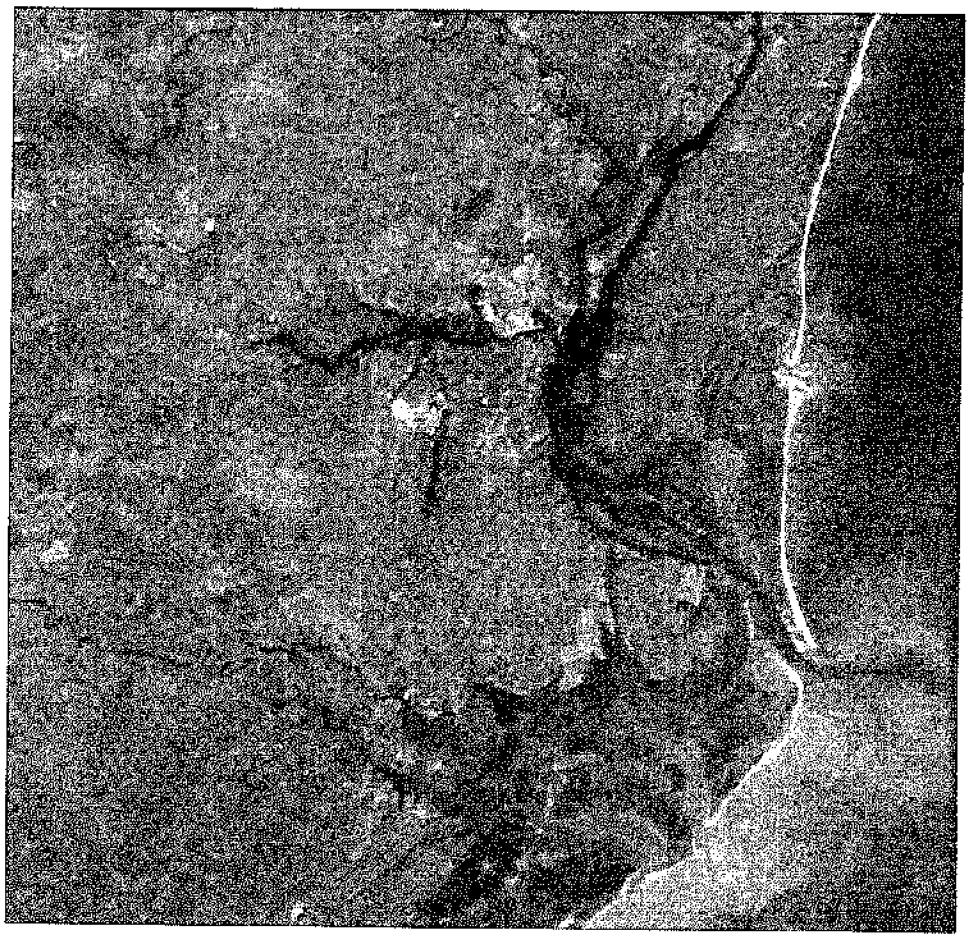
Characterization of the Physical, Chemical and Biological Conditions and Trends in Three South Carolina Estuaries: 1970–1985



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Characterization of the Physical, Chemical, and Biological Conditions and Trends in Three South Carolina Estuaries: 1970–1985

Volume II
Winyah Bay and North Inlet Estuaries

South Carolina Sea Grant Consortium
Charleston, South Carolina
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PREFACE

The South Carolina Sea Grant Consortium, with support from the National Ocean Pollution Program Office of the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, organized and managed a project involving scientists from the Marine Resources Research Institute (SC Wildlife and Marine Resources Department) and the Belle W. Baruch Institute (University of South Carolina) to characterize three South Carolina estuaries - Charleston Harbor, North Inlet and Winyah Bay. The results of this two-year study are presented in two volumes, each preceded by an Executive Summary.

Volume I includes the Executive Summary and detailed information and analyses for Charleston Harbor, while Volume II includes the Executive Summary and the results for North Inlet and Winyah Bay.

Kevin B. Davis and Robert F. Van Dolah of the SC Wildlife and Marine Resources Department researched and wrote on Charleston Harbor Estuary. The report on North Inlet and Winyah Bay was prepared by Elizabeth R. Blood and F. John Vernberg of the University of South Carolina. The Executive Summary was prepared by M. Richard DeVoe of the SC Sea Grant Consortium with the assistance of Katherine H. Doak. All documents were copyedited by Anne Miller (University of South Carolina) and M. Richard DeVoe and word processed by Cheryl Nybras (University of South Carolina).

The project investigators and staff thank Dr. Larry Pugh, National Ocean Pollution Program Office, for his insight, guidance and patience, without which this effort would have been most difficult to complete.

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Cover Photo: Color composite based on Landsat TM of the Winyah Bay and North Inlet estuaries.

