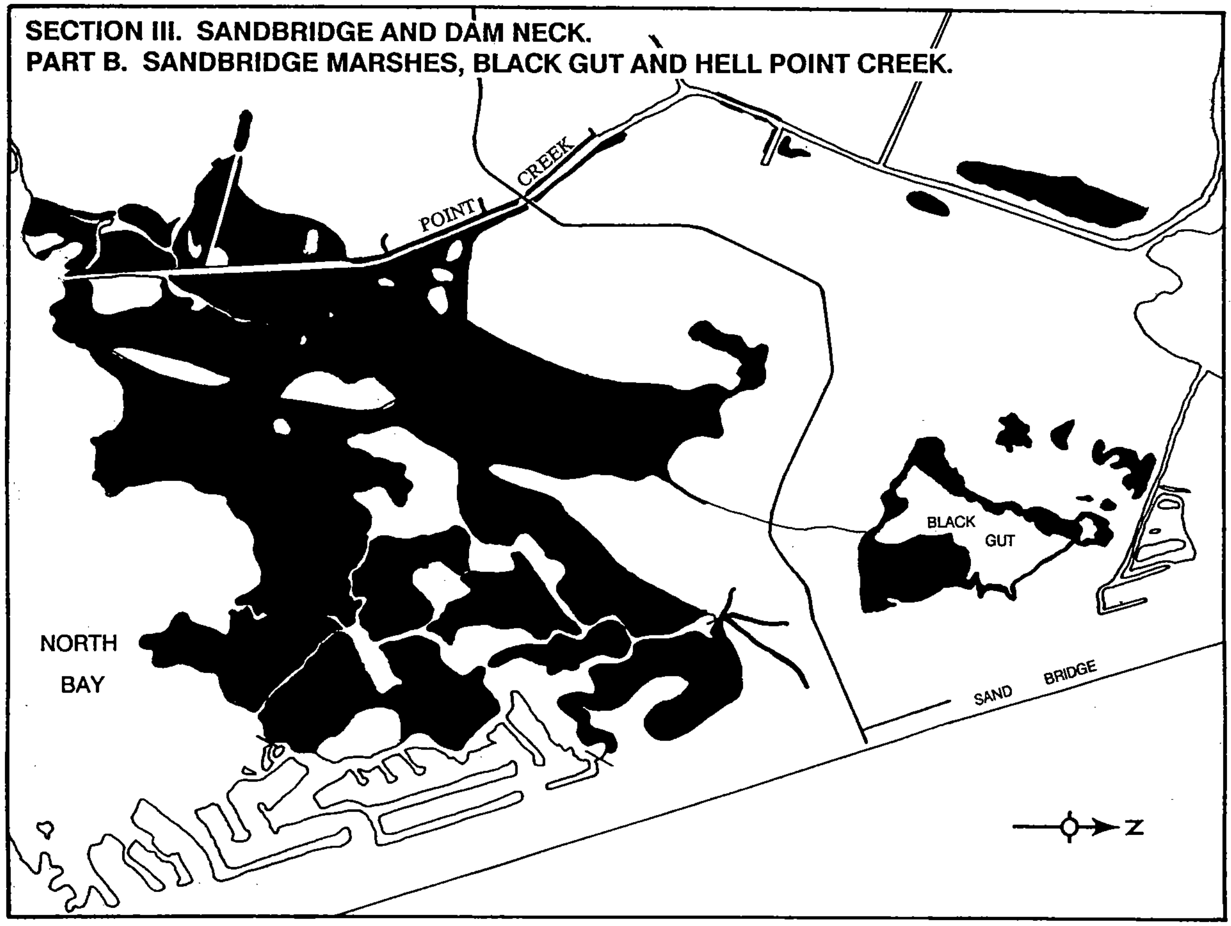

Figure 11. Section III. Sandbridge and Dam Neck. Part B. Sandbridge Marshes, Black Gut, and Hell Point Creek.

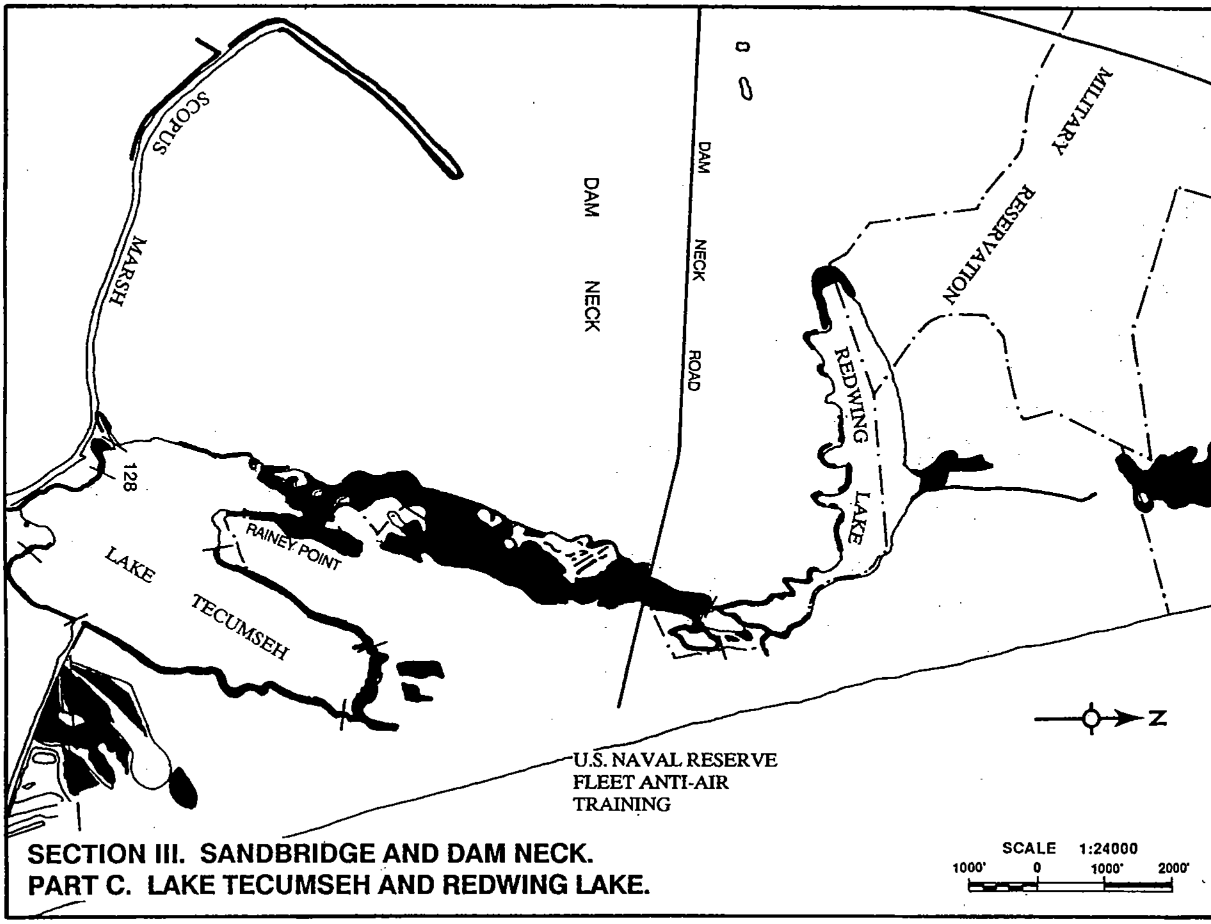

Figure 12. Section III. Sandbridge and Dam Neck. Part C. Lake Tecumseh and Redwing Lake.

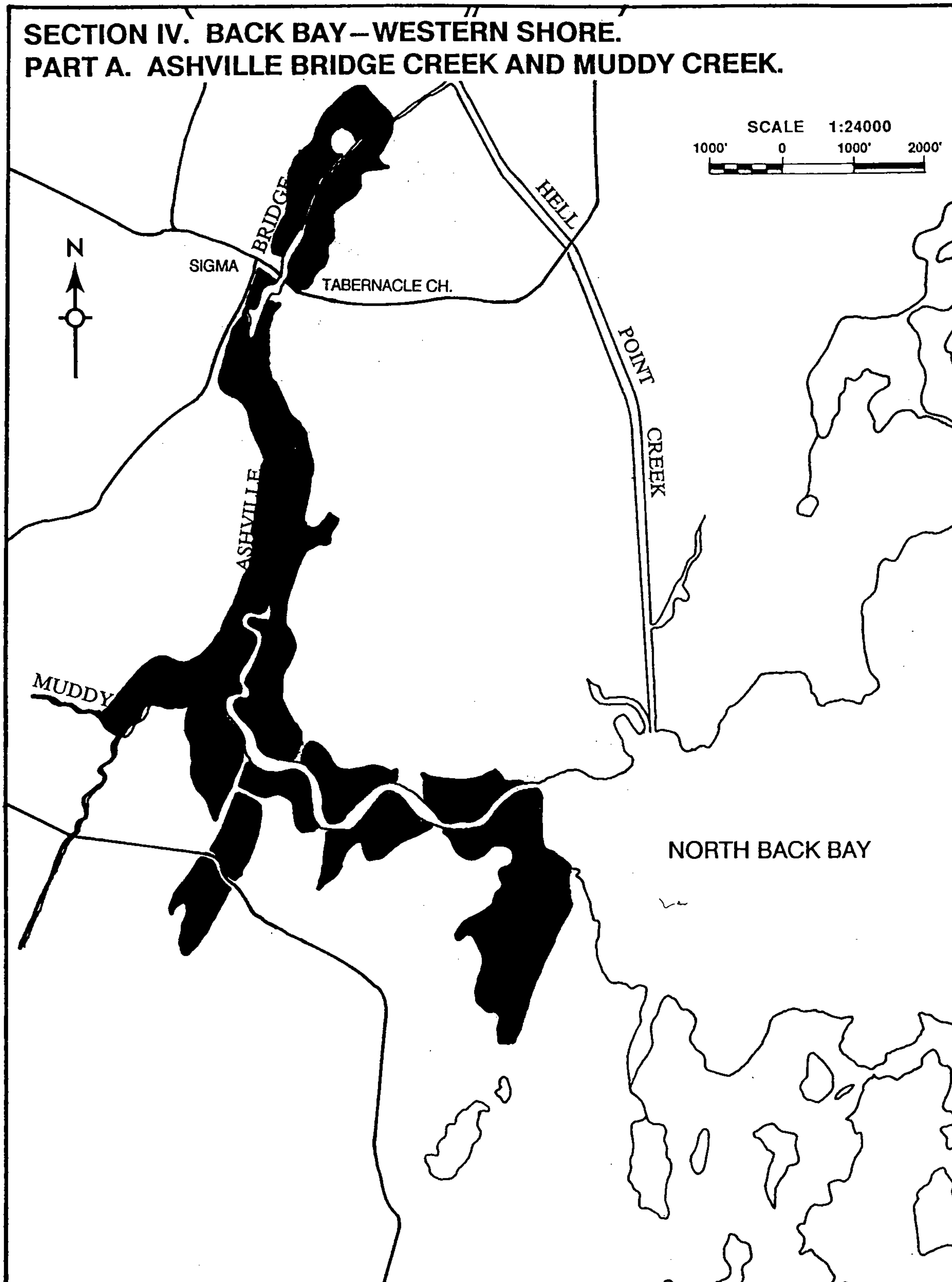

Figure 13. Section IV. Back Bay - Western Shore. Part A. Ashville Bridge Creek and Muddy Creek.

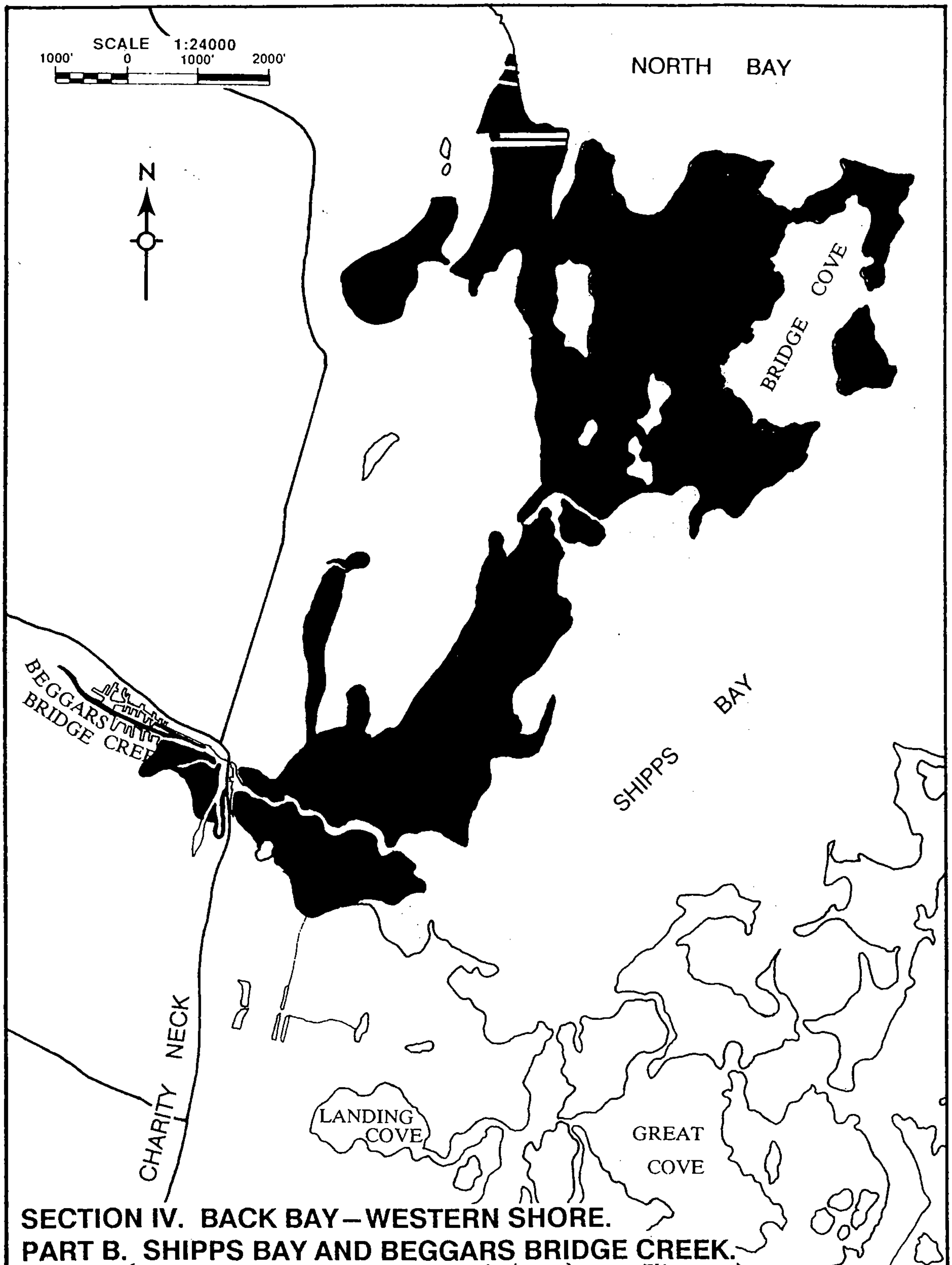

Figure 14. Section IV. Back Bay - Western Shore. Part B. Shipps Bay and Beggars Bridge Creek.

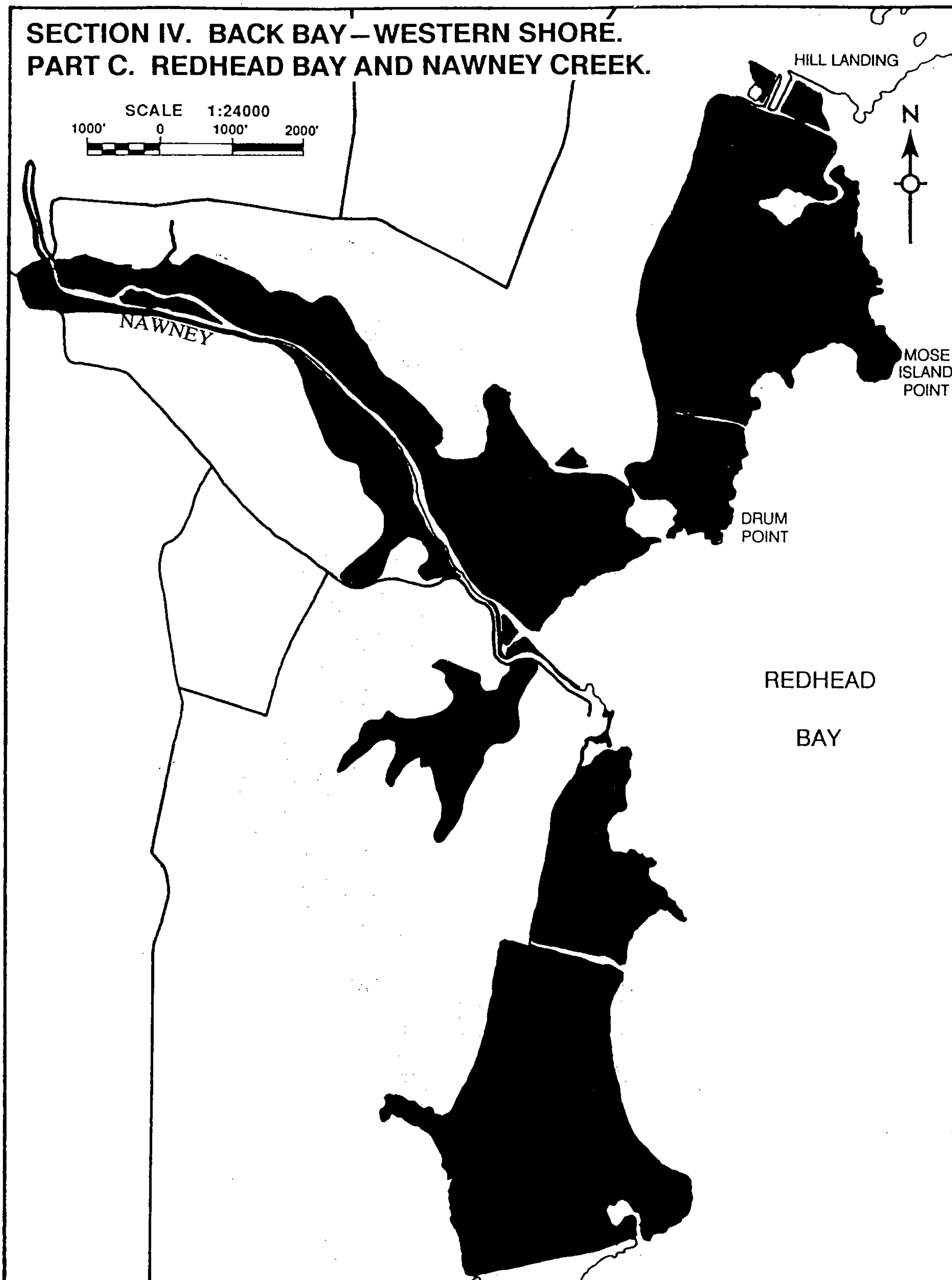

Figure 15. Section IV. Back Bay - Western Shore. Part C. Redhead Bay and Nawney Creek.

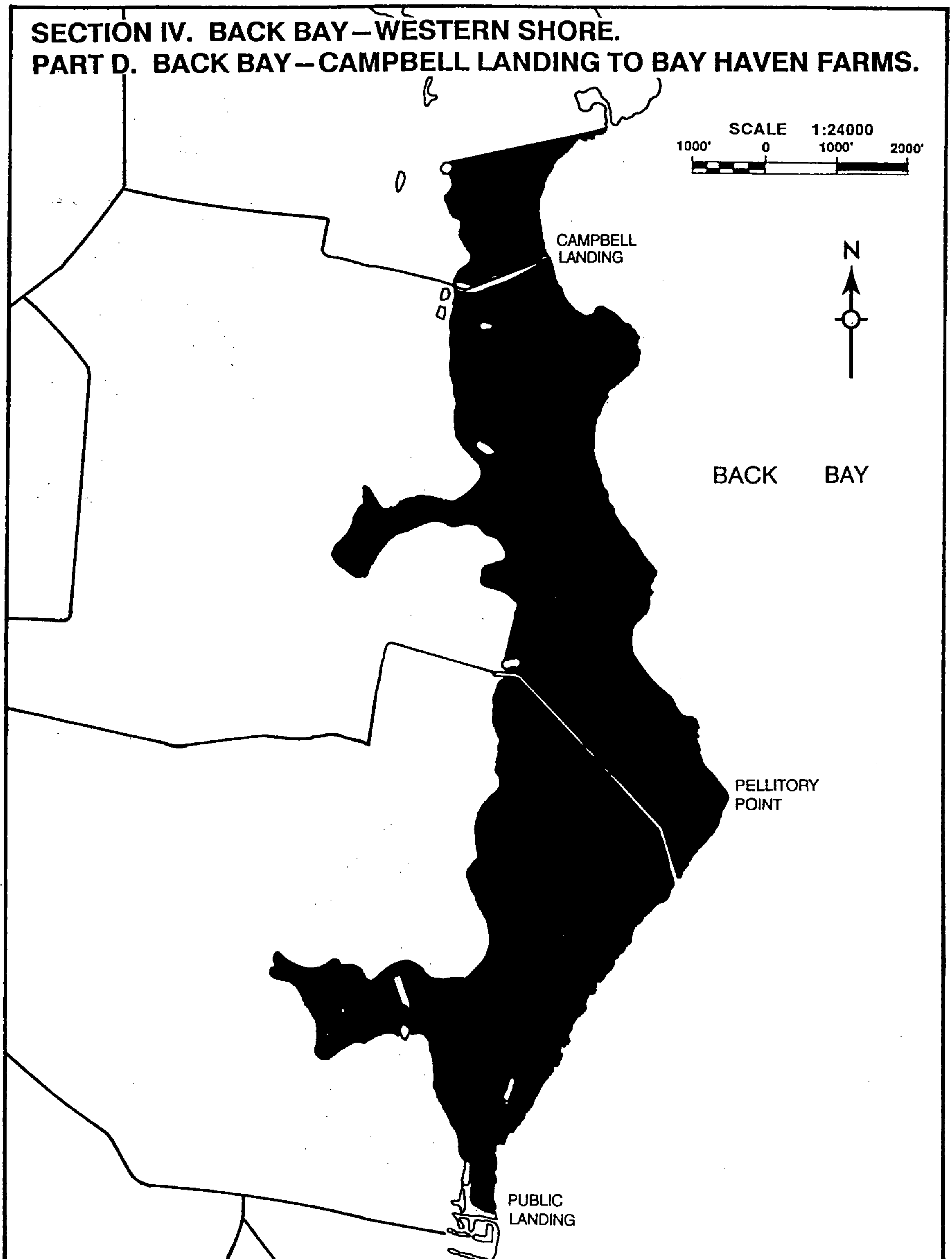

Figure 16. Section IV. Back Bay - Western Shore. Part D. Back Bay - Campbell Landing to Bay Haven Farms.

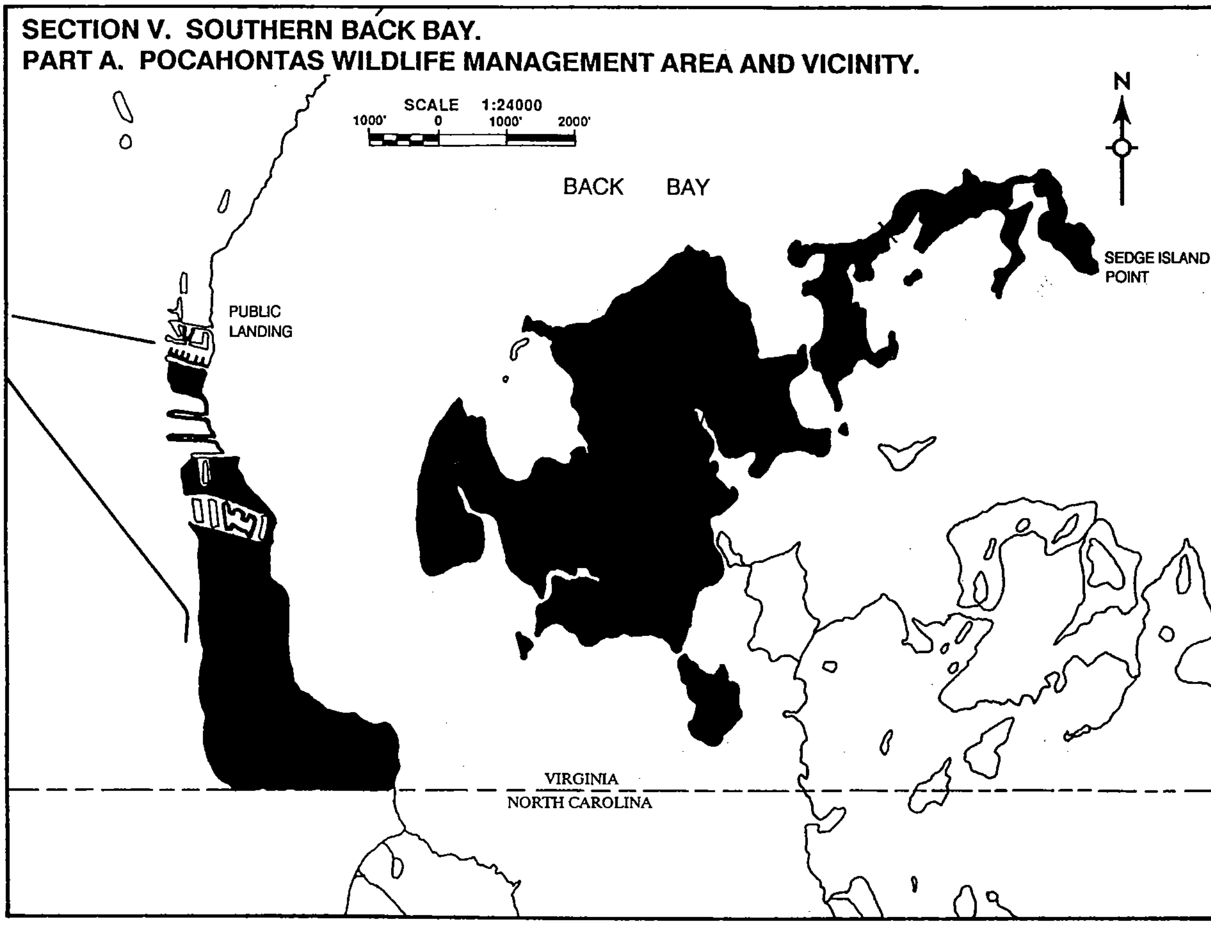

Figure 17. Section V. Southern Back Bay. Part A. Pocahontas Wildlife Management Area and Vicinity.

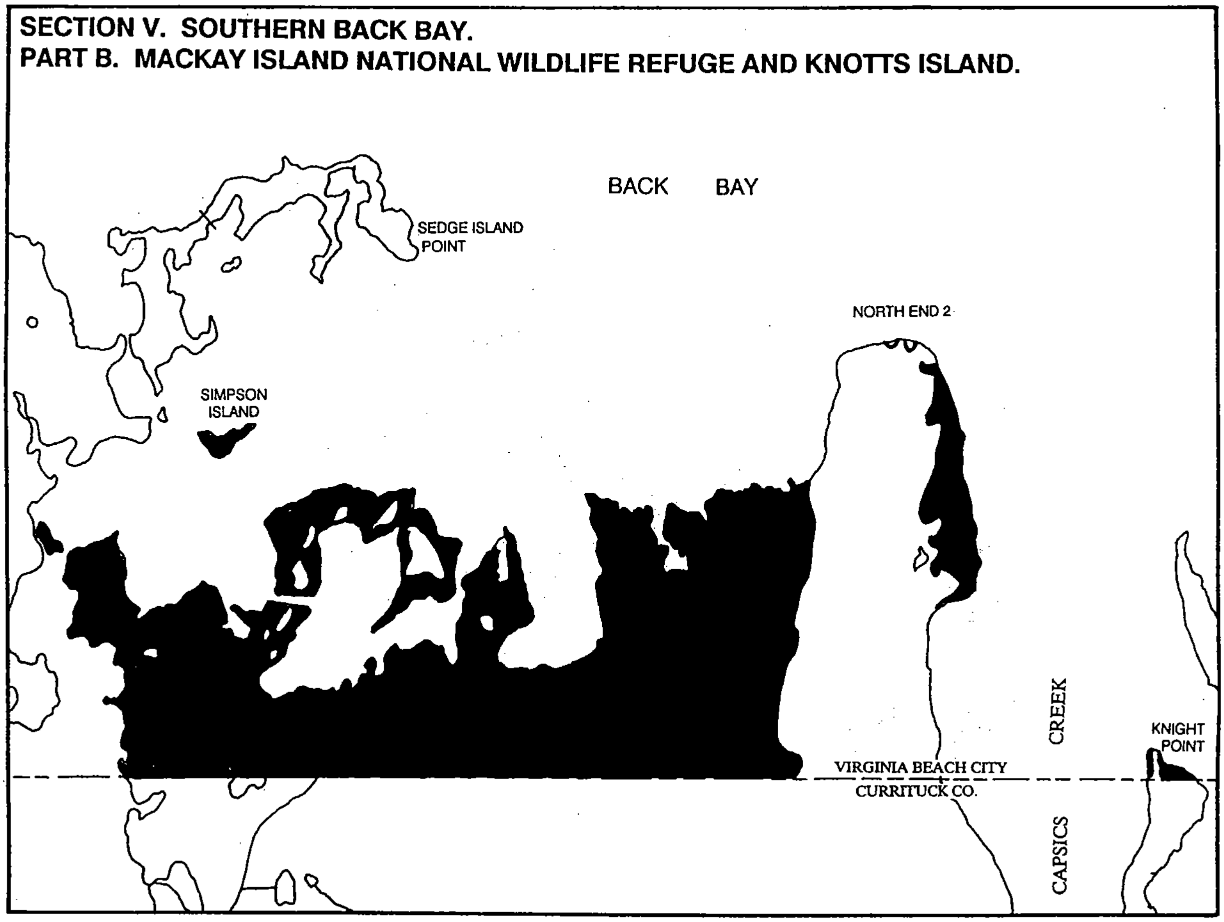

Figure 18. Section V. Southern Back Bay. Part B. Mackay Island National Wildlife Refuge and Knotts Island.

The Rare Plants of False Cape State Park, Virginia Beach City, Virginia

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Abstract: In 1990, the Virginia Department of Conservation and Recreation, Division of Natural Heritage, conducted an inventory of rare plants within False Cape State Park. The goal was to provide data for the development of a management strategy to protect the Park's rare plants. There are 37 plants monitored by the Division of Natural Heritage that have been recorded within the Park and 30 were observed during the 1990 inventory, including 18 previously not recorded. Extensive populations of some of these species were observed. This number of rare plants species is higher than in any other area of equal size in Virginia. This high number is attributed to the location of False Cape, the density and quality of natural communities, and the existence of some rare community types. Once the inventory of rare plants was completed, management priorities were determined by identifying the habitats in False Cape with rare species. Seven habitats were noted, ranging from the marshes of Back Bay with 13 rare plant species to the maritime forest and wet, sandy roadsides with 2 rare species each. Management recommendations were prescribed to ameliorate threats to the rare plants in these habitats. The two major recommendations were monitoring and control of populations of *Phragmites communis* (Cav.) Steudel in the marshes of Back Bay and the waterfowl impoundments and the monitoring of pig, horse, and deer damage to the interdunal swale flora. Despite some threats to False Cape State Park, the Park represents the most significant refuge for natural vegetation and rare plants within the Back Bay watershed and one of the most significant concentrations of rare plants within the Commonwealth.

Introduction

False Cape State Park is a 1749 hectare State Park managed by the Virginia Department of Conservation and Recreation's Division of State Parks. The Park includes a stretch of Atlantic Ocean barrier spit bordered on the south by the North Carolina boundary, on the north by Back Bay National Wildlife Refuge, on the east by the Atlantic Ocean, and on the west by Back Bay. Numerous islands and marshes within Back Bay lie inside the Park's boundary including Cedar Island, Little Cedar Island, Simon Island, Horse Island, Big Ball Island, and Little Ball Island. Most of the Park and its vegetation are relatively undisturbed, except for the northern 10% which is impounded and managed for waterfowl through a cooperative agreement between the Department of Game and Inland Fisheries and the Department of Conservation and Recreation.

The undisturbed vegetation in False Cape State Park can be described as parallel vegetation zones occurring north to south from the Atlantic Ocean west to Back Bay. The first zone encountered is primary dune dominated by *Uniola paniculata* L. which is found immediately west of the ocean beach. *Ammophila breviligulata* Fernald, *Panicum amarum* Elliott, *Oenothera humifusa* Nuttall, and *Euphorbia polygonifolia* L. are also common in this zone.

A dune and swale topography creates alternating upland and wetland vegetation behind the primary dune. The higher, more xeric dunes, some still active with blow-outs, are sparsely vegetated with *Hudsonia tomentosa* Nuttall, *Panicum amarum* Elliott, and other species tolerant of the xeric conditions. The low areas between dunes form seasonally-inundated pools, known as "interdunal swales" which are dominated by a diverse and varied assemblage of wetland herbs and shrubs. Some of the more common dominant species include *Solidago tenuifolia* Pursh, *Andropogon virginicus* L., *Spartina patens* (Aiton) Muhl., and *Salix caroliniana* Michaux. Tyndall (1978) described the vegetation of a number of interdunal swales in the northeastern corner of the Park. Shrub thickets with *Quercus virginiana* Miller, *Myrica cerifera* L., and *Myrica pensylvanica* Loisel. are common between the high dunes and low swales in this zone.

Proceeding westward, a maritime forest of *Pinus taeda* L. and *Quercus virginiana* Miller occurs interspersed with *Myrica cerifera* L. thickets and xeric, open sands. West of the forest and down slope from the dunes, swamp forests with diverse woody vegetation grade into the marshes of Back Bay. The marshes are fresh to slightly brackish and dominance varies greatly. Dominant species in the marshes include *Spartina cynosuroides* (L.) Roth, *S. patens* (Aiton) Muhl., *Typha angustifolia* L., *Scirpus olneyi* Gray, *Phragmites communis* (Cav.) Steudel, and *Juncus roemerianus* Scheele.

Historically, the vegetation of the region has gone through a number of dramatic changes. A brief review of the history of Currituck Spit, which includes False Cape State Park, is presented by Hennigar (1977a). In the late 1800's and early 1900's, the spit was heavily logged and grazed causing massive wind erosion and movement of sand. This resulted in an exodus of human inhabitants in the 1920's. In 1935, a dune stabilization project was initiated extending 125 miles and covering all of False Cape State Park and Back Bay National Wildlife Refuge. The result of the dune stabilization has been a gradual revegetation of the active sands. Four photographs which show this revegetation are presented by Hennigar (1977b).

The botanical significance of the False Cape region of Back Bay was well documented by Fernald (1935, 1936, 1940, 1947) and is apparent by the high number of rare species collected at False Cape. Due to the large number of rare plants recorded in the region and the Park's diverse assemblage of natural communities with undisturbed vegetation, the Virginia Department of Conservation and Recreation's Division of Natural Heritage staff decided to inventory the rare plant species. The ultimate goal of this inventory was to provide sufficient data to determine a protection strategy to insure the continued existence of the Park's rare plants and significant habitats.

Methods

At the beginning of the 1990 field season, all existing information on rare plant populations recorded for the False Cape area was compiled. To gather these data, the Division of Natural Heritage data base was searched, botanical literature was checked, and herbaria which might have specimens from the area were reviewed. In addition to checking these sources, botanists who had been to False Cape State Park were interviewed.

Data compiled from these sources were used to direct 30 man- days of field work which began on February 8,1990 and continued through October 17, 1990. The location and habitat of each rare species previously recorded from False Cape State Park were surveyed during the appropriate flowering season and data on each occurrence of rare species were recorded. In addition to searching for species documented previously, field investigations were directed towards obtaining information on other rare plants that might be found in the Park.

For all rare species which were found during the surveys, the species, identifying characteristics, date, population boundaries, concentrations within population boundaries, approximate number of individuals, phenology, habitat, and threats to the species were recorded. Upon collection of the data, long-term viability and management needs of the species were assessed.

Voucher specimens to be deposited at WILLI, FARM, VPI, or ODU were collected to provide verifications for rare species which were not previously recorded at False Cape State Park.

Results

There were 37 rare plant species which are monitored by the Division of Natural Heritage that were recorded as extant or historical occurrences in False Cape State Park. There were 12 collected prior to 1990 and verified during 1990 field work, 7 collected prior to 1990 and not found during the 1990 field work, and 18 collected in 1990 for the first time. A summary on the status and distribution of the 37 species is presented below along with a natural heritage rank which summarizes the species' status on a global and state basis. For an explanation of the natural heritage ranks refer to Lipford, *et al* (1987).

Aster elliottii T.&G., Elliott's Aster, (G3G4/S1):

This species was collected on October 14, 1971 (Harvill & Wise 24889, FARM). Label data reads "interdune swale near Newport New Club, False Cape", but the species was not relocated in any interdunal swales during 1990 field work. In 1990, a population of this Aster was located in the marsh/shrub swamp ecotone of Back Bay along Deal Creek less than 0.3 km north of the North Carolina line. There were at least 1000 plants observed blooming over 50 square meters on October 15.

Bacopa monnieri (L.) Wettstein, Coastal Water Hyssop, (G5?/S1S2):

Bacopa monnieri (L.) Wettstein was first collected in interdunal swales south of False Cape by Fernald (1935) and was commonly found during 1990 throughout the Park in open wetlands including interdunal swales, waterfowl impoundments, and the marshes of Back Bay. *Bacopa* was most prevalent in the impoundments, with thousands of plants observed flowering and fruiting over many hectares of the impoundment's exposed shores.

Bulbostylis ciliatifolia (Ell.) Fernald, Capillary Hairsedge, (G5/S1):

This species was collected on October 16, 1971 (Harvill & Wise 24907, FARM). Label data reads "interdunal swale near Barbour Heights", but no plants were found during 1990 field work.

Carex reniformis (Bailey) Small, Reniform Sedge, (G4?/S1):

This species was collected on June 25, 1971 (Harvill & Wise 23936, FARM). The collection label reads "Swale near Dudley Club, south of False Cape", but the species was not relocated during 1990 investigations.

Cladium mariscoides (Muhl.) Torrey, Twig Rush, (G5/S2):

On June 26, 1990, this species was found growing in two interdunal swales southeast of the contact station approximately 1.5 km south of the Park's northern boundary. The larger of the subpopulations, less than 200 meters from the other subpopulation, had many thousands of plants which were observed fruiting over at least 0.5 hectares.

Cyperus haspan L., Sheathed Flatsedge, (G5/S2S3):

This species was first collected in 1934 (Fernald & Long 3733, URV) in an interdunal swale south of False Cape. Fernald (1935) reported that the species was local in this habitat, however, in 1990 it was commonly found in many wetlands throughout the Park. The plant occurred in interdunal swales, waterfowl impoundments, and the marshes of Back Bay. Like *Bacopa monnieri* (L.) Wettstein, *Cyperus haspan* L. is most prevalent in the impoundments, with thousands of plants observed flowering and fruiting over many hectares of the impoundment's exposed shores.

Dichromena colorata (L.) Hitchcock, A Sedge, (G4G5/S1):

This sedge was first collected in 1934 in an interdunal swale south of False Cape (Fernald & Long 3740, VPI). The species was also found at a number of locations in 1990, but not in any of the interdunal swales which were surveyed. During 1990 field work, the species was observed on the edge of a waterfowl impoundment, two wet, mowed lawns, and in the low herbaceous ecotone areas where Back Bay marshes meet the woodland and swamps of the barrier spit. Fernald (1935) listed the species as local which appeared to be true in 1990 also. Though six patches were found, each of these patches covered less than 10 square meters with fewer than 100 flowering plants per patch.

Drosera intermedia Hayne, Spoon-Leaved Sundew, (G5/S2S3):

Drosera intermedia Hayne was first collected at False Cape State Park in 1971 (Harvill & Wise 24559, FARM) in an open, sandy, flat area near Barbour Hill. The species was observed frequently in 1990. Many thousands of plants occurred on wet sands of the interdunal swales throughout the Park and on the sandy edge of one impoundment. In swales which had accumulated a mucky bottom, plants would generally occur only along the drier, sandier edges.

Eleocharis halophila Fernald & Brack., Salt-marsh Spikerush, (G4/S1):

Eleocharis halophila Fernald & Brack. was first collected at False Cape on June 20, 1935 (Fernald, Griscom, & Long 4566, VPI) in wet, sandy depressions. On June 25, 1990, a species of *Eleocharis* which may represent *halophila* was collected in a marsh at the edge of an impoundment in the northern portion of the Park northwest of Barbour Hill. Hundreds of fruiting plants were seen over 20 square meters. Verification of the identity of the collected *Eleocharis* is pending.

Eleocharis radicans (Poiret) Kunth, Rooted Spikerush, (G5/S1):

This species was collected on August 2, 1934 (Fernald, Griscom & Long 6030, URV). Data from the 1934 collection label reads "open wet sand bordering inundated swales back of dunes, south of False Cape". Fernald (1935), reporting this species under the name *E. lindheimeri* (Clarke) Svenson, stated that the plant formed a dense turf, however, no plants were found during 1990 field work.

Eleocharis rostellata Torrey, Beaked Spikerush, (G5/S1):

On October 15, 1990, a 5 square meter patch of this species was located in a brackish marsh of Back Bay along Deal Creek less than 200 meters from the North Carolina line. There were at least 1000 culms, most sterile, but a small percentage elongate, repent, and rooting at the tips.

Erigeron vernus (L.) T.&G., White Top Fleabane, (G5/S1):

Erigeron vernus (L.) T.&G was found on June 3, 1971 (Harvill & Wise 25250, FARM) in a "Sandy clearing between False Cape Park HQ and Barbour Hill". In 1990, 7 small subpopulations of this species were found, 5 in interdunal swales, and 2 in wet mowed areas. The species was found near the northern and southern boundaries of the Park as well as areas in between. The species was in flower when observed in June and was in late flower and fruit by August.

Euphorbia ammannioides HBK., A Spurge, (G3G4/S1):

In 1990, 200 individuals of this *Euphorbia* were found growing with the closely-related *Euphorbia polygonifolia* L. in the open sands behind the primary dune less than 0.5 km north of the North Carolina border. A population covering at least 1 hectare was observed in flower and fruit on August 14. Much more of this habitat is found than was searched at False Cape and it is likely that a larger population of this species will be found in the Park.

Fimbristylis caroliniana (Lam.) Fernald, Carolina Fimbry, (G4/S1):

Fernald (1935) mentions the collection of this species, under the name *Fimbristylis puberula* (Michx.) Vahl, in inundated swales back of the dunes, south of False Cape. In 1990, 2 subpopulations of this species were found. The first site had at least 20 plants in a peaty interdunal swale 1.1 km north of the Park's southern boundary and 0.3 km west of the Ocean. The second station included 30 or more plants growing in a wet, mowed area approximately 0.5 km north of the Park's southern boundary and 1.1 km west of the Ocean.

Galium hispidulum Michaux, Coast Bedstraw, (G5/S1S2):

This species was found on August 3, 1971 (Harvill & Wise 24291, FARM) in "Dunes near Dudley Club, s of False Cape". No plants were observed during 1990 field work.

Heterotheca gossypina (Michaux) Shinners, Cotton Golden-Aster (G5/S1S2):

This species was first collected at False Cape on September 1, 1971 (Harvill & Wise 24616, FARM) in "Dunes, Dudley Club South of False Cape". In 1990, this species was found in xeric sands of four open dune areas in the middle and southern sections of the Park. Plants were flowering when observed on August 14.

Iresine rhizamatosa Standley, Eastern Bloodleaf, (G5/S1):

This species was collected in rich woods on Cedar Island by Fernald (1936), but was not found during 1990 work in the Park.

Iva imbricata Walter, Sea-Coast Marsh-Elder, (G5?/S2S3):

In 1990, this shrub was observed growing behind the primary dunes within 1 km of the North Carolina line. At least 50 flowering plants were observed growing amidst dune grasses on August 15.

Juncus crassifolius Buchneau, A Rush, (G?/S2)

This species was collected in 1990 along a damp, sandy roadside which traverses a portion of the Back Bay marsh at Wash Woods. A group of fewer than 50 plants was observed fruiting in mid-October.

Juncus elliottii Chapman, Bog Rush, (G4G5/S2S3):

In 1990, this species was discovered in an interdunal swale less than 0.5 km south of the Park's northern boundary. At least 100 individuals were found over 0.2 hectares of a 3-hectare interdunal swale complex. This rush was flowering and in early fruit when observed on June 26.

Juncus megacephalus M.A. Curtis, Big-Head Rush, (G4G5/S1S2):

Fernald (1935) reported that his 1934 collection was very near, if not exactly at the same location as R.M. Harper's collection of this species on July 23, 1918, in interdunal swales along the coast about 2 miles north of the North Carolina boundary. In June 1990, this species was found in fruit at seven sites in the northern portion of False Cape State Park, including four in the interdunal swales, two in the marshes of Back Bay, and one in a waterfowl impoundment. The total number of plants observed was over 1000 and it seems probable that more sites will be found in the Park with further exploration.

Lilaeopsis carolinensis C.&R., Carolina Lilaeopsis, (G3/S1):

Fernald (1940) reported a collection of this species on Back Bay's Long Island, near the False Cape boundary. In 1990, this plant was observed in the Park occurring abundantly in the marshes and shores of Back Bay. The species was also found on the northern tip of Cedar Island and in one area of a waterfowl impoundment. Since the species reproduces vegetatively, it was difficult to determine the number of individuals, but the species was noted to cover many hectares, often forming dense patches.

Limosella subulata Ives, Mudwort, (G4/S1?):

This species was collected in interdunal swales south of False Cape by Fernald (1935), but was not found during 1990 work in the Park.

Lippia nodiflora (L.) Michaux, Common Frog-Fruit, (G5/S1):

Though Fernald (1935,1940) did not locate *Lippia nodiflora* within the Park, he did find the plant near Park boundaries in a number of Back Bay marshes. On October 17, 1990, a 20 square meter patch of this species was found in the Park. The population was found east of Little Ball Island in a marsh dominated by *Spartina patens* (Aiton) Muhl. about 5 meters from the edge of Back Bay.

Lobelia elongata Small, Elongated Lobelia, (G3G5/S1):

This plant was observed in 1990 occurring in the marshes of Back Bay from near the southern boundary of the Park to near the northern boundary. Though widespread, the species was relatively scarce with fewer than 60 individuals observed. The plant was in late flower and fruit when seen in mid-October.

Ludwigia alata Elliott, Winged Seedbox, (G3G4/S1):

On August 16, 1990, one individual of this seedbox was found in the Park. The plant was in flower, growing in a *Scirpus olneyi* Gray marsh on the eastern side of Big Ball Island.

Ludwigia brevipes (Long) Eames, Long Beach Seedbox, (G4G5/S2):

Fernald (1935) reported an extensive station for this species in shallow pools and wet sand of dune hollows south of False Cape. In 1990, an extensive population was still present occurring in many of the interdunal swales and impoundments throughout the Park. Many hundreds of plants were observed creeping over open mud and around taller herbs.

Paspalum distichum L., Joint Paspalum, (G5/S2S3):

In 1990, two 10 square meter patches of this species were found at the edge of a waterfowl impoundment within 0.5 km of the northern boundary of the Park. The patches were approximately 20 meters from one another and were flowering when observed on October 16.

Phalaris caroliniana Walter, May Grass, (G5?/S1):

Fernald (1936) reported this species at the border of a brackish marsh on Cedar Island, but the species was not found in 1990 when Cedar Island was visited.

Physalis viscosa L., Sticky Ground-Cherry, (G4G5/S1):

In 1990, this species was observed along the primary dune extending north from the southern boundary of the Park for at least 3 kilometers. The plant was in flower and fruit when seen in August. At least 300 individuals were found.

Quercus hemisphaerica Bartr., Darlington's Oak, (G5/S2):

In 1990, this evergreen oak was found abundantly with *Quercus virginiana* Miller in the maritime forests extending from the southern boundary almost 8 km north to the Park's contact station. Extreme variability in leaf shape suggested hybridization with other *Quercus* species.

Rhynchospora fascicularis (Michaux) Vahl, Fasciculate Beakrush, (G5/S1):

In August and October of 1990, this species was observed throughout the Park in interdunal swales and wet sand of roadsides. In some areas this plant dominated, and many thousands of plants were observed.

Spiranthes odorata (Nutt.) Lindl., Sweetscent Ladies'-Tresses, (G4/S2):

On October 15 and 17, 1990, fewer than 20 individuals of this orchid were found in Back Bay marshes along Deal Creek and Big Ball Island. The plants were observed growing along the edges of channels and in areas where the marsh was dominated by marsh vegetation under 1 meter tall. Plants were blooming and in early fruit.

Tillandsia usneoides L., Spanish Moss, (G5/S2S3):

This epiphyte was first collected August 3, 1971 (Harvill & Wise 24288, FARM) at "Dudley Club, False Cape State Park on Live Oak". In 1990, this species was found at 4 locations in the maritime forest extending north from the Park's southern boundary about 2.5 km to the Wash Woods Cemetery area.

Triglochin striata R.&P., Three-ribbed Arrowgrass, (G5/S2S3):

In 1990, this species was abundant throughout the marshes of Back Bay and was also found in two of the Park's impoundments. Tens of thousands of plants grew in the marshes, forming carpets of low growth under the taller vegetation. The species was observed in flower and fruit from mid-June until mid-October.

Typha domingensis Persoon, Southern Cattail, (G4G5/S2S3):

Though Fernald (1935) did not locate *Typha domingensis* within the boundaries of the Park, he did note the species' general abundance in the marshes of Back Bay. Many subpopulations of this species were found in 1990, forming pure stands in the marshes of False Cape State Park and dominating small areas with its congener, *Typha angustifolia* L.

Vaccinium macrocarpon Aiton, Large Cranberry, (G4/S2S3):

This species was seen in 1990 in two of the Park's interdunal swales, one east of the Wash Woods and the other within 1 km of the southern boundary. The plants occurred in the sandier swales near and under tall shrubs. Immature fruits were observed in mid-August.

Discussion

According to the Division of Natural Heritage (unpublished data), the total of 37 rare plants recorded at False Cape State Park is a higher number than any area of similar size in Virginia. This high number is due, in part, to the geographic position of the Park which is situated at the southeastern corner of the state. Refer to Knepper, *et al* (1990) for phytogeographical information on rare plant distributions and the significance of this region.

Another reason for the high number of rare species is the quality and density of False Cape State Park's natural communities. Currently the active, natural hydrologic and geologic processes are undisturbed in most of the Park. This results in an expansive natural area with little evidence of recent human disturbance.

A number of the natural communities at False Cape are rare or uncommon in Virginia which also contributes to the high number of rare species. The interdunal swales at False Cape, a very rare wetland type in Virginia, illustrate that a rare natural community can have a high number of rare species. In 1990, 11 rare plants were recorded in the interdunal swales.

In addition to the significant number of rare species, many of the rare plants at False Cape State Park had extensive and vigorous populations. *Bacopa monnieri* (L.) Wettstein, *Cyperus haspan* L., *Drosera intermedia* Hayne, *Juncus megacephalus* M.A. Curtis, *Lilaeopsis carolinensis* C.&R., *Ludwigia brevipes* (Long) Eames, *Quercus hemisphaerica* Bartr., *Rhynchospora fascicularis* (Michaux) Vahl, *Triglochin striata* R.&P., and *Typha domingensis* Persoon occurred in large numbers over relatively large areas. Assuming unaltered land use, these species should persist in the Park.

There were seven species previously recorded at False Cape State Park which were not located during 1990 work. Even though time was taken to check for those species, more thorough field work is needed to determine if the species still occur within the Park or if the species were overlooked in 1990. Since four of the seven species which could not be located were historically recorded from the interdunal swales, future work should concentrate in this habitat.

The ultimate goal of this inventory was to provide data to determine management needs for the rare plants of the Park. To prioritize management requirements, the Park's rare plant species were sorted by habitat type. For rare species in each of the habitats listed in the summary below, management recommendations are prescribed based on the condition of the habitat and the rare species present.

Rare plants of Back Bay marshes (13 species)

Aster elliottii
Bacopa monnieri
Cyperus haspan
Dichromena colorata
Eleocharis rostellata
Juncus megacephalus
Lilaeopsis caroliniana
Lippia nodiflora
Lobelia elongata
Ludwigia alata
Spiranthes odorata
Triglochin striata
Typha domingensis

Rare plants of interdunal swales (11 species)

Bacopa monnieri
Cladium mariscoides
Cyperus haspan
Drosera intermedia
Erigeron vernus
Fimbristylis caroliniana
Juncus elliottii
Juncus megacephalus
Ludwigia brevipes
Rhynchospora fascicularis
Vaccinium macrocarpon

Rare plants of waterfowl impoundments (10 species)

Bacopa monnieri
Cyperus haspan
Dichromena colorata
Drosera intermedia
Eleocharis halophila
Juncus megacephalus
Lilaeopsis carolinensis
Ludwigia brevipes
Paspalum distichum
Triglochin striata

Rare plants of open dunes (4 species)

Euphorbia ammannioides
Physalis viscosa
Iva imbricata
Heterotheca gossipyna

Rare plants of wet, mowed areas (3 species)

Dichromena colorata
Erigeron vernus
Fimbristylis carolin.

Rare plants of maritime forest (2 species)

Quercus hemisphaerica
Tillandsia usneoides

Rare plants of wet, sandy roadsides (2 species)

Juncus crassifolius
Rhynchospora fascicularis

The habitat with the greatest number of rare plants was the marsh of Back Bay with 13 species observed in 1990. The primary threat to the marsh flora appears to be the abundance of the aggressive Common Reed, *Phragmites communis* (Cav.) Steudel. This grass quickly invades disturbed wetlands and has already formed extensive dense stands throughout the Park's marshes to the exclusion of most other plant species.

The first management recommendation regarding this threat is to minimize mechanical disturbance to the marsh so as to reduce the invasive ability of *Phragmites*. The second recommendation is to establish a long-term monitoring program to determine if the species is continuing to spread within the marsh. If it is determined that this is the case, immediate control measures are recommended. No other threats to rare plants within the marsh were identified. If *Phragmites* invasion can be stopped or reversed, the future of the rare species in the marsh appears secure.

The habitat identified with the next highest number of rare plants was the interdunal swales where 11 species were observed. The immediate threat identified to the flora of the swales was rooting and grazing by pigs, horses, and deer. Numerous trenches through the sandy or muddy swale bottoms created by rooting feral pigs in 1990 were evidence of this threat. Also in 1990, a *Sagittaria* species was severely grazed in 3 interdunal swales and none of the hundreds of individuals flowered. These plants only managed to produce small leaves by the end of the season.

Currently a hunting season is used to control populations of feral pigs and deer. A continuation of current hunting policy is recommended plus the establishment of a monitoring program to determine if there is damage to rare plant populations which may cause the loss of species in the Park's swales. If the possibility of this loss is documented, then a change in hunting is recommended to adequately control pig and deer populations. If grazing is causing a possible loss of rare species, another recommendation to ameliorate the threat is to eliminate or limit the number of horses which currently roam through the Park.

The rare flora of the interdunal swales is subject to two long-term threats. First, *Phragmites communis* (Cav.) Steudel, a threat to the flora of other areas of the Park, may invade the interdunal swales, threatening the rare flora of this habitat. Periodic monitoring of the swales for the presence of *Phragmites* is recommended and control measures should be taken if needed. The second long-term threat to rare species is succession of the swales from open herbaceous wetlands to shrub swamp. Although data were not collected on the rate of this succession, observations suggest that, at some point in time the swales will not provide the open, herbaceous areas necessary for most of the rare species to persist. Monitoring of successional trends in the interdunal swales is recommended.

There were 10 rare plants which were found in the waterfowl impoundments in 1990. Like the marshes of Back Bay, the flora of the impoundments are threatened by the Common Reed, *Phragmites communis* (Cav.) Steudel, which is common in dense patches in some areas of the impoundments.

Recommendations to ameliorate this threat follow those for Back Bay; minimize mechanical disturbance and monitor the *Phragmites* to determine the rate of spreading. If the species is spreading, then immediate actions should be taken to halt this invasion. Since the water levels of the impoundments are manipulated artificially, an additional recommendation is to study the effects of this manipulation on the spread of *Phragmites*. No other threats to rare plants within the impoundments were identified. If the *Phragmites* invasion can be stopped or reversed, the future of the rare species appears secure.

Six rare species were observed in the open dunes and maritime forests where no threat to the flora was observed. If land use is not altered in the Park, the rare species of these habitats appear viable.

Little special management is recommended for the rare species which were found in wet, mowed areas and the wet, sandy roadsides. Since all species found in these areas except *Juncus crassifolius* Buchneau are more common in natural habitats elsewhere in the Park, management is only recommended for the *Juncus*. Where this species occurs, a management plan which includes monitoring of population levels and roadside maintenance is recommended. Maintenance practices should be adjusted if the population declines.

Even though there are threats to the rare flora of False Cape State Park, the Park represents the most significant refuge for natural vegetation and rare plants within the Back Bay watershed and one of the most significant concentrations of rare plants within the Commonwealth. In contrast with other lands within the watershed, the southern 90% of False Cape State Park is managed for its natural area values. Manipulative or damaging management practices including ditching, impoundments, hydrological alteration, road and building construction, and silviculture have largely been avoided.

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A Catalog of the Vascular Flora of the Back Bay Watershed

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Abstract: The Back Bay Region has long been known for the richness of its flora. This catalog is an attempt to bring together all the known listings of the flora, both historic and recent. Previous references to the flora of this area are also provided in the bibliography. The area under discussion includes False Cape State Park, Back Bay National Wildlife Refuge (including its proposed expansion), the community of Sandbridge ending at the Dam Neck Naval Fleet Combat Training Center fence, Trojan and Pocahontas Waterfowl Management Areas, Mackay Island National Wildlife Refuge north of the causeway, the Virginia portion of Knotts Island, and other public and private lands and waterways draining into the bay. The Catalog presently is comprised of 109 families, with 309 genera encompassing 574 species.

Over fifty of the plants listed are currently on the Virginia Natural Heritage Program's list of rare species. It is obvious that further destruction of their natural habitats can only speed the extirpation of many of these species.

Methods

Several different methods have been used to obtain the information used in this compendium of species. By far, the greatest number of species were added through personal field observation and collection, either alone, or in the company of other experienced field botanists. Among these experts were J.Christopher Ludwig, James E. Perry, Richard Stalter, Eric Lamont, Thomas Padgett, Byron Carmean, and Lytton J. Musselman. A second source were collections at the Old Dominion University Herbarium and the Back Bay National Wildlife Refuge. The third source was the historical record including the journals Rhodora and Castanea. Several entries were added through personal interviews with other Back Bay enthusiasts. The authors personal collection is at the Old Dominion University (ODU) Herbarium. Nomenclature follows the Manual of the Vascular Flora of the Carolinas (Radford, et al. 1968).

Catalog

** denotes from historical records (pre 1971) only.*

FERNS AND FERN ALLIES

LYCOPODIACEAE Club Moss Family
Lycopodium appressum (Chapm.) Lloyd & Underw.

OPHIOGLOSSACEAE Adder's Tongue Family
Ophioglossum vulgatum L.

OSMUNDACEAE Flowering Fern Family
Osmunda cinnamomea L.
O. regalis var. spectabilis (Willd.) Gray

PTERIDACEAE Bracken Fern Family
Pteridium aquilinum (L.) Kuhn

ASPIDACEAE
Thelypteris palustris Schott

BLECHNACEAE Chain-Fern Family
Woodwardia areolata (L.) Moore
W. virginica (L.) Smith

ASPLENIACEAE
Asplenium platyneuron (L.) Oakes

AZOLLACEAE Mosquito Fern Family
Azolla caroliniana Willd.

GYMNOSPERMS

PINACEAE Pine Family
Pinus serotina Michaux
P. taeda L.
P. virginiana Miller

TAXODIACEAE Bald Cypress Family
Taxodium distichum (L.) Richard

CUPRESSACEAE Juniper Family
Juniperus virginiana L.

ANGIOSPERMS

MONOCOTS

TYPHACEAE Cat-tail Family
Typha angustifolia L.
T. domingensis Persoon
T. latifolia L.

SPARGANIACEAE Bur-reed Family

Sparganium androcladum (Engelm.) Morong

POTAMOGETONACEAE Pondweed Family

Potamogeton pectinatus L.
P. perfoliatus var. bupleuroides (Fern.) Farwell
P. pulcher Tuckerm.

RUPPIACEAE Ditch-Grass Family

Ruppia maritima L.

ZANNICHELLIACEAE Horned Pondweed Family

Zannichellia palustris L.

NAJADACEAE Naiad Family

Najas quadalupensis (Spreng.) Magnus

JUNCAGINACEAE Arrow-Grass Family

Triglochin striata R. & P.

ALISMATACEAE Water-Plantain Family

Sagittaria falcata Pursh
S. graminea Michaux
S. latifolia Willd.
S. subulata Buch.

HYDROCHARITACEAE Frog's-Bit Family

Elodea nutallii (Planch.) St.John
Limnobium spongia (Bosc) Steudel
Vallisneria americana Michaux

POACEAE Grass Family

Aira caryophyllea L.
Ammophila breviligulata Fernald
Andropogon scoparius Michaux
A. virginicus L. var. glomeratus (Walter) DC.
Anthoxanthum odoratum L.
Aristida lanosa Muhl. ex Ell.
Arundinaria gigantea (Walter) Muhl.
Bromus sp.
Cenchrus tribuloides L.
Cynodon dactylon (L.) Persoon
Dactylis glomerata L.
Distichlis spicata (L.) Greene
Echinochloa crusgalli (L.) Beauvois
E. walteri (Pursh) Heller
Eleusine indica (L.) Gaertn.
Elymus riparius Wiegand.
E. villosus Muhl.
E. virginicus L.
Eragrostis elliottii Watson
E. hirsuta (Michaux) Nees
E. peregrina Weig.
E. refracta (Muhl.) Scribner
E. spectabilis (Pursh) Steudel
Erianthus cortortus Baldw. ex Ell.
E. giganteus (Walter) Muhl.
Festuca eleator L.
F. myuros L.
F. octoflora Walter
Glyceria septentrionalis Hitchcock
Leersia oryzoides (L.) Swartz
Leptochloa fascicularis (Lam.) Gray
**Melica mutica* Walter
Panicum aciculare Desvaux ex Poiret
P. agrostoides var. *condensum* (Nash) Fernald
P. amarulum Hitch. & Chase
P. amarum L.
P. anceps Michaux
P. boscii Poiret
P. dichotomiflorum Michaux
P. dichotomum L.
P. ensifolium Baldwin ex Ell.
P. lancearium Trinius
P. scoparium Lam.
**P. sphagnicola* Nash
P. spretum Schultes
P. villosissimum var. *pseudopubescens* (Nash) Fernald
P. virgatum Schultes
Paspalum dilatatum Poiret
P. distichum L.
P. setaceum Michx. var. *supinum* (Bosc) Trin.
**Phalaris caroliniana* Walter
Phragmites australis (Cav.) Steudel
Poa annua L.
Polypogon monspeliensis (L.) Desf.
Sacciolepis striata (L.) Nash
Setaria geniculata (Lam.) Beauv.
S. magna Grisebach
S. viridis (L.) Beauvois
Sorghum halepense (L.) Persoon
Spartina alterniflora Loisel.
S. cynosuroides (L.) Roth
S. patens (Aiton) Muhl.
Sphenopholis obtusata (Michaux) Scribner
**Sporobolus asper* (Michaux) Kunth
S. poiretii R. & S.
Triplasis purpurea (Walter) Chapman
Tripsacum dactyloides L.
Uniola laxa (L.) BSP.
U. paniculata L.
Zizania aquatica L.

CYPERACEAE Sedge Family

Bulbostylis capillaris (L.) Clark var. *isopoda* Fernald
**B. ciliatifolia* (Ell.) Clark
Carex alata Torrey
C. comosa Boott
C. frankii Kunth
C. howei Mackenzie
C. kobomugi Ohwi
C. nigromarginata Schweinitz
**C. reniformis* (Bailey) Small
C. retroflexa Muhl. ex Schkuhr
C. vulpinoidea Michaux
Cladium jamaicense Crantz
C. mariscoides (Muhl.) Torrey
Cyperus albomarginatus Martius & Schrader ex Nees
C. compressus L.
C. engelmanii Steudel
C. erythrorhizos Muhl.
C. flavescens L.
C. haspan L.
C. ovularis (Michaux) Torrey
C. polystachyos var. *texensis* (Torrey) Fernald
C. retrorsus var. *Nashii* (Britton) Fernald
C. rivularis Kunth
C. strigosus L.
C. tenuifolius (Steudel) Dandy
Dichromena colorata (L.) Hitchcock
Dulichium arundunaceum (L.) Britton
Eleocharis albida Torrey
E. ambigens Fernald
E. falax Weatherby

E. flavescens (Poiret) Urban
E. halophila Fernald & Brack.
E. obtusa (Willd.) Schultes
E. parvula (R. & S.) Link
E. quadrangulata (Michaux) R. & S.
**E. radicans* (Poiret) Kunth
E. rostellata Torrey
E. tuberculosa (Michaux) R. & S.
Fimbristylis autumnalis (L.) R. & S.
F. puberula (Michaux) Vahl *forma pycnostachya* Fernald
F. spadicea (L.) Vahl
Fuirena pumila Torrey
F. squarrosa Michaux
Lipocarpha maculata (Michaux) Torrey
Rhynchospora caduca Ell.
R. fascicularis (Michaux) Vahl
R. inexpansa (Michaux) Vahl
R. macrostachya Torrey
R. rariflora (Michx.) Ell.
Scirpus acutus Muhl.
S. americanus Persoon
S. cyperinus (L.) Kunth
S. olneyi Gray
S. robustus Pursh
S. validus Vahl

ARACEAE Arum Family
Acorus calamus L.
Orontium aquaticum L.

LEMNACEAE Duckweed Family
Lemna perpusilla Torrey
Spirodela oligorrhiza (Kurz) Hegelm.
S. polyrrhiza (L.) Schleid
Wolffia columbiana Karsten
W. papulifera Thompson
Wolffiella floridana (J.D.Smith) Thompson

XYRIDACEAE Yellow-eyed Grass Family
Xyris caroliniana Walter
**X. difformis* Chapman
X. jupicai Richard

BROMELIACEAE Pineapple Family
Tillandsia usneoides L.

COMMELINACEAE Spiderwort Family
Aneilema keisak Hasskarl
Commelina communis L.
C. diffusa Burman f.
C. virginica L.

PONTEDERIACEAE Pickerelweed Family
Heteranthera reniformis R. & P.
Pontederia cordata L.

JUNCACEAE Rush Family
Juncus abortivus Chapman
J. acuminatus Michaux
J. biflorus Ell.
J. bufonius L.
J. canadensis J.Gay ex LaHarpe
J. coriaceus Mackenzie
J. dichotomus Ell.
J. effusus L.
J. elliottii Chapman
J. marginatus Rostk.
J. megacephalus M.A.Curtis
J. repens Michaux
J. roemarianus Scheele
J. scirpoides Lam.
J. tenuis Willd.
J. validus Coville

LILIACEAE Lily Family
Allium vineale L.
Hemerocallis fulva L.
Ornithogalum umbellatum L.
Smilax bona-nox L.
S. glauca Walter
S. laurifolia L.
S. rotundifolia L.
Yucca filamentosa var. *filamentosa* L.
Y. gloriosa

IRIDACEAE Iris Family
Iris virginica L.
Sisyrinchium angustifolium Miller
S. mucronatum Michx. var. *atlanticum* (Bicknell) Ahles

ORCHIDACEAE Orchid Family
**Calopogon pallidus* Chapman
C. pulchellus (Salisbury) R.Brown
Cypripedium acaule Aiton
Goodyera pubescens (Willd.) R. Brown
Habenaria cristata (Michaux) R. Brown
**Liparis lilifolia* (L.) Richard
**Listera australis* Lindley
**Malaxis unifolia* Michaux
Pogonia ophioglossoides (L.) Ker
Spiranthes cernua (L.) Richard var. *odorata* (Nutt.) Correll
S. praecox (Walter) Watson
S. vernalis Engelm. & Gray

DICOTS

SAURURACEAE Lizard's tail Family
Saururus cernuus L.

SALICACEAE Willow Family
Populus heterophylla L.
Salix caroliniana Michaux
S. nigra Marshall

MYRICACEAE Wax-Myrtle Family
Myrica cerifera L.
M. heterophylla Raf.
M. pensylvanica Loisel.

JUGLANDACEAE Walnut Family
Carya tomentosa (Poiret) Nuttall

BETULACEAE Birch Family
Betula nigra L.
Carpinus caroliniana Walter

FAGACEAE Beech Family
Castanea pumila (L.) Miller
Fagus grandifolia Ehrhart
Quercus alba L.
Q. falcata Michaux
Q. hemisphaerica Bartram
Q. incana Bartram
Q. laurifolia Michaux

Q. michauxii Nuttall
Q. nigra L.
Q. phellos L.
Q. virginiana Miller

ULMACEAE Elm Family
Celtis laevigata Willd.
**C. laevigata* Willd. var. *smallii* (Beadle) Sargent
C. occidentalis L.

MORACEAE Mulberry Family
Morus alba L.
M. rubra L.

URTICACEAE Nettle Family
Boehmeria cylindrica (L.) Swartz
Pilea pumila (L.) Gray

LORANTHACEAE Mistletoe Family
Phoradendron serotinum (Raf.) M.C.Johnston

ARISTOLOCHIACEAE Birthwort Family
**Hexastylis arifolium* (Michaux) Small

POLYGONACEAE Buckwheat Family
Polygonella articulata (L.) Meisner
Polygonum arifolium L.
P. aviculare L.
P. hydropiperoides Michaux
P. pensylvanicum L.
P. persicaria L.
P. prolificum (Small) Robinson
P. punctatum L.
P. sagittatum L.
Rumex acetosella L.
R. conglomeratus Murray
R. crispus L.
R. verticillatus L.

CHENOPODIACEAE Goosefoot Family
Atriplex patula L.
Chenopodium album L.
C. ambrosioides L.
Salsola kali L.
**Suaeda linearis* (Ell.) Moq.

AMARANTHACEAE Amaranth Family
Alternanthera philoxeroides Grisebach
Amaranthus cannabinus (L.) J.D.Sauer
**Iresine rhizomatosa* Standley

PHYTOLACCACEAE Pokeweed Family
Phytolacca americana L.

AIZOACEAE Carpet-weed Family
Mollugo verticillata L.
**Sesuvium maritimum* (Walter) BSP.

CARYOPHYLLACEAE Pink Family
**Arenaria lanuginosa* (Michaux) Rohrbak
**Paronychia riparia* Chapman
Scleranthus annuus L.
Silene caroliniana Walter
Spergularia marina (L.) Grisebach
Stellaria media (L.) Cyrillo

CERATOPHYLLACEAE Hornwort Family
Ceratophyllum demersum L.

NYMPHAEACEAE Water Lily Family
Nymphaea odorata Aiton

NELUMBONACEAE Sacred Bean Family
Nelumbo lutea (Willd.) Persoon

RANUNCULACAEA Crowfoot Family
Ranunculus hederaceus L.
R. pusillus Poiret
R. scleratus L.

MAGNOLIACEAE Magnolia Family
Liriodendron tulipifera L.
Magnolia grandiflora L.
M. virginiana L.

LAURACEAE Laurel Family
Persea borbonia (L.) Sprengel
Sassafras albidum (Nutt.) Nees

BRASSICACEAE Mustard Family
Arabidopsis thaliana (L.) Heynhold
Cakile edentula (Bigelow) Hooker
Capsella bursa-pastoris (L.) Medicus
Cardimine hirsuta L.
C. parviflora (Britton) O.E.Schulz
Lepidium virginicum L.

DROSERACEAE Sundew Family
Drosera capillaris Poiret
D. intermedia Hayne
D. rotundifolia L.

HAMAMELIDACEAE Witch-Hazel Family
Hamamelis virginiana L.
Liquidambar styraciflua L.

ROSACEAE Rose Family
**Agrimonia mollis* (T.& G.) Britton
A. parviflora Aiton
Amelanchier canadensis (L.) Medicus
Crataegus crus-galli L.
C. phaenopyrum (L. f.) Medic
Duchesne indica (Andrz.) Focke
Geum canadense Jacquin
Potentilla canadense L.
Prunus serotina Ehrhart
Rosa carolina L.
R. palustris Marshall
Rubus argutus Link
R. cuneifolius Pursh
Sorbus arbutifolia (L.) Heynhold

FABACEAE Pea Family
Albizza julibrissin Durazzini
Cassia fasciculata Michaux
C. nictitans L.
Desmodium paniculatum (L.) DC.
D. strictum (Pursh) DC.
Galactia regularis (L.) BSP.
Lespedeza capitata Michaux
L. cuneata (Dumont) G. Don
Melilotus alba Desr.
Strophostyles helvola (L.) Ell.
S. umbellata (Muhl. ex Willd.) Britton
Trifolium arvense L.
T. dubium Sibthorp
T. hybridum L.
T. pratense L.
T. repens L.
Vicia angustifolia Reichard

LINACEAE Flax Family
Linum virginianum L. var. *medium* Planchon

OXALIDACEAE Wood-sorrel Family
Oxalis florida var. *filipes* (Small) Ahles

GERANIACEAE Geranium Family
Geranium carolinianum L.
G. molle L.

RUTACEAE
Zanthoxylum clava-herculis L.

POLYGALACEAE Milkwort Family
Polygala curtissii Gray
P. mariana Miller

EUPHORBIACEAE Spurge Family
Cnidoscolus stimulosus Michaux
Croton glandulosus var. *septentrionalis* Muell-Arg.
Euphorbia ammannioides HBK.
E. maculata L.
E. polygonifolia L.
E. supina Raf.

ANACARDIACEAE Cashew Family
Rhus copallina L.
R. radicans L.
R. toxicodendron L.
R. vernix L.

AQUIFOLIACEAE Holly Family
Ilex glabra (L.) Gray
I. opaca Aiton
I. vomitoria Aiton

CELASTRACEAE Staff-tree Family
Euonymus americanus L.

ACERACEAE Maple Family
Acer rubrum L.

RHAMNACEAE Buckthorn Family
Berchemia scandens (Hill) Koch

VITACEAE Grape Family
Ampelopsis arborea (L.) Koehne
Parthenocissus quinquefolia (L.) Planchon
Vitis aestivalis Michaux
V. cinera Engelm.
V. labrusca L.
V. rotundifolia Michaux
**V. vulpina* L.

MALVACEAE Mallow Family
Hibiscus moscheutos L.
Kosteletskya virginica (L.) Presl

HYPERICACEAE St. John's-wort Family
Hypericum gentianoides (L.) BSP.
H. hypericoides (L.) Crantz
H. mutilum L.
**H. prolificum* L.
H. stans (Michaux) P. Adams & Robson
H. virginicum L.

CISTACEAE Rockrose Family
Helianthemum canadense (L.) Michaux
Hudsonia tomentosa Nuttall
Lechea maritima Leggett var. *virginica*
L. villosa Ell.

VIOLACEAE Violet Family
**Viola brittoniana* Pollard
V. lanceolata L.
V. palmata L. var. *soraria* (Willd.) Pollard

CACTACEAE Cactus Family
Opuntia compressa (Salisbury) Macbride
O. drummondii Graham

ELAEAGNACEAE
Elaeagnus pungens Thunberg
E. umbellata Thunberg

LYTHRACEAE Loosestrife Family
Ammannia coccinea Rottbell
A. teres Raf.
Decodon verticellatus (L.) Ell.
Lythrum lineare L.
Rotala ramosior (L.) Koehne

MELASTOMATACEAE Meadow Beauty Family
Rhexia mariana L.

ONAGRACEAE Evening-Primrose Family
Ludwigia alata Ell.
L. alternifolia L.
L. brevipes (Long) Eames
L. linearis Walter
L. palustris (L.) Ell.
L. repens Forster
L. sphaerocarpa Ell.
Oenothera biennis L.
O. humifusa Nuttall
O. lacinata Hill

HALORAGACEAE Water-milfoil Family
Myriophyllum brasiliensis Camb.
M. exalbescens Fernald
M. pinnatum (Walter) BSP.
Proserpinaca palustris L.

ARALIACEAE Ginseng Family
Aralia spinosa L.
Hedera helix L.

APIACEAE Parsley Family
Centella asiatica (L.) Urban
Cicuta maculata L.
Daucus carota L.
Foeniculum vulgare Miller
Hydrocotyle bonariensis Lam.
H. ranunculoides L.
H. umbellata L.
H. verticillata Thunb. var. *triradiata* (A.Richard) Fernald
Lilaeopsis carolinensis C. & R.
L. chinensis (L.) Kuntze
Ptilimnium capillaceum (Michaux) Raf.
Sium suave Walter

NYSSACEAE Sour Gum Family
Nyssa sylvatica Marshall var. *biflora* (Walter) Sargent

CORNACEAE Dogwood Family
Cornus florida L.
C. stricta Lam.

CLETHRACEAE White Alder Family
Clethra alnifolia L.

ERICACEAE Heath Family
Chimaphila maculata (L.) Pursh
Gaylussacia baccata (Wang.) K.Koch
G. frondosa (L.) T. & G.
Oxydendrum arboreum (L.) DC.
Rhododendron viscosum (L.) Torrey
Vaccinium corymbosum L.
V. macrocarpon Aiton
V. stamineum L.

PRIMULACEAE Primrose Family
Anagallis arvensis L.
Samolus parviflorus Raf.

EBENACEAE Ebony Family
Diospyros virginiana L.

LOGANIACEAE Logania Family
Gelsemium sempervirens (L.) Aiton
Polypremum procumbens L.

GENTIANACEAE Gentian Family
Bartonia virginica (L.) BSP.
Obolaria virginica L.
**Sabatia brachiata* Ell.
S. dodecandra (L.) BSP.
S. stellaris Pursh

APOCYNACEAE Dogbane Family
Apocynum cannabinum L.
Vinca major L.

ASCLEPIADACEAE Milkweed Family
Asclepias incarnata L.
A. lanceolata Walter

CONVOLVULACEAE Morning-glory Family
Calystegia sepium (L.) R.Brown
Cuscuta campestris Yuncker
Dichondra carolinensis Michaux
Ipomoea coccinea L.
I. hederacea var. *hederacea* (L.) Jacquin
I. lacunosa L.
I. pandurata (L.) G.F.W. Meyer
I. purpurea (L.) Roth

HYDROPHYLLACEAE Waterleaf Family
**Hydrolea quadrivalis* Walter

BORAGINACEAE Borage Family
**Heliotropium curassavicum* L.

VERBENACEAE Vervain Family
Callicarpa americana L.
Lippia lanceolata Michaux
L. nodiflora (L.) Michaux
Verbena officinalis L.
V. scabra Vahl

LAMIACEAE Mint Family
Glechoma hederacea L.
Lamium amplexicaule L.
L. purpureum L.
Lycopus rubellus Moench var. *angustifolius* (Ell.) Ahles
L. virginicus L.
Monarda punctata L.
Prunella vulgaris L.
Scutellaria integrifolia L.
Stachys nuttallii Shuttlew.
Teucrium canadense L.

SOLANACEAE Nightshade Family
Datura stramonium L.
**Physalis pubescens* L.
P. viscosa ssp. maritima (M.A.Curtis) Waterfall
Solanum carolinense L.

SCROPHULARIACEAE Figwort Family
Agalinis purpurea (L.) Pennell
Bacopa monnieri (L.) Pennell
Gratiola pilosa Michaux
**Limosella subulata* Ives
Linaria canadensis (L.) Dumont
Lindernia anagallidea (Michaux) Pennell
**Mimulus alatus* Aiton
Paulownia tomentosa (Thunb.) Steudel
Trichostema dichotomum L.
Verbascum blattaria L.
V. thapsus L.
Veronica officinalis L.

BIGNONIACEAE Trumpet-Creeper Family
Campsis radicans (L.) Seemann

OROBANCHACEAE Broom-rape Family
Epifagus virginiana (L.) Barton

LENTIBULARIACEAE Bladderwort Family
Utricularia biflora Lam.
U. inflata Walter
U. subulata L.

PLANTAGINACEAE Plantain Family
Plantago aristata Michaux
P. lanceolata L.
P. major L.
P. rugelii Dcne.
P. virginica L.

RUBIACEAE Madder Family
Cephalanthus occidentalis L.
Diodia teres Walter
D. virginiana L.
Galium aparine L.
G. circaezans Michaux
G. hispidulum Michaux
G. obtusum var. *obtusum* Bigelow
G. tinctorium L.
Mitchella repens L.
Oldenlandia uniflora L.

CAPRIFOLIACEAE Honysuckle Family
Lonicera japonica Thunberg
L. sempervirens L.
Sambucus canadensis L.
Viburnum nudum L.

CUCURBITACEAE Gourd Family
Melothria pendula L.

CAMPANULACEAE Bluebell Family
Lobelia cardinalis L.
L. elongata Small
L. inflata L.
Specularia biflora (R.& P.) F.& M.

ASTERACEAE Composite Family
Achillea millefolium L.
Ambrosia artemisiifolia L.
Artemisia stellariana Bess.
A. vulgaris L.

ASTERACEAE Composite Family (continued)

Aster dumosus L.
A. elliottii T.& G.
A. puniceus L.
A. racemosus Ell.
A. tenuifolius L.
Baccharis halimifolia L.
Bidens bipinnata L.
B. cernua L.
B. discoidea (T. & G.) Britton
B. mitis (Michaux) Sherff
B. vulgata Greene
Cichorium intybus L.
Carduus spinosissimus Walter
Conyza canadensis (L.) Cronquist
Coreopsis latifolia Michaux
Elephantopus carolinianus Willd.
E. nudatus Gray
E. tomentosus L.
Erechitites hieracifolia (L.) Raf.
Erigeron annuus (L.) Persoon
E. bonariensis L.
**E. canadensis* L. var. *pusillus* (Nutt.) Ahles
E. philadelphicus L.
E. vernus (L.) T. & G.
Eupatorium capillifolium (Lam.) Small
E. coelestinum L.
E. hyssopifolium L.
E. perfoliatum L.
E. rotundifolium L.
E. serotinum Michaux
Gaillardia pulchella Foug.
Gnaphalium obtusifolium L.
G. purpureum L.
Helenium amarum (Raf.) H. Rock
Heterotheca gossypina (Michaux) Shinners
H. graminifolia (Michaux) Shinners
H. mariana (L.) Shinners
Hieracium gronovii L.
H. venosum L.
Hypochoeris radicata L.
Iva frutescens L.
I. imbricata Walter
Krigia virginica (L.) Willd.
Lactuca canadensis L.
Mikania scandens (L.) Willd.
Pluchea foetida (L.) DC.
P. purpurascens (Swartz) DC.
Pyrrhopappus carolinianus (Walter) DC.
Senecio tomentosus Michaux
Solidago erecta Pursh
S. fistulosa Miller
S. graminifolia (L.) Salisbury
S. microcephala (Greene) Bush
S. nemoralis Aiton
S. odora Aiton
S. puberula Nuttall
S. sempervirens L. var. *mexicana* (L.) Fernald
S. tenuifolia Pursh
Sonchus oleraceus L.
Taraxacum officinale Wiggers
Vernonia glauca (L.) Willd.
V. noveboracensis (L.) Michaux
Xanthium strumarium L.

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Submerged Aquatic Vegetation Trends of Back Bay, Virginia

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Introduction

Submerged aquatic vegetation (SAV) is an important part of a healthy Back Bay ecosystem. SAV helps to stabilize sediments that enter the system and to deter shoreline erosion. The submerged macrophytes serve as filters, improving the quality of the water column by removing many pollutants and dissolved nutrients (Clark, *et al.*, 1973; and Stevenson, *et al.*, 1979). These aquatic plants provide important habitats for a variety of wildlife species, which use the grass beds for shelter, feeding and breeding areas. SAV is a major primary producer in the food chain associated within the aquatic and adjoining upland habitats. The added physical characteristics of the plants within the aquatic environment allow for a greater diversity of wildlife species, when compared to habitats not supporting SAV (Stevenson & Confer, 1978).

SAV has declined in many areas along the East Coast of the United States. Declines in waters of Virginia are well known: the Chesapeake Bay (Stevenson & Confer, 1978; Stevenson, et al., 1979; and Hurley, 1990), the Potomac River (Carter, et al., 1983), and Back Bay (Sincock, *et al.*, 1965; Settle & Coggin, 1976; and Schwab, 1984). In most waters SAV has fluctuated in density, species composition and frequency. Declines in SAV vary with the body of water and have been reported to be caused by disease, run-off, changes in salinity, turbidity, weather and various natural occurrences (Stevenson & Confer, 1978; Carter, *et al.*, 1983; Hurley, 1990; and Sincock, *et al.*, 1965).

Vegetation sampling transects on Back Bay were established in 1958 (Sincock, *et al.*, 1965) and surveys have been conducted annually except for five years. The survey originally included volumes, however in 1974 the volume measurement was deleted; since then only SAV species and their frequencies have been recorded. (Settle and Coggin, 1975).

Methods

Aquatic vegetation is sampled during the September to November period. SAV frequency and species composition are determined through collection of three two-square-foot bottom samples taken at 500 foot intervals along eight transect lines (Fig. 1). Modified oyster tongs are used to collect a total of 264 samples.

Trends

Prior to Sincock's (1965) data collection, little quantitative data were available. The natural closing of the Currituck Sound Inlet in 1830 changed Back Bay from a saltwater estuary to a brackish to freshwater ecosystem. Waterfield (1951), Chief of Survey Branch, Army Corps of Engineers, Norfolk District, reported that SAV in the years 1923-24 "noticeably began to disappear." In August of 1956 it was reported that SAV was "very scarce" in Back Bay and that in 1955 SAV was "95% more abundant" than in 1956 (Waterfield, 1956). Although there was considerable interest in the Back Bay ecosystem, no large scale surveys were undertaken until 1958.

In 1958 the U. S. Fish and Wildlife Service (then known as the Bureau of Sport Fisheries and Wildlife) and the states of Virginia and North Carolina began an extensive survey of the Back Bay/Currituck Sound ecosystems. The Survey was headed by John L. Sincock, then Chief, Section of Wetland Ecology of the Bureau, and included personnel from the Virginia Commission of Game and Inland Fisheries and the North Carolina Wildlife Resources Commission. The survey on vegetation, waterfowl, fish and environmental parameters from 1958 through 1964 resulted in four volumes of data, little of which has been published.

The focus of this paper is on SAV trends in Back Bay, VA and all the data for 1958 through 1964 have been taken from the Back Bay-Currituck Sound Data Report (Sincock, *et al.*, 1965). The data available after 1964 have been gathered from the Virginia Department of Game and Inland Fisheries (VDGIF) Annual Pittman- Robertson Reports. There were five years (1979, 1981-82 and 1985- 86) when the SAV transects were not surveyed.

The Sincock Data Report (1965) covered a seven year period when SAV frequency in 1958 was 51%, peaked at 81% in 1962 and dropped to 14% in 1964 (Fig. 2). The dominant SAV species during five years of the survey period was southern naiad (*Najas guadalupensis*) (Sincock, *et al.*, 1965). In 1963, naiad was the second most common species and by 1964 had nearly disappeared from the transects.

The years 1965 and 1966 had the lowest frequencies (12%) recorded for the Bay prior to 1984 (Coggin, 1966; and Schwab, 1985). In 1965 the 36 inch diameter pipe and pump were installed to increase the salinity in Back Bay (Coggin, 1966). Eurasian milfoil (*Myriophyllum spicatum*) was noted in small trace amounts for the first time in 1966, and occurred on 12% of the survey points in 1967 (Coggin, 1968).

Milfoil was the predominate SAV species recorded on all eight transects from 1971 to 1978 and all frequencies were over 50% (Settle and Taylor, 1979). The SAV transect survey was not conducted in 1979 (Settle and Taylor, 1980). SAV frequency dropped from 72% in 1978 to 50% in 1980; milfoil was present on 44% of the points surveyed, and remained the most common SAV species encountered (Settle, 1981).

During the years 1981 and 1982, the SAV transects were not surveyed. The survey was conducted in 1983 and the frequency of aquatic vegetation had dropped to 14%, with milfoil the most frequently found species (Schwab, 1984). In 1984 the Bay was nearly void of SAV species with only 8% (7% milfoil) of the points having any vegetation present (Schwab, 1985). In Buck Island Bay, Major Cove and Horse Island Creek, areas not surveyed by the transects, good growths of milfoil, wildcelery (*Vallisneria americana*) and muskgrass (*Chara* spp.) were noted (Schwab, 1985). Again, the SAV survey was not conducted during 1985 and 1986. In 1986 an attempt to introduce hydrilla (*Hydrilla verticillata*) to Back Bay was undertaken in hopes of establishing some SAV in the system (Schwab, 1987). Hydrilla is an exotic species (as is milfoil) and first appeared in the United States in the 1960s (Hurley, 1990). Though hydrilla is considered a nuisance species by some due to its growth habit of forming surface mats, it can increase carrying capacity for both waterfowl and fish (Montalbano, *et al.*, 1979); Johnson and Montalbano, 1984; Esler, 1990; and Hurley, 1990).

In 1987 the survey was conducted during 8 of the 12 months in an attempt to determine if SAV frequencies fluctuated from month to month (Schwab, *et al.*, 1988). In July of 1987 the SAV frequency was 5%, the November frequency was 1%, and the June, 1988 survey had a coverage of 4%. The 1% reading in November was the lowest for the 12 month period. Milfoil was the predominate species present, with wildcelery and sago pondweed (*Potamogeton pectinatus*) present in only trace amounts (Schwab, *et al.*, 1988). During the 1988 survey period, the frequency of SAV increased over 1987 by 3%, however the 1989 and 1990 survey periods were 1% and 0% respectively (VDGIF unpub. data).

Summary

The SAV in Back Bay, VA has shown two periods of high frequency and two of decline during the years 1954-1990. The transect surveys have been conducted since 1958, with the exception of five years, using a standard method. From 1958 to 1963, a period of high frequencies of SAV, southern naiad and sago pondweed were the predominate species. The 1964-1966 period saw SAV frequencies drop to 12%. In 1966 milfoil was found in trace amounts and from 1967-1989 was the predominate species of SAV on Back Bay, with a peak frequency of 88% in 1973. SAV on Back Bay transects has declined to 0% in 1990, dropping from 50% in 1980.

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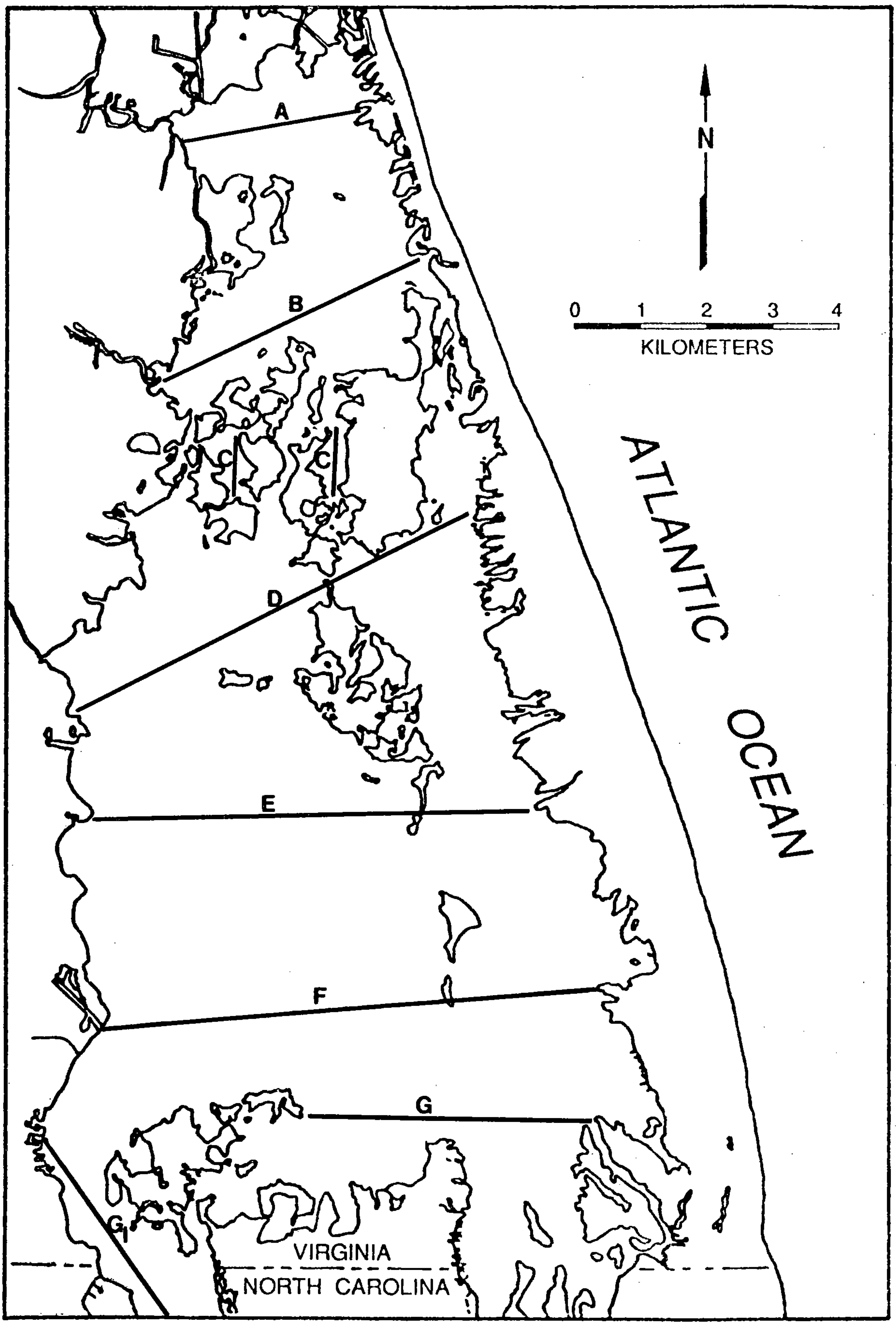

Figure 1. Submerged Aquatic Vegetation Transects, established 1958.

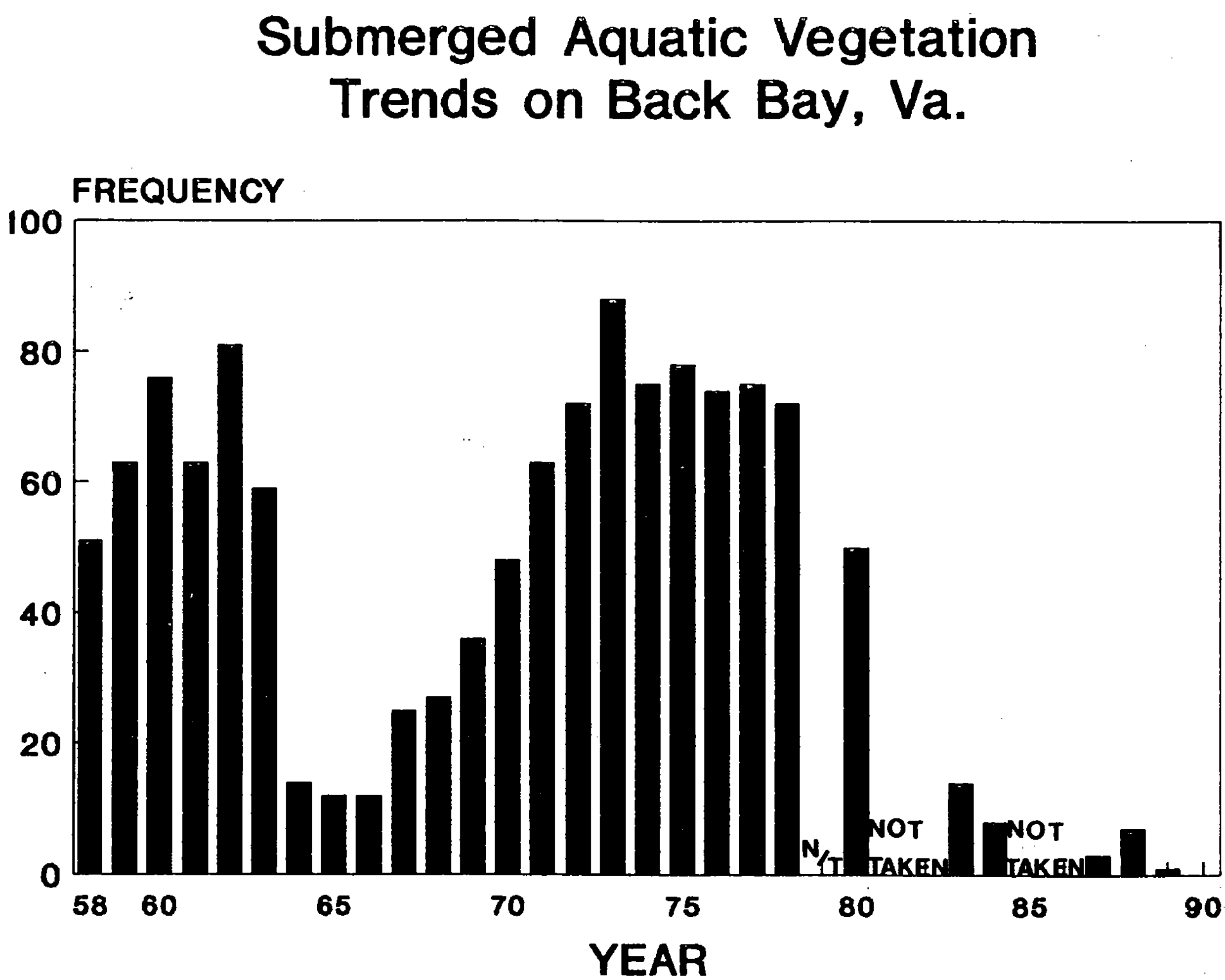

Figure 2. Frequency of Submerged Aquatic Vegetation on Back Bay, Va. 1958-1990.

IV. Management

The Currituck Sound Drainage Basin: Perceived Issues and Prospective Management Alternatives

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Introduction

The Water Quality Act of 1987 (Public Law 100-4) created a National Estuarine Program with a fourfold purpose:

1. identification of nationally significant estuaries that are threatened by pollution, development, or overuse;
2. promotion of comprehensive planning for, and conservation and management of, nationally significant estuaries;
3. preparation of management plans; and
4. coordination of estuarine research (101 Stat 61).

The law gave "priority consideration" to Albemarle Sound, North Carolina. A joint project of the United States Environmental Protection Agency (EPA) and the State of North Carolina, the Albemarle-Pamlico Estuarine Study (A/P Study) was the first program designated under the 1987 amendments to the Clean Water Act. Developing a comprehensive resource management plan for the Albemarle-Pamlico drainage basin emerged as a major goal of the A/P Study.

This paper will summarize the results of a project designed to gather and analyze background information necessary for development of a comprehensive management plan for the Currituck Sound drainage basin, a small portion of the greater Albemarle-Pamlico watershed. In addition to the waters of Currituck Sound, the study area included 26,000 acres of open water in Back Bay, Virginia and the land draining into Currituck Sound, Back Bay, Northwest River, North Landing River, and other tributaries to Currituck Sound (Figure 1). Based on North Carolina Center for Geographic Information and Analysis calculations, the Currituck Sound watershed covers approximately 733 square miles.

Land in the Currituck Sound watershed is devoted to many different uses including agricultural production, urban development, and preservation. A sprawling city, farms, hamlets, forests, marshes, and sand dunes jointly occupy the study area. The City of Virginia Beach, located in the northernmost portion of the drainage basin, threatens to expand urban development southward. Rapid population growth and development are challenging the Currituck Sound drainage basin's current rural character. Thus, the study area is in a period of change. The natural system is being surrounded by people and manmade environments.

Future management of this rapidly changing watershed and its many resources depends on the answers to two questions:

1. What are the the perceived issues surrounding management of the Currituck Sound drainage basin?
2. What types of responsive management alternatives are available?

Methods

Government officials, natural resource managers, and researchers performing investigations in the study area were consulted for their views concerning management issues in the Currituck Sound drainage basin. Fifteen formal interviews and numerous informal interviews were conducted over an 8 month period from December 1989 through July 1990. Interview questions were tailored for the respective represented agencies or research programs.

In addition, a short survey was used to determine general issue perception of the Currituck Sound Watershed Advisory Committee, the 15-member advisory panel for the project. Members of the advisory committee included representatives of three federal resource management agencies, state officials from North Carolina and Virginia, a regional representative from southeastern Virginia, and a member of the Albemarle Citizens' Advisory Committee.

Perceived Management Issues

During the course of the project, natural resource managers and scientists were asked to define management issues for Currituck Sound. There are no correct or incorrect opinions. Each interviewee had an individual perception of the issues in the watershed based on personal experiences, observations, and scientific evidence. Perceptions differed widely between interviewees.

Although no clear consensus exists on the nature and extent of problems in the Currituck Sound watershed, the interviews/surveys yielded two broad issue categories:

1. Currituck Sound is perceived to be a declining resource with respect to water quality, the fishery, and waterfowl wintering grounds.
2. Responsibility for management of this ecosystem is split among multiple federal, state, and local jurisdictions.

Interviewees also discerned the potential for future problems stemming from the continued growth and development predicted for the region, especially in regards to the limited water supply. Controversy surrounding the City of Virginia Beach's plans to pipe drinking water from Lake Gaston to the city has already eroded the relationship between the State of North Carolina and Commonwealth of Virginia. Resource managers recognized the need for immediate unified action in order to halt the decline of this shared estuarine system and address the water supply issue.

Issue 1: Declining Resource Values

Water Quality

At the present time, no one has examined Currituck Sound and its tributaries in terms of defining the highest uses for the Sound and conditions necessary to optimize those uses. In the absence of such standards, it is difficult to assess the status of water quality in the study area. Moreover, there is currently little water quality data for the Sound system, especially the portion located in North Carolina. Several interviewees and members of the Currituck Sound Watershed Advisory Committee pointed to the lack of scientific evidence to document declining water quality in Currituck Sound. Regardless, almost everyone agreed that water quality problems exist in the Sound and its tributaries. Eight of nine respondents to the issues survey ranked water quality problems as the "issue of greatest concern in terms of detrimental effects on the Currituck Sound drainage basin". What evidence is there to support this perception?

In a 1986-87 study conducted in Back Bay, Virginia, suspended solids and total Kjeldahl nitrogen (TKN) surpassed or violated Environmental Protection Agency (EPA) reference levels (Southwick and Norman, 1987). A later study found very poor water clarity and high turbidity values in Back Bay. The turbidity appears to be "correlated with the continuing decline in aquatic vegetation" (Southwick, 1989). Between 1972-78, submerged aquatic vegetation (SAV) suffered severe, rapid population declines in Back Bay.

In the North Carolina portion of the drainage basin, the North Carolina Division of Environmental Management operates one water quality monitoring station. Located at Point Harbor, the station monitors monthly for chlorophyll a, dissolved oxygen, coliform bacteria, pH, turbidity, and certain metal concentrations. In 1989, chlorophyll a concentrations violated the North Carolina standard on one occasion. Although it was not a gross violation of the 40 microgram per liter standard, the 42 microgram per liter reading was indicative of high nutrient levels in the water. As a result, the mouth of Currituck Sound will be classified as "support threatened" for its class "C" water uses which include propagation of aquatic life and secondary recreation (John Dorney, personal communication).

Ideas abound concerning the causes and symptoms of the perceived Currituck Sound water quality problems. The interviews focused attention on three issues affecting water quality in the Currituck Sound drainage basin: agricultural runoff, development, and salinity changes.

In the Back Bay-North Landing River watershed, there are approximately 350 farm units with an average size of 100 acres (Mann, 1984). For the Currituck Sound drainage basin as a whole, the exact number of farms is unknown. No one can deny that cropland management impacts water quality in the Currituck Sound drainage basin. One might question the extent of agricultural runoff's contribution to perceived water quality problems. Overall, farm acreage has declined while the water quality situation has worsened. This observation on reduced farm acreage is based on scrutiny of Agricultural Stabilization and Conservation Service (ASCS) aerial photographs dating from the 1930's to the present (Ron Southwick, personal communication).

Much of the farmland no longer in production has been developed and is now part of the Virginia Beach urban complex. The Currituck Sound watershed lies within the Norfolk-Virginia Beach Mean Metropolitan Statistical Area. A region experiencing rapid growth, the drainage basin has expanded in terms of urban area and population. Currituck County, a bedroom community for the mushrooming cities to the north, underwent a greater than 20 percent increase in permanent population between 1980-86 (Albemarle-Pamlico Estuarine Study, undated). Development, like agriculture, contributes to the perceived water quality issue.

The population increase for Virginia Beach during the 1970's exceeded 50 percent (Mann, 1984). Tidewater Virginia grew more slowly in the 1980's, but the overall population continued to climb. Most of the urbanization occurred in the northern sector of Virginia Beach and to the northwest of the city. This helped preserve the water quality of Back Bay and the rural quality of the southern portion of the coastal city. Furthermore, the City of Virginia Beach has expressed the desire to continue efforts to protect the rural character of the Back Bay watershed. Adopted by the City Council, the Comprehensive Plan established a "green line" south of which development is limited. However, as developable land becomes more scarce north of the "green line", there will be increasing pressure to expand southward. This is a matter of great concern to those involved in management of the Currituck Sound watershed and its resources.

The final perceived problem affecting water quality in the Sound is changes in salinity. The saltwater versus freshwater controversy has existed for many years in North Carolina. The argument climaxed in the early 1980's when citizens proposed introduction of seawater into Currituck Sound to restore water quality. This idea was based on the principle that positively-charged particles in saline water will bind with negatively-charged soil particles and precipitate out of solution. This, in turn, results in improved water clarity and, thereby, allows sunlight to penetrate the water column. One desired outcome is increased plant production which is beneficial for fish and waterfowl (Norman, 1988).

Salinities in excess of ten percent sea strength, however, interfere with largemouth bass (*Micropterus salmoides*) reproduction (Currituck Sound Task Committee, 1980). For this reason, sports fishermen opposed introduction of saltwater into Currituck Sound, a nationally famous largemouth bass fishery. North Carolina never attempted to change this freshwater estuary's salt content due to the prohibitive cost and uncertainty about possible effects (Currituck Sound Task Committee, 1980). The City of Virginia Beach did pump seawater into Back Bay intermittently between 1965 and the mid-1980's. During this time, water quality in the Bay did not improve. In fact, water clarity and vegetation reached "record lows" during the pumping period (Norman and Southwick, 1987). The Virginia Fish and Game Department forced Virginia Beach to discontinue pumping seawater into Back Bay in 1985. Presently, there is general agreement that the Currituck Sound-Back Bay complex should be managed as a freshwater estuary.

Resource managers and researchers also perceived declining water quality to be a significant management issue for the Currituck Sound drainage basin. Although the available data indicate that Currituck Sound possesses the highest level of water quality in the coastal area of northeastern North Carolina (Currituck Sound Task Committee, 1980; John Dorney, personal communication), there is still concern among resource professionals. Agricultural production and rapid urban development in the watershed are viewed as the primary causes of declining water quality in the Currituck Sound-Back Bay complex.

The Fishery and Waterfowl Habitat

Along with water quality, there is a general perception that the fishery and waterfowl habitat is declining. Below normal rainfall during the 1980's has resulted in reduced freshwater input into Currituck Sound. The salinity level has increased "beyond tolerable limits for most freshwater species" (Kornegay, 1989). Although fish populations are not statistically lower than in the 1970's (Kornegay, 1989), many fishermen feel they just are not catching the numbers of fish they did in past years (Mike Corcoran, personal communication). Sportsmen in the Back Bay area would agree (Norman, 1988). Norman, a biologist with the Virginia Department of Game and Inland Fisheries, summarized the sport fishing situation as follows:

> "This gold mine of a freshwater fishery began a rapid decline in the early 1980's and has continued its decline up to the present day. As a result, there is virtually no freshwater fishery in Back Bay today" (Norman, 1988).

Norman and his coworker Ron Southwick believe that high salinity levels and loss of the formerly abundant submerged aquatic vegetation (SAV) contributed to the decline in the freshwater fishery and waterfowl habitat.

Rapid development in the Currituck Sound drainage basin has also had a negative impact on wildlife, especially waterfowl. Prior to the 1980's, Currituck Sound was one of the premier waterfowl wintering areas along the Atlantic flyway. During the last decade, however, there has been a significant decline in populations of ducks, geese, and swans utilizing Currituck Sound. Based on aerial, midwinter surveys, waterfowl populations in the Currituck Sound area have decreased at a "much greater rate than elsewhere in eastern North Carolina" (Dennis Luszcz, personal communication). Luszcz, Waterfowl Project Leader for the North Carolina Wildlife Resources Commission, attributes the decline to increased human disturbance, loss of submerged aquatic vegetation, and rising salinity levels. "There have been noticeable changes in a short period of time" (Dennis Luszcz, personal communication).

Issue 2: Lack of a Coordinated Management Approach

The State of North Carolina and Commonwealth of Virginia share responsibility for any decline in the waters or resource values of the Currituck Sound-Back Bay complex. Ecosystems do not recognize state borders. This leads us to the second broad issue category uncovered during the interviews: lack of cooperation between/among the governing bodies responsible for the management of the Currituck Sound drainage basin.

Several agencies representing four different levels of government manage land and water in the study area (Table 1). No one agency, however, possesses all the functions required for effective natural resource management. In addition, there is no comprehensive environmental management plan for the Currituck Sound watershed. Presently, the many managing agencies operate independently. Federal, state, and local officials agree that North Carolina and Virginia must cooperate in order to best manage the Currituck Sound- Back Bay complex.

Analysis of Prospective Management Alternatives

This section of the report will focus on three classes of management options in order of increasing departure from existing conditions:

1. Alternatives requiring no new institutions
   — Maintenance of the status quo
   — Increased local government action
2. Alternatives requiring formation of new, non-statutory institutions
   — Administrative agreement
   — Interstate planning agency
3. Alternatives requiring formation of new, statutory institutions
   — Interstate compact
   — Federal-interstate compact.

Alternatives Requiring No New Institutions

Maintenance of the Status Quo

Maintaining current management strategies in the Currituck Sound- Back Bay complex would allow time for scientists to gather and analyze data on the status of the resource. This new information, in turn, would more definitively answer the questions of whether and why Currituck Sound is in a state of decline. In this scenario, the basis for future action would be fact rather than perception. No difficult or binding decisions would have to be made at this time. Thus, maintaining the status quo is politically attractive.

However, under the current management system, the responsible agencies have failed to manage and monitor Currituck Sound/Back Bay. This is evident from the shortage of published material dealing with the study area. In addition, local governments such as Currituck County have not received sufficient expert help in managing the Sound resources (Yates Barber, personal communication). In some cases, however, local governments in the watershed have acted without drawing on the available expertise. The result has been a perceived decline in the quality of the Currituck Sound/Back Bay ecosystem and its many resources.

Finally, the current management strategies do not address the perceived need for cooperative management of the bi-state resource, especially in the critical areas of growth management, water quality control, and water supply. Currently, North Carolina and Virginia work independently on problems related to management of the Currituck Sound drainage basin. There is no concerted effort to manage the watershed as a system.

Increased Local Government Action

Local governments in the Currituck Sound watershed constantly face two seemingly opposed forces: development pressure and demands for environmental protection. In addition, local governments must provide public services and facilities to serve existing populations. Preserving the natural character of the Currituck Sound-Back Bay complex and promoting development in the drainage basin is impossible without active local government participation. Federal and state agencies have only limited authority in this arena while "local governments have the jurisdiction—through zoning and police powers—to thoroughly address the wide variety of water quality problems and their sources" (Division of Coastal Management, 1986). Land use planning and growth management systems are methods whereby local governments such as Currituck County and the cities of Chesapeake and Virginia Beach can balance preservation and development. Among the many alternatives available to local governments for growth management are: transfer of development rights, preferential assessment, performance zoning, population caps, annual permit limits, conservation easements, and local environmental impact ordinances.

Increased local government action in management of the Currituck Sound drainage basin has inherent advantages. Involving local people who live in the watershed and depend upon the estuarine ecosystem for their livelihood is the primary advantage of this option. Traditionally, North Carolina has given local governments authority in the land use regulation arena due to the belief that "citizens should have maximum direct control over the specific areas within which they live and work" (Green and Heath, 1984). Local governments are already involved in management of the Currituck Sound watershed. They possess planning, permitting, and enforcement powers granted to them by the respective states. Under this alternative, no time would be wasted in negotiating an agreement between the multiple agencies involved in management of the resource. Local governments could act immediately to enact growth management measures.

However, no single local government has complete geographic jurisdiction over the Currituck Sound drainage basin and, for that reason, cannot single-handedly resolve the watershed's problems. In addition, the local governments lack resources such as money and manpower which are essential for education, research, and policy enforcement. Finally, the local governments have a vested economic interest in promoting development: "They [local governments] have a legislative charge and public mandate to pursue economic development to some degree" (John Carlock, personal communication). Environmental problems resulting from rapid or unplanned growth may be ignored until the situation reaches crisis proportions.

Alternatives Requiring New, Non-Statutory Institutions

Administrative Agreement

According to Zimmerman and Wendell (1951), the administrative agreement is "...an informal or a formal arrangement between administrative departments or officers of two or more states..." which does not require the approval of Congress. This third alternative offers opportunity for action at the state level outside the confines of a legally-binding interstate compact. The primary powers and functions of an agency formed by administrative agreement include development of institutional arrangements for cooperation on water resource matters of mutual interest and formation of joint positions on major issues in the broad arenas of water resources management and water quality control (North Carolina-Virginia Water Resources Management Committee et al., 1982).

An agency formed by administrative agreement has certain advantages over the preceding alternatives and alternative interstate institutions. First, this less formal mechansim can avoid the delays and political repercussions involved with legislative ratification. In addition, committees formed by administrative agreement generally operate within pre-existing agencies, thereby, they place a low financial burden on the participating states. Finally, there is a precedent for cooperation between the State of North Carolina and the Commonwealth of Virginia via this mechanism. In 1974, Governors Godwin and Holshouser created the now defunct North Carolina-Virginia Water Resources Management Committee by written agreement. The Committee concentrated on water resource problems in the North Carolina-Virginia Tidewater area, of which the Currituck Sound drainage basin is a significant portion.

The voluntary administrative agreement mechanism suffers several disadvantages including organizational and structural problems. Typically, agencies formed by administrative agreement lack planning, regulatory, and enforcement powers. Other inherent problems in this type of agency include inability to influence water resources decisions made by local and regional governing bodies; lack of accountability; inadequate financial resources; and poor continuity in time (North Carolina-Virginia Water Resources Management Committee et al., 1982). A final disadvantage of the administrative agreement is its somewhat uncertain legal status. Article I, Section 10 of the Constitution of the United States prohibits agreements and compacts among states without the consent of Congress. A literal interpretation of this directive would construe the term "agreement" as to include every agreement, written or verbal, formal or informal. In 1893, however, the Supreme Court ruled that the constitutional prohibition as to compacts or agreements among the states without the consent of Congress was "directed to the formation of any combination tending to increase the political power in the States, which may encroach upon or interfere with the just supremacy of the United States" (148 U.S. 503, 519 (1893)). Clearly, an administrative agreement between North Carolina and Virginia designed to deal with water resources issues in the Currituck Sound drainage basin would not interfere with the power relationship between the two states and the nation.

Interstate Planning Agency

The interstate planning agency functions to develop and encourage planning processes between the states (Advisory Commission on Intergovernmental Relations, 1972). Normally, interstate planning commissions have the power to:

> "collect, analyze, and distribute data; conduct studies and prepare reports on existing or potential problems; serve as an advisory board; and identify and recommend actions to local, state, or Federal jurisdictions for more coordinated management" (North Carolina-Virginia Water Resources Management Committee et al., 1982).

In the case of the Currituck Sound drainage basin, an interstate planning agency would prepare plans to direct management of the Sound complex and its many resources. These plans, however, should be consistent with the two basin states' existing coastal area management programs. The North Carolina Coastal Area Management Act directs all State agencies to keep informed of federal and interstate agency plans, activities, and procedures within their areas of expertise that affect the coastal area:

> "Where federal or interstate agency plans, activities, or procedures conflict with State policies, all reasonable steps shall be taken by the State to preserve the integrity of its policies" (G.S. 113A-127).

North Carolina and Virginia would be free to voluntarily implement the recommendations of such an interstate planning agency.

An interstate planning commission can be in operation much more quickly than a more formal coordinative mechanism such as an interstate compact commission (Chesapeake Bay Legislative Advisory Commission, 1979). Thus, an interstate planning agency could easily be designed as a precursor to a formal cooperative management program. Serving as a foundation for cooperation, the agency's first priority would be exchange of information and identification of basinwide problems. The interstate planning agency "can serve as a visible regional focus for water problems and can help develop a regional perspective toward water resources management" (North Carolina- Virginia Water Resources Management Committee et al., 1982).

As with any option, the interstate planning agency mechanism does have drawbacks. First, this form of agency lacks the regulatory and enforcement powers needed to implement its plans. Member states participate on a voluntary basis and are not obliged by law to put the interstate agency's plans into effect, reducing the interstate planning agency to an advocacy role (Advisory Commission on Intergovernmental Relations, 1972). In addition, this type of agency usually must rely on federal, state, and local agencies for information, aid in preparing plans, and execution of plans. Jurisdictional fragmentation in the drainage basin would slow the work of an interstate planning agency just as it currently prevents effective management of the Currituck Sound-Back Bay system. These disadvantages have hindered many interstate planning commissions to the point that they had only "marginal impact on improving basinwide water resources management" (North Carolina-Virginia Water Resources Management Committee et al., 1982).

Alternatives Requiring New, Statutory Institutions

Interstate Compact Commission

Since the inception of America, states have entered legally- binding compacts in order to address bi- or multi-state issues in a cooperative fashion. These compacts are contractual in nature and take precedence over other state statutes (21 U.S. 1, 91-92 (1823)). If necessary, an interstate compact can be enforced by suit in the Supreme Court.

Creation of a compact between the State of North Carolina and Commonwealth of Virginia would require that the states' respective legislatures pass identical laws authorizing the compact. Then, Congress would have to give consent through resolution or ratifying legislation. Congressional approval, however, is not a large obstacle as Congress generally grants consent to compacts drawn and agreed to by the party states (Leach and Sugg, 1959). Moreover, the Federal Coastal Zone Management Act (90 Stat 1019) granted consent of Congress to any two or more coastal states to negotiate and enter into agreements or compacts which do not conflict with any law or treaty of the United States, for

1. "developing and administering coordinated coastal zone planning, policies, and programs...and
2. establishing executive instrumentalities or agencies which such States deem desirable for the implementation of such agreements or compacts" (16 U.S.C. 1456b(b)).

Similar in content, wording, and form to an international treaty (Zimmerman and Wendell, 1951), interstate compacts are, essentially, treaties between two or more states. "It is generally accepted that the compact device affords the most appropriate legal base for administration of a single facility that stretches across state lines" (Barton, 1967). This reasoning may also be applied to natural systems such as the Currituck Sound-Back Bay complex which straddles the North Carolina-Virginia border. The interstate compact insures intergovernmental cooperation on activities affecting interjurisdictional resources. This form of agreement has been successfully utilized to abate and control pollution in shared watersheds as well as to facilitate development of water and related land resources.

Interstate compacts have some advantages over other coordinative mechanisms in addressing interstate problems. First, the compact is a formal, legally-binding agreement indicative of the participating states' commitment to resolving the issue at hand. After the agreement is finalized, execution of compact terms is mandatory rather than voluntary. This mechanism is more powerful and stable than the administrative agreement or interstate planning agency. Generally, compact representatives meet on a regular basis, thereby maintaining a continuous interactive relationship among the member states. An interstate compact commission, with aid from existing management institutions, could manage the Currituck Sound-Back Bay complex from an ecosystem perspective.

Although this alternative has great potential, it has been utilized, primarily, when all else failed. States are reluctant to enter an interstate compact until they are convinced that independent federal, state, and local efforts cannot resolve the problem. Public and political acceptablitity of the compact mechanism is generally low because this formal coordinative device if often viewed as an infringement on traditional state and local jurisdictions. Acceptability of the compact mechanism as a coordinative tool for management of the Currituck Sound drainage basin may be further hampered by North Carolina's recent controversial involvement in the Low Level Radioactive Waste Compact and the Southeastern Compact. As a result of the compact affiliations, North Carolina has been selected as the site for a low level radioactive waste repository and a hazardous waste incinerator. Exhibiting the Not In My Backyard (NIMBY) Syndrome, many North Carolinians have revolted against the respective compacts' waste disposal decisions. The State of North Carolina, however, is legally obligated to fulfill compact duties.

The amount of time required to negotiate and ratify an interstate compact is also a major negative aspect of this alternative. The average time needed for compact formation is greater than 8 years (Muys, 1971). During the negotiation and ratification periods, the party states usually engage in few or limited cooperative efforts. As a result, immediate problems receive little attention and may worsen. There is no reliable way to estimate how long it would take North Carolina and Virginia to agree on terms for a compact. Perhaps, the two states would never reach a mutually satisfactory agreement.

Other predominant drawbacks of the interstate compact mechanism stem from member states' jealousy and distrust of compact commissions (Leach and Sugg, 1959). Often, state and local government officials fear that a compact commission will become a "regional supergovernment" that will ride roughshod over their interests (North Carolina-Virginia Water Resources Management Committee et al., 1982). This distrust and fear prompts states to limit the powers of compact commissions to the point that they become ineffective in resolving issues (North Carolina-Virginia Water Resources Management Committee et al., 1982). Another result of distrust on part of the member states is that the compact commission is purposefully alienated from the respective states' administrations and legislatures: the commission stands alone as a regional agency (Leach and Sugg, 1959). Lack of integration into the administrative fabric, in turn, leads to inadequate liaison and coordination (Chesapeake Bay Legislative Advisory Commission, 1979).

An interstate compact commission could effectively manage the Currituck Sound drainage basin if granted sufficient acceptance and power. The State of North Carolina and Commonwealth of Virginia should not consider this alternative, however, unless they are convinced that the identified problems need a regional solution. In order to succeed, this option would require enormous commitment, cooperation, and effort.

Federal-Interstate Compact Commission

A compact in which the federal government is a full and formal participant, the federal-interstate compact acts as a "mechanism to unite the constitutional powers of state and federal government while creating a regulatory agency of all party jurisdictions" (Council of State Governments, 1979). Enactment of a federal-interstate compact requires ratification by the signatory states' legislatures and, also, Congressional approval. Congress must give consent to the compact itself and to federal participation on the resulting compact agency. Typically, federal-interstate compact commissions are composed of the governors of the respective member states and one representative appointed by the President of the United States (North Carolina-Virginia Water Resources Management Committee et al., 1982).

The federal-interstate compact mechanism is very similar to the interstate compact commission discussed in the previous section. The federal government serves as a full member of a federal-interstate compact commission. In contrast, ordinary interstate compact commissions exclude the federal government from membership.

Federal-interstate compact agencies have one distinct advantage over other mechanisms for interstate cooperation: they require cooperation between the states and the federal government. In the Currituck Sound drainage basin, the United States Fish and Wildlife Service alone is responsible for management of more than 125,000 acres of land. In addition, the Environmental Protection Agency, Army Corps of Engineers, and Soil Conservation Service play a significant role in land and water resources management. The federal-interstate compact mechanism provides the opportunity for the highest attainable level of cooperation between the multiple agencies responsible for management of the study area. Additionally, a federal-interstate compact would have sufficient power and authority to address the water supply and land space issues in the Currituck Sound drainage basin.

There are, of course, distinct disadvantages to this cooperative mechanism. First, a federal-interstate compact commission would suffer all the drawbacks common to the interstate compact commission. Furthermore, formation of a federal-interstate compact commission to deal with the perceived issues in the Currituck Sound drainage basin would present a significant departure from the water laws and institutions of North Carolina and Virginia. It would be very difficult to build the broad public and political support necessary to create such an agency (North Carolina-Virginia Water Resources Management Committee et al., 1982).

Comparison of the Alternative Management Strategies

Each prospective coordinative mechanism possesses distinct advantages and disadvantages. Ultimately, selection and implementation of a management alternative will depend upon the priorities of the many managing agencies in the study area and of the citizens in the two states. Comparing the prospective management alternatives in terms of critical attributes and capabilities will provide the information necessary for final decision making (Tables 2 and 3).

No single alternative possesses all the desirable characteristics and capabilities of the ideal natural resource management agency. For example, maintenance of the status quo ranks high for public and political acceptability; however, this alternative does not vest complete geographic jurisdiction in a single managing agency. In contrast, a federal-interstate compact commission would have jurisdiction over the entire study area, but would probably fail to gain widespread political and public support. The compact mechanism would represent a significant departure from current management strategies.

The prospective management alternatives fall along continuums for flexibility and power. Flexibility allows a natural resource management agency to take more innovative approaches to solving problems. A flexible agency is not restrained by controls and standard operating procedures. Ranking the management alternatives in order from most to least flexible produces the following list:

1. Maintenance of the status quo
2. Increased local government action
3. Adoption of an administrative agreement
4. Creation of an interstate planning agency
5. Formation of an interstate compact commission
6. Formation of a federal-interstate compact commission.

Compact commissions are inflexible because their duties are explicitly stated in their ratifying legislation. The formality and contractual nature of compacts limit flexibility (Leach and Sugg, 1959). Ironically, the exact attributes of the compact mechanism which curb flexibility serve to empower compact agencies. Typically, compact commissions have planning, regulatory, and enforcement powers (North Carolina-Virginia Water Resources Management Committee et al., 1982) as well as complete geographic jurisdiction. Flexibility and power are inversely related. Thus, arranging the prospective management alternatives from most to least powerful results in a list that is the inverse of the one above:

1. Formation of a federal-interstate compact commission
2. Formation of an interstate compact commission
3. Creation of an interstate planning agency
4. Adoption of an administrative agreement
5. Increased local government action
6. Maintenance of the status quo.

Conclusions

There are two broad categories of perceived issues surrounding management of the Currituck Sound drainage basin. First, Currituck Sound is perceived to be a declining resource with respect to water quality, the fishery, and waterfowl wintering grounds. Insufficient data exist to confirm the opinion that Currituck Sound is a declining resource, however. No comprehensive study has been conducted for the Currituck Sound-Back Bay complex since the early 1960's when the Bureau of Sport Fisheries and Wildlife, North Carolina Wildlife Resources Commission, and Virginia Commission of Game and Inland Fisheries carried out a cooperative study popularly referred to as the "Sincock Study".

Second, no single resource management agency has complete geographic jurisdiction over the watershed. Since the time of the "Sincock Study", the Currituck Sound watershed has experienced rapid population growth and development. Much change has occurred in the study area. Throughout this period of growth and change, North Carolina and Virginia have failed to cooperate in the management of their shared ecosystem. Responsibility for management of the Currituck Sound-Back Bay system was, and still is, split among multiple federal, state, and local jurisdictions.

Many resource managers perceive a crisis situation for Currituck Sound. Government officials, resource managers, and the public must reach a consensus on the best course of action. Selection of a responsive management strategy stands as the first step toward resolving the issues of the Currituck Sound drainage basin as well as the entire Albemarle-Pamlico Estuarine study area.

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Table 1. Resource Managing Agencies in the Currituck Sound Watershed

Government Level	**Agency**
Federal	Army Corps of Engineers (COE)
	Environmental Protection Agency (EPA)
	Fish & Wildlife Service (USFWS)
	⅞ Back Bay National Wildlife Refuge
	⅞ Currituck National Wildlife Refuge
	⅞ Dismal Swamp National Wildlife Refuge
	⅞ Mackey Island National Wildlife Refuge
	Soil Conservation Service (SCS)
State	
North Carolina	Division of Coastal Management (DCM)
	⅞ Currituck Banks Estuarine Research Reserve
	Division of Environmental Management (DEM)
	Division of Land Resources (DLR)
	Division of Marine Fisheries (DMF)
	Division of Water Resources (DWR)
	Wildlife Resources Commission (WRC)
	⅞ Northwest River Game Lands
Virginia	Council on the Environment (VCOE)
	Chesapeake Local Assistance Department (CLAD)
	Department of Game and Inland Fisheries (DGIF)
	⅞ Pocahontas Waterfowl Management Area
	⅞ Trojan Waterfowl Management Area
	Division of Soil and Water Conservation (DSWC)
	Division of State Parks (DSP)
	⅞ False Cape State Park
	Marine Resources Commission (MRC)
	State Water Control Board (SWCB)
County	
North Carolina	Camden County
	Currituck County
	Dare County
City	
Virginia	Chesapeake
	Virginia Beach
Regional	
North Carolina	Albemarle Regional Development Commission (ARDC)
Virginia	Hampton Roads Planning District Commission (HRPDC) (HRPDC was formerly referred to as the Southeastern Virginia Planning District Commission)

Table 2. Comparison of the Prospective Management Alternatives.

Attributes of a Successful Natural Resource Management Agency	Management Alternatives* 1	2	3	4	5	6
Complete geographic jurisdiction	No	No	No	Yes	Yes	Yes
Continuity in time	No	No	No	Yes	Yes	Yes
Flexibility	Yes	Yes	Yes	Yes	No	No
Political/Public acceptability	Yes	Yes	Yes	Yes	No	No
Power to enforce plans at ecosystem level	No	No	No	No	Yes	Yes
Wide special interest appeal (Represent varied interests)	Yes	Yes	Yes	Yes	Yes	Yes

* **No new institutions**
1=Maintenance of status quo
2=Increased local government action

New, Non-statutory Institutions
3=Agency formed by administrative agreement
4=Interstate planning agency

New, Statutory Institutions
5=Interstate compact commission
6=Federal-interstate compact commission

Table 3. Comparison of the Prospective Management Alternatives (b).

Duties of a Natural Resource Management Agency (after Matthews, 1976)	Management Alternatives*					
	1	2	3	4	5	6
Planning	Yes	Yes	No	Yes	Yes	Yes
Public education	Yes	Yes	Yes	Yes	Yes	Yes
Regulatory/enforcement functions	Yes	Yes	No	No	Yes	Yes
Receiving and administering funds	Yes	Yes	No	Yes	Yes	Yes
Research	Yes	No	No	Yes	Yes	Yes
Fostering intergovernmental relations	No	No	Yes	Yes	Yes	Yes

* **No new institutions**
1=Maintenance of status quo
2=Increased local government action

New, Non-statutory Institutions
3=Agency formed by administrative agreement
4=Interstate planning agency

New, Statutory Institutions
5=Interstate compact commission
6=Federal-interstate compact commission

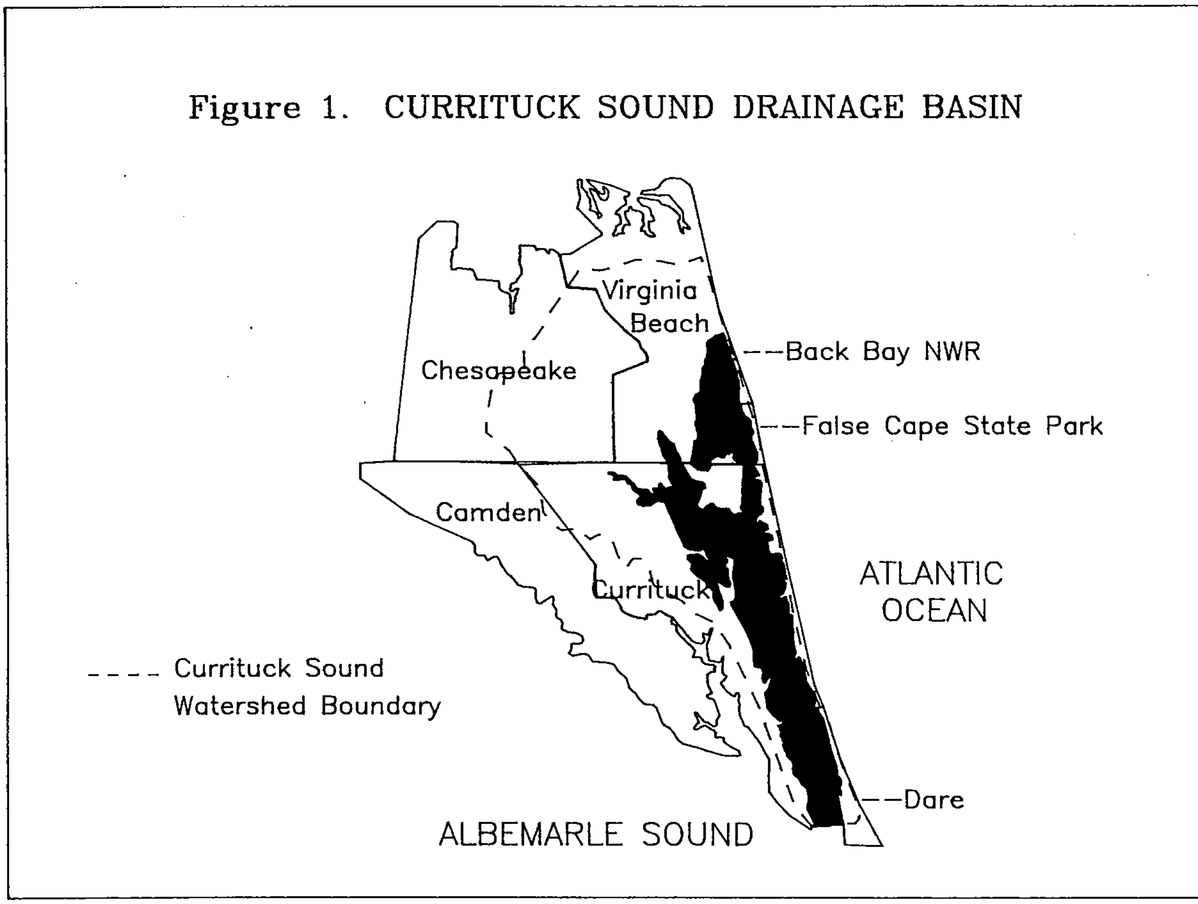

Figure 1. Currituck Sound Drainage Basin

Water Table Management

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Soils

Approximately 85 percent of the soils in Back Bay Watershed are poorly or very poorly drained. The General Soil Map for the Back Bay Watershed is on Figure 1. A Management Plan for Back Bay, Mann and Cortell (1984). These soils meet the definition of "Hydric" as defined in the "Federal Manual for Identifying and Delineating Jurisdictional Wetlands". An Interagency Cooperation Publication (1989).

The soils are nearly level and range in elevation from sea level to about 15 feet mean sea level (msl) at the crest of Pungo Ridge. There are some areas that extend several miles before the elevation rises from sea level to about 5 feet.

The seasonal high water table of the "hydric" soils range from 0 to about 1 foot. Soil Survey of the City of Virginia Beach (1985). Typically, the soils are underlain by sandy material at about 1m. The upper layers range in texture from loamy to fine silty. The permeability of the most restrictive layer ranges from moderate to very slow. Soil Survey of the City of Virginia Beach (1985).

Cropping Systems

The typical cropping system is Corn, Wheat, and Soybeans. Corn is planted in early April, and is harvested in August; winter wheat is planted in October and harvested the following June and immediately planted to no-till or minimum-tilled soybeans. The soybeans are harvested in October or November. This results in three crops being produced and harvested in two years.

Many agricultural management activities influence the environmental problems associated with crop production. These include tillage practices, fertilization, pesticide application, methods and rates, and drainage and irrigation practices.

Typical Drainage System

Open ditch drainage systems have been used in the Back Bay Watershed since the 1600s. The spacing varies from about 50m to 100m. The field or "tap" ditches are usually 0.8m deep with submains and main ditches ranging up to about 1.5m deep. Shallow drains called "hoe drains" are constructed perpendicular to the direction of the row. These are used to facilitate movement of water that may be "trapped" between the rows. The fields between the ditches are "crowned" and they are usually called "cuts". The ditch banks usually have dense riparian vegetation. This consists primarily of herbaceous plants, but may include a variety of woods plants.

Intensive drainage systems that are necessary to provide trafficability during wet periods have tended to overdrain many areas and reduce yields. Presentation made by Evans and Skaggs at the American Society of Agricultural Engineers, Canada (1989). Water table management systems provide drainage during wet periods and also minimize over drainage by using water control structures to manage the water level in the drainage outlet.

Researchers in North Carolina have been investigating the influence of water table management on water quality for over 15 years. Evans and Skaggs, American Society of Agricultural Engineers, (1989). Studies indicate that controlled drainage tends to reduce outflow from drainage systems compared to either uncontrolled surface or surface drainage. Researchers observed approximately a 50 percent reduction in total annual outflow from controlled fields at Tidewater Research Station, compared to uncontrolled fields. Gilliam (1978). Annual outflows determined at 14 artificially drained sites in eastern North Carolina are shown on Table 1.

Researchers observed only minor differences in phosphorous or nitrate-nitrogen concentrations in drainage outflow from controlled drainage as compared to uncontrolled drainage. These studies were conducted on 5 different sites in 4 counties in the Tidewater region of North Carolina. Outflow measured at each site contained varying proportions of surface and subsurface drainage with only minor differences in nutrient concentration. Nutrient concentrations differences were observed among sites but this was believed to be due to differences in soil type, crop grown and fertilization rates. Nutrient concentrations observed in drainage outflow from these two studies are summarized in Table 2.

Higher water table levels provided by drainage control increases the potential for denitrification and resulted in lower concentrations of nitrate-nitrogen compared to uncontrolled drainage.

Studies by Gambrell have shown considerable denitrification occurred in poorly drained soils with high water table. Gambrell (1974). This resulted in less nitrate-nitrogen leaving the fields in drainage waters when compared to better drained soils.

Nutrient Transport

The most frequently observed benefit of water table management for water quality has been its influence on total nutrient transport in drainage outflow. Drainage control reduced the annual transport of total nitrogen (No_3-N and TKN) at the field edge by 7 kg/ha (46.5%) and total phosphorous by 0.19 kg/ha (44%) in field studies conducted by Evans et al. (1989). Gilliam et al., 1978 observed a reduction in nitrate-nitrogen from 25-30 kg/ha for uncontrolled drainage to 12-15 kg/ha with drainage control. Of the 12-15 kg/ha reduction with controlled drainage, 50 percent (6 kg/ha) resulted from winter control (Dec.-Feb.). Annual effluxes estimated in the 14 site studies are summarized in Table 3.

Management

The operation of a water table management system includes two important management considerations. The first concern is management of the system for optimum production efficiency. The second concern is management of the system for maximum water quality. Farmers are concerned about the optimum depth of water under the crop. Experience has shown that yield reductions will not occur on most soils for short term fluctuations. General water table management guidelines to promote water quality for a 2 year rotation of corn-wheat-soybeans are shown in Table 4. Most of the control elevations adjustments are related to trafficability and seasonal fluctuations in rainfall.

Management during the non-growing season is beneficial for water quality. During May through August potential evapotranspiration exceeds precipitation. Mann (1984). Essentially, no water is leaving the soil system by leaching into the groundwater. The soil system begins to recharge beginning in about December and extends to about May. This means that the greatest potential loss from the soil system from leaching is during the winter and early spring. The water budget analysis for Virginia Beach is shown in Table 5. This is why it is particularly important to manage the water control structures during the winter and early spring.

Another important consideration is trafficability. Trafficability is absolutely essential for efficient production. Water level must be low enough to allow drying of the surface layer to permit equipment to operate. Soil compaction will occur if the soil is too wet resulting in slower hydraulic conductivity, irregular water movement pattern and poor soil tilth.

Monitoring The System

Field water table elevations may be considerably different from the water level in the outlet ditches or elevation in the control structures. Intensive management of these systems is required for both production and water quality.

Systems cannot be properly managed by merely observing the water level at the drainage outlet or control structure. The response time for water table fluctuations in the field may be several days longer than similar water level fluctuations in the outlet ditch. Field water table monitoring wells (observation wells) are essential for proper system management. The construction, location, installation and monitoring frequency of observation wells has been reported by Doty (1986), Evans and Skaggs (1985) and Evans and Skaggs (1989). Figure 2 illustrates the observation and calibration systems for "open" systems, parallel ditches or tile systems outletting directly into ditch outlets. Agricultural Water Table Management - A Guide for Eastern North Carolina (1985).

Summary

The results of over 15 years of water quality water table management research in North Carolina have shown the potential to improve drainage water quality by controlled drainage and water table management. The potential water quality benefits are dependent on management intensity. Results of these studies can be transferred to the Back Bay Watershed since soils, cropping systems and management are very similar to those in North Carolina.

Management strategies and guidelines were developed for water table management systems from the results of the earlier research. The management guidelines address both production and water quality considerations.

Based on information presently available, water quality benefits to reduce eutrophication problems in surface waters can be provided with steady state weir elevations in drainage control structures to minimize drainage outflow volumes. Management strategies for this situation are compatible for both production and drainage water quality. The primary management requirement for drainage water quality is year round drainage control.

Data is not presently available to evaluate the overall impact that these changes in drainage water management would have on the estuarine ecosystem.

Based on data generated by research in North Carolina, water control structures are being installed and managed to : (1) create optimum growing conditions for crops, and (2) minimize NPS pollution.

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Table 1. Annual Outflow at the Field Edge as Influenced by Water Table Management Strategy and Soil Type.

Soil	Drainage Strategy *	Total Drainage Outflow$_{cm}$ No. Control @	Controlled	% Reduction
Bladen $ (Acredale)	Subsurface	45.1	40.6	11.1
	Surface	36.7	35.6	3.1
Hyde #	Subsurface	25.6	26.9	40.0
	Surface	21.9	14.8	32.4
Portsmouth $	Subsurface	35.9	31.4	14.3
	Surface	30.3	25.4	19.3
Portsmouth #	Subsurface	24.8	13.2	46.8
	Surface	13.7	9.6	29.9
Tomotley $	Subsurface	38.0	35.3	7.6
	Surface	31.1	30.1	3.3
Average	Subsurface	34.0	23.2	31.8
	Surface	30.1	22.4	25.6

Source: Evans and Skaggs Paper 89-2129
ASAE Meeting in Canada

Table 2. Nutrient Concentration in Drainage Outflow at the Field Edge as Influenced by Management Strategy.

		Nutrient Concentrations, mg/L					
		No. Control @			Controlled		
Soil	Drainage Strategy *	NO_3N	TKN	TP	NO_3N	TKN	TP
Bladen $ (Acredale)	Subsurface	9	1.4	.05	6.6	1.4	.07
	Surface	2.4	1.4	.11	2.2	1.4	.12
Hyde #	Subsurface	—	—	—	3.6	.9	.02
	Surface	—	—	—	3.1	1.7	.07
Portsmouth $	Subsurface	10.5	1.5	.02	7.9	1.4	.05
	Surface	3.7	1.5	.06	2.6	1.5	.09
Portsmouth #	Subsurface	—	—	—	9.0	1.4	.02
	Surface	—	—	—	—	—	—
Tomotley $	Subsurface	11.4	1.5	.02	8.0	1.4	.05
	Surface	4.2	1.4	.1	2.3	1.4	.12
Average	Subsurface	8.7	1.4	.05	6.8	1.5	.07
	Surface	3.0	1.8	.14	2.6	1.7	.12

Source: Evans and Skaggs Paper 89-2129
ASAE Meeting in Canada

Table 3. Nitrogen and Phosphorus Transport in Drainage Outflow Influenced by Soil Type and Water Table Management Strategy.

		Annual Nutrient Transport, kg/ha							
		No Control@				Controlled			
Soil	Drainage Strategy *	NO_3N	TKN	TN=	TP	NO_3N	TKN	TN=	TP
Bladen $	Subsurface	40.8	6.4	74.2	.21	26.8	5.5	43.4	.27
(Acredale)	Surface	8.7	5.3	14.0	.42	7.7	5.1	12.8	.44
Hyde #	Subsurface	9.3	2.2	11.4	.10	6.1	1.4	7.5	.07
	Surface	6.8	3.8	10.6	.31	4.6	2.6	7.2	.21
Portsmouth $	Subsurface	37.7	5.4	43.1	.08	24.7	4.5	29.2	.15
	Surface	11.3	4.5	15.8	.19	6.6	3.7	10.3	.26
Portsmouth #	Subsurface	22.3	3.5	25.8	.10	11.9	1.8	13.7	.05
	Surface	9.6	2.2	11.8	.11	6.7	1.5	8.2	.08
Tomotley $	Subsurface	43.5	5.8	49.3	.07	28.2	5.1	33.3	.16
	Surface	13.0	4.5	17.5	.31	6.9	4.3	11.2	.35
Average	Subsurface	26.5	4.6	31.1	.21	14.2	3.8	17.3	.17
	Surface	8.5	5.3	13.8	.48	4.5	3.1	7.6	.28

Source: Evans and Skaggs Paper 89-2129
ASAE Meeting in Canada

Table 4. General Water Table Management Guidelines to Promote Water Quality for a 2-Year Rotation of Corn—Wheat—Soybeans.

Period	Production Activity	Control Setting	Comments*
Mar. 15-Apr. 15	Tillage, Seedbed Preparation, Planting	36 inches	Just low enough to provide trafficability
Apr. 15-May 15	Crop Establishment, Early Growth	24-30 inches	
	Nitrogen Sidedress	21-36 inches	Just low enough to provide trafficability
May 15-Aug. 15	Crop Development and Maturity	21-24 inches	Temporary adjustment during wet periods
Aug. 15-Oct. 15	Harvesting, Tillage, Plant Wheat	30-36 inches	Low enough to provide trafficability
Oct. 15-Mar. 1	Wheat Establishment	24 inches	Lower during extremely wet periods
Mar 1.-Mar. 15	Sidedress Wheat	24-36 inches	Low enough to provide trafficability
Mar. 15-Jun. 15	Wheat Development and Maturity	21-24 inches	Temporary adjustment wet periods
Jun. 15-Jul. 15	Harvest Wheat Tillage, Plant Beans	30-36 inches	Depends on season
Jul. 15-Nov. 1	Soybean Development and Maturity	21-24 inches	Temporary adjustment to allow cultivation
Nov. 1-Dec. 15	Soybean Harvest	36-42 inches	Low enough to provide trafficability
Dec. 15-Mar. 15	Fallw	12-24 inches	

*** Season (Weather) Considerations**

1. Most adjustments are related to trafficability and must take into acount weather conditions at the time and soil characteristics.
   - — in an unusually dry season: control can be 3-6 inches higher.
   - — in an unusually wet season: control should be 3-6 inches lower.
   - — in course textured soils: trafficability can be provided with the water table approximately 6 inches higher (example: arapahoe, ballahack, coarser portsmouth).
2. Supplemental water availability is also an important consideration
   - — if water is limiting: conserve as much rainfall as possible and still provide crop protection and trafficability.

Table 5. Water Budget Analysis: Virginia Beach, Station: Norfolk, Virginia, Latitude: 36 54′ N, Longitude: 76 12′ W, Period of Record: 1946-1981.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Temperature (F)	50.5	41.4	48.1	57.8	66.7	74.5	78.3	76.9	71.8	61.7	51.6	42.3	59.30
Precipitation (in.)	3.35	3.31	3.42	2.71	3.34	3.62	5.70	5.62	4.20	3.06	2.94	3.11	44.68
Potential Evapotranspiration (in.)	1.03	0.26	0.93	2.31	3.66	5.54	6.38	5.92	4.02	2.33	1.02	0.05	33.60
Precipitation Minus Potential Evapotranspiration (in.)	2.32	3.05	2.49	0.40	-0.32	-1.92	-0.68	-0.30	0.18	0.73	1.92	2.61	11.08
Soil Storage (in.)	6.00	6.00	6.00	6.00	5.68	4.11	3.67	3.97	4.15	4.88	6.00	6.00	
Change in Storage (in.)	0.00	0.00	0.00	0.00	-0.32	-1.57	-0.44	+0.30	+0.18	+0.73	+1.12	0.00	
Actual Evapotranspiration (in.)	1.03	0.26	0.93	2.31	3.66	5.19	6.14	5.62	4.02	2.33	1.02	0.50	33.01
Water Deficit (in.)	0.00	0.00	0.00	0.00	0.00	0.35	0.24	0.00	0.00	0.00	0.00	0.00	
Water Surplus (in.)	2.32	3.05	2.49	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.80	2.61	11.67
Runoff (in.)	1.91	2.48	2.49	1.44	0.72	0.36	0.18	0.09	0.05	0.05	0.40	1.50	11.67

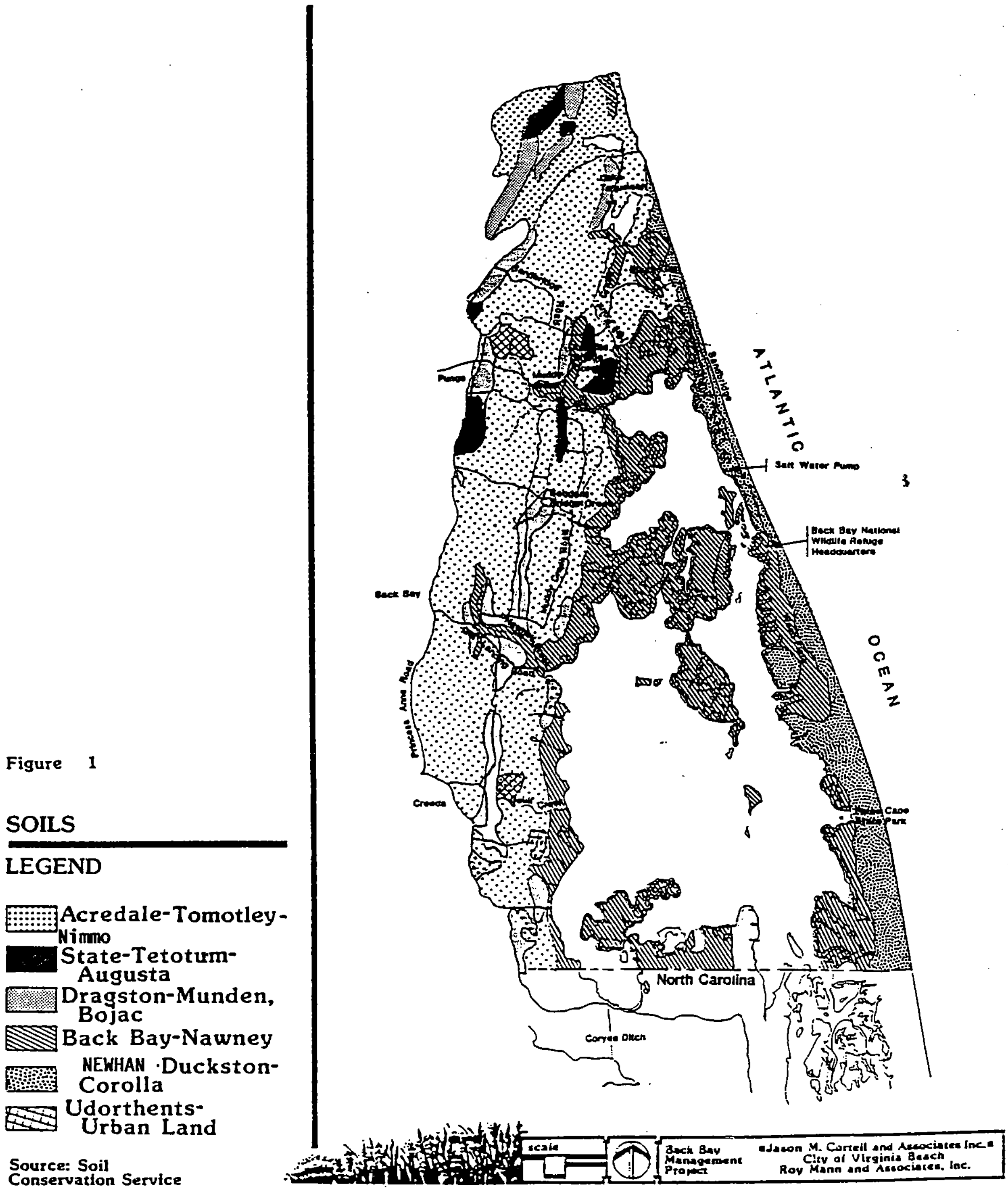
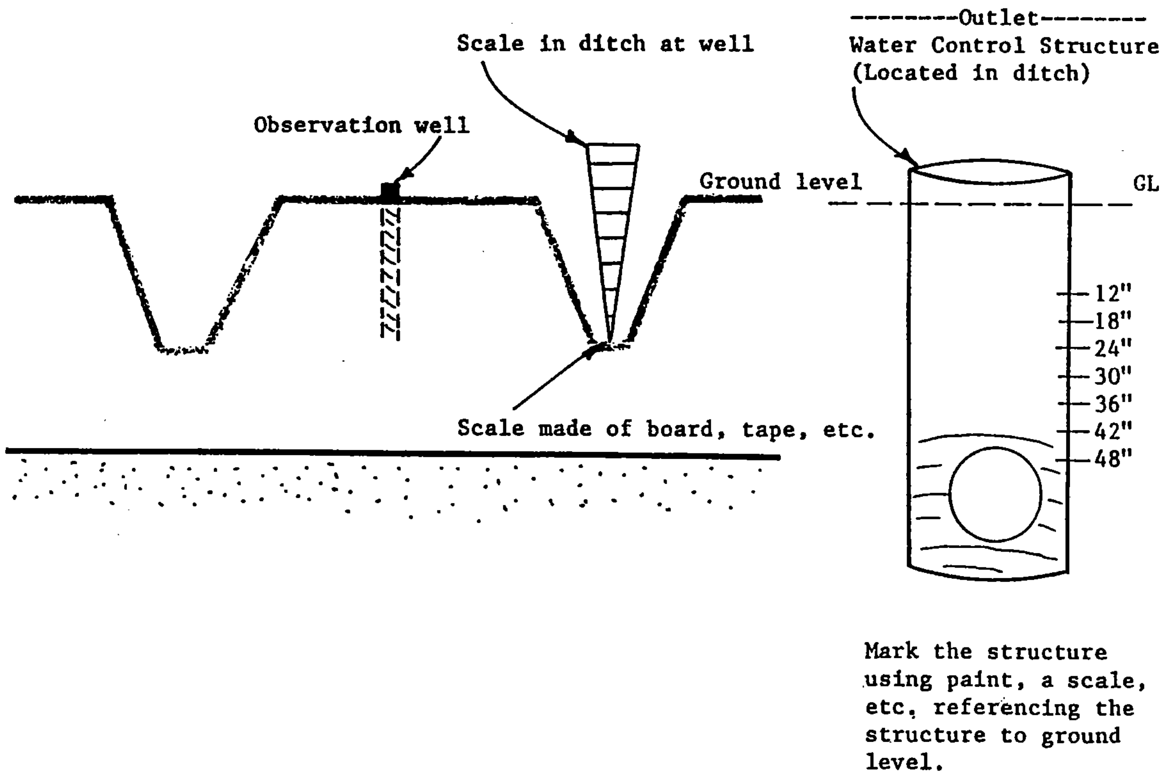


Figure 1. Soil map for the Back Bay Watershed.

FIGURE 2



AGRICULTURAL WATER TABLE MANAGEMENT - A GUIDE FOR EASTERN NORTH CAROLINA 1985

Figure 2. Observation and calibration procedures for parallel ditches, or tile systems, outletting directly into ditch outlets.

Refuge Management: Committed to the Future

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Abstract: The Back Bay National Wildlife Refuge was established on June 6, 1938, "...as a refuge and breeding ground for migratory birds and other wildlife." During its first 30 years, the Refuge was managed similar to other areas of the National Wildlife Refuge System. Dikes were constructed, facilities were built, and wildlife management programs were initiated. In the late 1960's, the emphasis of the area changed, as increasing numbers of beach oriented visitors, primarily using 4 wheel drive vehicles, began using the area. By 1971 public use reached 348,000 visits per year. Throughout the 1970's and early 1980's Refuge Management focused primarily on administration of a Motor Vehicle Access Permit Program that was designed to control this use and preserve wildlife habitat. By the mid-1980's the vehicle access situation was brought under control, and the Refuge began to turn its attention to more traditional management activities. From 1986 - 1990 major strides were made in the areas of environmental education, impoundment rehabilitation, fire management, land acquisition, and cooperation with other agencies and private groups. As the 1990's begin, the Refuge is committed to providing leadership in habitat protection, progressive land management, environmental education, restoration of the Back Bay watershed,and establishing and continuing partnerships between the public and private sectors.

History

The Back Bay National Wildlife Refuge (Refuge) is a unit of the National Wildlife Refuge System (System). The System, a collection of over 90 million acres of lands and waters managed specifically for wildlife, began in 1903 with the establishment of the Pelican Island Refuge. Today, there are over 450 National Wildlife Refuges, with at least one in every state. These Refuges are administered by the U.S. Fish and Wildlife Service (Service), an agency of the Department of the Interior.

After the passage of the Duck Stamp Act in the early 1930's, many of the earliest units of the System were established. On June 6, 1938 Back Bay Refuge came into existence, when the Service purchased 4,589 acres of the barrier spit and islands near the center of the Back Bay ecosystem. Shortly thereafter, approximately 4,600 acres of the bay were closed to the taking of migratory birds by Presidential Proclamation, effectively creating over 9,000 acres of wintering, resting and feeding area for migratory birds.

Since Refuge establishment, management activities have been geared towards providing habitat for migratory birds - specifically waterfowl. Early management focused on development of freshwater marshes on the barrier spit, to compliment the brackish marsh and Submerged Aquatic Vegetation (SAV) in Back Bay. The main techniques for freshwater marsh development included construction of "ring dikes" in the 1950's and, later, the construction of the East, West and cross-dikes. Through these construction activities, approximately 650 acres of primarily unvegetated wash flats were converted to freshwater impoundments by 1970. These areas were then managed for snow geese and other waterfowl, primarily through agricultural practices such as: plowing, discing, seeding and burning. Water level manipulation was also used to enhance the attractiveness of the area to waterfowl.

With the increase in personal leisure time in the years following World War II, public use of the Refuge began to increase. The primary focus of this use was the Refuge beach and dunes. Visitors in four-wheel-drive vehicles came in ever-increasing numbers, resulting in an estimated 348,000 visits by 1971. The Service recognized the damage caused by off-road-vehicle activity and, on February 28, 1973, published the first of many annual rulemakings which limited beach and vehicular use. These proposed limits resulted in major controversy and a lawsuit against the Service. The overall effects on Refuge management activities were significant expenditures of staff time and dollars on controlling public use and a de-emphasis of traditional wildlife management activities. In fact, by the mid-1970's over 50% of the annual Refuge staff effort was expended in controlling access and administration of the Motor Vehicle Access Permit Program (MVAPP).

These efforts began to pay off and, by the mid-1980's, as the vehicle access situation was brought under control, the Refuge staff began to emphasize more traditional Refuge management activities. Today only an estimated 15% of Refuge staff effort is directed toward the necessary administration of the MVAPP.

New Direction

In the fall of 1986 this renewed emphasis on habitat management was illustrated by the implementation of the first ever deer hunt on Back Bay NWR. This hunt was sorely needed to reduce an overpopulated deer herd and to minimize the negative impacts that whitetails were having on Refuge habitats. At about the same time, the Refuge staff began to take a closer look at the habitat management program. Over the years the necessary pre-occupation with the MVAPP, coupled with staff retirements and transfers, had eliminated the institutional knowledge that Refuge staff needed to productively manage habitat - especially impounded wetlands. The decline of the Bay in the early 1980's, historically low waterfowl population numbers, lack of public support and understanding of environmental issues, and new emphasis in the Service to improve management of refuges, motivated Refuge personnel to action. This action focused on three main areas; 1) habitat management, 2) protection and enhancement of the Back Bay watershed and, 3) environmental education and wildlife-oriented public use.

1. Habitat Management

With the realization that Refuge habitats were undermanaged, Refuge staff set out to "rediscover" past management practices. The water management activities of the late 1970's - early 1980's were critically examined and new direction was initiated. An experiment in the winter of 1986 and spring of 1987 in the refuge's "A" Pool, demonstrated that desirable wetland plants could be encouraged through increases in summer water levels and winter discing of black needlerush (*Juncus romerianus*). Through the use of these two techniques alone, an explosion of water hyssop (*Bacopa* spp.), saltmarsh bullrush (*Scirpus robustus*) and American threesquare (*Scirpus americanus*) was observed. Since a more stable water supply was needed to expand this management throughout the existing impoundments, a water supply channel was excavated into Back Bay. The channel (1,400 feet long x 25 feet wide x 6 feet deep) now supplies a steady source of water to the 12,000 gal/min permanent pumping station on the Refuge.

Concurrent with changes in the water management regime, Refuge personnel increased mechanical manipulations and improved wildlife inventory procedures. Mowing, discing, and burning operations increased. Ground and aerial surveys were expanded. Visits by Service wetland management experts confirmed that the management changes were producing better habitat. By the winters of 1987-1988 and 1988-1989, increased waterfowl use of the impoundments was evident. In the 1988-1989 wintering period, a peak of 35,000 greater snow geese (*Chen caerulescens*) was observed on the Refuge - the highest recorded number in nearly 20 years. Many of these birds were observed in disced or burned marshes. In the 1987-1988 wintering period, several thousand American black ducks (*Anas rubripes*) and mallards (*A. platyrhynchos*) were observed feeding on acorns (among other foods), in the marginal marshes east of the east dike, areas that had been recently flooded in attempts to attract more waterfowl.

In the years from 1986-1989, Refuge staff demonstrated that the impoundments could be enhanced for use by wintering waterfowl. At the same time however, it became evident that the aging dikes and water control structures were inadequate to ensure the long term productivity of the area. Therefore, planning was initiated to rehabilitate the entire system. Engineering analysis and physical data gathering was the first step. Plans were drawn up and finalized. Permits were applied for and an environmental analysis of the proposal was prepared and submitted for public comment. By late 1989, plans were finalized and permits were received.

In early 1990, Ducks Unlimited, Inc. (DU) under the auspices of their MARSH program and in the spirit of the North American Waterfowl Management Plan, agreed to support the Impoundment Rehabilitation Project. DU committed $187,500 over two years towards the $500,000 project. The Service will commit over $300,000 before the project is completed.

The project will increase Refuge management capabilities on existing wetland areas, create 300 acres of new and improved marsh habitat and increase water management flexibility throughout the impoundment system. Major components of the project include: raising and re-sloping eight miles of existing dikes, installing 13 new water control structures, constructing 6,000 feet of new dikes, creating two storage pools totalling 53 acres, and excavating eight miles of water transport ditches.

Surplus water will be made available to the adjacent Barbours Hill Wildlife Management Area for the enhancement of 137 acres of waterfowl habitat. Benefits of the project will extend not only to migratory birds but also to freshwater fish, amphibians, aquatic mammals, invertebrates and reptiles. Improved conditions for wildlife will also improve observation and educational opportunities for Refuge visitors. The project supports the goals of the North American Waterfowl Management Plan, an international strategy for the recovery of declining waterfowl populations.

2. *Protection and Enhancement of the Back Bay Watershed*

It is no secret that the once-renowned waterfowl populations and bass fishery of Back Bay, Virginia have declined dramatically in recent years. Lands surrounding Back Bay are increasingly threatened by potential and on-going land development. These low- lying lands serve as an important filter for pollutant and sediment-laden runoff from adjacent areas. The boundary of the Back Bay National Wildlife Refuge was expanded in 1989 to include an additional 6,340 acres of brackish marsh, forested swamp, and "critical edge" upland habitat, important to a variety of wildlife species and for its natural filtering effect. Within the U.S. Fish and Wildlife Service's policy of working with willing sellers, the Refuge hopes to acquire and manage the land to improve its value to wildlife and reduce the amount of sediment and pollutants flowing into Back Bay. The approved Refuge acquisition project supports the goals of the North American Waterfowl Management Plan. However, Refuge acquisition alone will not be enough to solve the current problems of the Back Bay resource or the potential problems that may be brought on by rampant residential development. Recovery is ultimately dependent on the cooperation and assistance of State and local governments, private organizations and individual citizens.

As a major land owner in the Back Bay watershed and a steward for its natural resources, Service concerns regarding the decline in the natural resources and water quality in the bay have resulted in a proposed new initiative to address water quality issues. The Back Bay Initiative, as envisioned, is a multi-year effort to address water quality problems and provide possible remedies. The overall objectives are to: 1) review water quality, land use, and biological data pertaining to Back Bay and northern Currituck Sound for the purpose of evaluating historic and present day water quality trends, land use patterns, and ecosystem impacts; 2) establish and coordinate a communications network with Federal, State, and local government agencies and private conservation groups and citizens to encourage efforts to protect and enhance water quality in Back Bay; 3) establish and coordinate a scientific workgroup to evaluate water quality issues in Back Bay and subsequently determine what is necessary to begin efforts to improve water quality; 4) conduct scientific studies to investigate the impacts from contaminants such as pesticides, herbicides, nutrients, and sediments to natural resources in the bay. A request for funding for this effort during 1991 is currently pending.

Active participation from various agencies and the general public is critical to the overall effort to identify and resolve water quality problems in the watershed. The improvement of water quality on a watershed scale can only be successful through the commitment and coordination of resources of the many agencies that have the expertise, funding, and/or regulatory authority to affect changes. The Service is poised to enter this partnership, and is willing to commit the necessary resources to protect and enhance this important resource.

3. *Environmental Education and Wildlife-Oriented Public Use*

Protecting and enhancing habitat today will not necessarily ensure its wise use in the future. To do that, the citizens of tomorrow must appreciate and understand the values of these areas to the plants and animals which inhabit them and accept the responsibilities of stewardship with which they will be entrusted. This is where a comprehensive program of environmental education and the provision for wildlife-oriented public use of Refuge resources enters the picture.

By 1987, the Refuge had completed the long transition from indiscriminate use of resources by the public to nearly exclusive wildlife-oriented use. Former non-wildlife-oriented uses such as off-road vehicling, swimming, surfing, sunbathing, kite flying, etc. have been replaced by birdwatching, nature observation, hiking, biking and shell collecting. These primarily, non-consumptive, uses are much less damaging to Refuge resources and are less complex and time-consuming to administer.

Environmental Educational opportunities at Back Bay began to expand dramatically in 1985. The Service is committed to providing environmental education opportunities for students. Local, regional and national educators are invited to investigate and utilize the resources of Back Bay National Wildlife Refuge with their colleagues and students. Teacher workshops at the Refuge provide orientation to Refuge lands, outdoor classroom sites, trails, interpretive facilities and equipment, and potential field activities. Refuge staff members are available to assist with: preliminary planning, group scheduling, library research, workshop registration, trip logistics and on-site group orientation.

Most classroom sites, associated trails/boardwalks, and Visitor Contact Station facilities are wheelchair accessible. Refuge habitats available for investigation include ocean, beach, pond, dune, bay, shrubland, maritime forest and marsh. During 1989, 3,700 students utilized the Refuge as an outdoor classroom. Many other individuals visited just to enjoy the resources of the area. These visitors and students gain a lasting impression of the beauty and significance of area resources. Many of them then take these images and experiences home with them and later support needed protection and management practices at the Refuge and in other areas.

Summary

Over the past 20 years, the Back Bay National Wildlife Refuge has undergone a major transition. During this period, emphasis has evolved from a major effort to control an adverse and damaging public use pattern (ORV's), to the more tradition role of habitat management. This transition illustrates the commitment of the Service to the protection and enhancement of important wildlife resources. Renewed habitat management efforts and cooperation with private sector partners are an example of the approach that will be required to ensure the preservation and restoration of the entire Back Bay watershed. The Service's commitment to Environmental Education, together with the programs of the State, City and other educators can result in an informed public willing to make the needed decisions that will ensure habitat protection and healthy wildlife populations in the future. The Service is committed to this future. We stand ready to forge new partnerships to see that Back Bay does not go the way of the Lynnhaven River and is a resource for all to appreciate and enjoy for many years to come.

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V. Poster Abstracts

Assessment of Organic and Metal Contaminants in Lower Back Bay and Upper Currituck Sound

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Studies were conducted at Mackay Island National Wildlife Refuge in 1988 and 1989 to provide baseline data for an assessment of organic chemicals and metal contaminants in the aquatic ecosystem. Longnose gar, gizzard shad, snapping turtles, common rangia clams and sediments were collected from sites in lower Back Bay and upper Currituck Sound for contaminant analyses.

Composite sediment samples were analyzed for the presence of metals, organochlorine pesticides and polycyclic aromatic hydrocarbons (PAHs). Organochlorine pesticides were not detected in the sediments. Various PAH compounds were detected in the sediments, although at trace concentrations which just exceeded the analytical detection limit (detection limit 0.01 parts per million wet weight). Metal residues were not elevated with respect to background levels typical of sediments in eastern North Carolina coastal ecosystems.

Mean metal residues in the fish (wholebody), turtles (livers) and clams (soft tissues) did not indicate contamination above background levels. Organochlorine pesticides were detected at low or trace levels. The most commonly observed organochlorine pesticides were p,p -DDE and p, p - DDD. Polychlorinated biphenyls (PCBs) were detected at overall low levels in those species analyzed (fish, turtles). Aliphatic hydrocarbons were present in rangia clams at levels indicative of chronic low-level exposure.

In summary, the contaminants detected at Mackay Island National Wildlife Refuge in the sediments and biological samples were present at low concentrations typical of background levels. The data do not indicate the presence of toxic "hotspots" on or immediately adjacent to the Refuge. This suggests that the present degradation in water quality in lower Back Bay and upper Currituck Sound may be linked to: 1) more conventional pollutants, such as excess nutrients and turbidity, associated with non-point source run-off; 2) changes in freshwater inflow due to annual fluctuations in rainfall; and/or, 3) other classes of agricultural chemicals, such as carbonates, organophosphates and chlorophenoxy acid herbicides.

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Refuge Land Acquisition: Helping Preserve Back Bay's Wildlife Heritage

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The once-renowned waterfowl populations and bass fishery of Back Bay, Virginia have declined dramatically in recent years. Lands surrounding Back Bay are increasingly threatened by on-going and potential land development. These lands serve as an important filter for pollutant and sediment-laden runoff from adjacent areas. The boundary of the Back Bay National Wildlife Refuge was expanded in 1989 to include an additional 6,340 acres of brackish marsh, forested swamp, and "critical edge" upland habitat, important to a variety of wildlife species and for its natural filtering effect. Within the U.S. Fish and Wildlife Service's policy of working with willing sellers, the Refuge hopes to acquire and manage the land to improve its value to wildlife and reduce the amount of sediment and pollutants flowing into Back Bay. Refuge acquisition plans support the goals of the North American Waterfowl Management Plan, an international strategy for cooperation, to aid in the recovery of declining waterfowl populations. Refuge acquisition alone will not be enough to solve the current problems of the Back Bay resource; recovery is dependent on the cooperation and assistance of State and local governments, private organizations and individual citizens.

Environmental Education: A Chance for the Future

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The U.S. Fish and Wildlife Service is committed to providing environmental education opportunities for the Nation's student body. Local, regional and national educators are invited to investigate and utilize the resources of Back Bay National Wildlife Refuge with their colleagues and students. Teacher workshops at the Refuge provide orientation to Refuge lands, outdoor classroom sites, trails, interpretive facilities and equipment, and potential field activities. Refuge staff members are available to assist with:

- Preliminary planning
- Group scheduling
- Library research
- Workshop registration
- Trip logistics and
- On-site group orientation.

Most classroom sites, associated trails/boardwalks, and Visitor Contact Station facilities are wheelchair accessible. Refuge habitats available for investigation include ocean, beach, pond, dune, bay, shrubland, maritime forest and marsh. During 1989, 3,700 students utilized the Refuge as an outdoor classroom.

U.S. Fish and Wildlife Service Back Bay Initiative: Goals and Objectives

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Back Bay has historically been noted for its abundant wildlife and fisheries. A testimony to this fact has been the establishment of two U.S. Fish and Wildlife Service National Wildlife Refuges (Back Bay and Mackey Island National Wildlife Refuges), three Virginia Department of Game and Inland Fisheries Waterfowl Management Areas (Pocahontas, Barbours's Hill, and Trojan Waterfowl Management Areas) and a State park (False Cape State Park). Back Bay has been a major stopover point for waterfowl in the North Atlantic flyway, it had prodigious submerged aquatic vegetation (SAV) beds and an outstanding fisheries. Since the 1920's these resources have fluctuated dramatically. Water quality in the bay is degraded, and at the present time, there is relatively little SAV in the bay, waterfowl use is drastically low, and fish populations are also generally depressed.

The U.S. Fish and Wildlife Service (Service) is a major land owner in the Back Bay watershed and is a steward for natural resources. Service concerns regarding the decline in the natural resources and water quality in the bay have culminated in a major new initiative to address water quality issues. The Back Bay Initiative is proposed as a multi-year initiative to address water quality issues in Back Bay, Virginia. The overall objectives are to; 1) review water quality, land use, and biological data pertaining to back Bay and northern Currituck Sound for the purpose of evaluating historic and present day water quality trends, land use patterns, and ecosystem impacts; 2) establish and coordinate a communications network with Federal, State, and local government agencies and private conservation groups and citizens to encourage participation efforts to protect and enhance water quality in Back Bay; 3) establish and coordinate a scientific workgroup to evaluate water quality issues in Back Bay and subsequently determine what scientific data are necessary to support efforts to improve water quality; 4) conduct scientific studies to investigate the impacts from contaminants such as pesticides, herbicides, nutrients, and sediments to natural resources in the bay. In 1991, the U.S. Fish and Wildlife Service is planning to conduct sediment bioassays to evaluate the pesticidal impacts on the bay by determining the relative toxicity of sediments in the bay. If the results from these assays prove the sediments are toxic, then the sediment will be analyzed to determine the potential causative agent(s). In 1992, the Service proposes to investigate nutrient discharges into the bay during storm events.

Participation from the various agencies can contribute to the overall effort to identify and resolve water quality problems in the watershed. The improvement of water quality on a watershed scale can only be successful through the commitment and coordination of resources of the many agencies that have the expertise, funding, and/or regulatory authority to affect changes.

Rx for Success at Back Bay National Wildlife Refuge: Take Two Committed Partners—Add Water

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As part of a major effort to improve habitats for waterfowl and other wetland-dependent wildlife, Ducks Unlimited, Inc. is contributing $187,500 in matching funds to help the U.S. Fish and Wildlife Service rehabilitate wetland impoundments at Back Bay NWR.

The three-year project will increase Refuge management capabilities on existing wetland areas, create 300 acres of new marsh habitat and increase water management flexibility throughout the impoundment system. Components of the project include:

- Raising and re-sloping 8 miles of existing dikes
- Installing 13 new water control structures
- Constructing 6,000 feet of new dikes
- Creating two storage pools totalling 53 acres and
- Excavating 8 miles of water transport ditches.

Surplus water will be made available to adjacent False Cape State Park/Barbours Hill Wildlife Management Area for the enhancement of 137 acres of waterfowl habitat. Benefits of the project will extend not only to migratory birds, but also the freshwater fish, amphibians, aquatic mammals, invertebrates and reptiles. Improved conditions for wildlife will also improve observation and educational opportunities for Refuge visitors. The project supports the goals of the North American Waterfowl Management Plan, an international strategy for the recovery of declining waterfowl populations.

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