Characterization of the Physical, Chemical, and Biological Conditions and Trends in Three South Carolina Estuaries: 1970-1985

Executive Summary

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INTRODUCTION

Estuaries are an extremely important resource which serve a multitude of often competing constituencies. The over 850 estuaries located along the nation's coasts serve as important nursery grounds and habitat for a variety of finfish, shellfish, and other aquatic organisms. The shores of estuaries are also prime sites for cities, business and industry, military facilities, and ports. Multiple uses of estuaries are expected to intensify as more of the population continues to move to the coastal areas.

Due, in part, to these increasing pressures, a number of federal- and state-sponsored programs (e.g., coastal zone management, fisheries management, water quality standardization) were developed in the late 1960's and early 1970's. Their underlying goal is the protection and, in some cases, rehabilitation of estuarine systems. It is paramount that information on the complex interaction of physical, chemical, biological, and geological processes in estuaries be developed to allow a better understanding of the behavior of estuarine systems and improved capability to manage them. Unfortunately, the diversity of research efforts conducted in our nation's estuaries has often been restricted along specific disciplinary lines, and few comprehensive studies have been attempted to date. As a result, estuarine management has usually focused on specific sites and particular needs, thus limiting evaluations of how effective estuarine management efforts have been.

In a recent review of estuarine research, the National Research Council's (NRC) Panel on Estuarine Research Perspectives indicated that although estuarine systems are undergoing continuous change, there are not many scientific studies which can adequately demonstrate such changes in particular estuaries (NRC 1983). The Panel further stated that it is difficult, if not impossible, to relate such changes, if they can indeed be accurately documented, to "some one or more causes, anthropogenic or other" (NRC 1983). They suggested that comparative studies of estuaries be conducted in urbanized areas and in less-developed regions where climatic and topographic characteristics are similar to "provide an insight into the long-term effects of anthropogenic stresses in the absence of (or as a supplement to) historical records" (NRC 1983).

The South Carolina Sea Grant Consortium, with support from the National Marine Pollution Program Office (National Oceanographic and Atmospheric Agency), coordinated the development and implementation of a project involving researchers from the Marine Resources Research Institute (SC Wildlife and Marine Resources Department) and the Belle W. Baruch Institute for Marine Biology and Coastal Research (University of South Carolina) to conduct a characterization study and analysis of three South Carolina estuaries.

OBJECTIVES AND RATIONALE

The overall goal of the project was to conduct a systematic review and comparison of the long-term trends (15-year period) in land and water use patterns and biological and physical changes of Charleston Harbor, North Inlet and Winyah Bay, three important South Carolina estuarine systems. The analyses sought to relate these trends to changes in pollutant concentration loadings and the resultant effects on the living marine resources of the two systems. Specific objectives of this assessment were

(1) to compile and synthesize data and information sources available for the review period and, where possible, evaluate long-term trends in land and water use patterns, water quality, and living

aquatic resources for each estuary;

(2) to where possible, correlate changes in historical use patterns with observed effects on the living marine resources; and

(3) to compare the trends from each estuary in a fashion which will be most useful to estuarine managers and scientists.

Charleston Harbor, North Inlet, and Winyah Bay estuaries are quite different with respect to human influence. The Charleston Harbor Estuary is located midway along the South Carolina coastline and is formed by the confluence of the Ashley, Cooper, and Wando rivers. The area surrounding the harbor is heavily populated and highly developed, with numerous urban, suburban, industrial, and military sites. Sources of pollution to the estuary include, for example, runoff from municipal and suburban areas, septic tanks overflows, sewage discharges, industrial outfalls, and runoff from agricultural areas (Mathews et al. 1980). However, far and above the most significant environmental perturbation to affect the Charleston Harbor Estuary was the diversion of more than 80% of the Santee River flow to the Cooper River in 1942 (see Kjerfve 1976; RPI 1980) and the recent rediversion of this water back into the Santee River beginning in 1985 (US Army Corps of Engineers Santee Rediversion Project).

The continual buildup of sediments which occurs in the Charleston Harbor and its river tributaries is derived from marsh erosion and requires maintenance dredging and removal. The harbor basin is usually dredged and maintained at a depth of 10.7 m. Upon completion of the Charleston Harbor Deepening Project in 1995, this depth will increase to 12.2 m.

The North Inlet estuary was chosen as our second system for study because it is a prime example of an estuary with minimal anthropogenic influence. North Inlet is located in Georgetown, South Carolina, and is part of the 17,500-acre Hobcaw Barony which is characterized by an estuarine-marsh complex and upland forest. It is a relatively undisturbed estuary; most of the marsh and adjacent uplands are undeveloped and owned by private foundations which have established these lands in perpetuity for conservation and research. North Inlet, with intermittent freshwater input and little salinity stratification, is classified as a 1A estuary. An important aspect of North Inlet is that the high quality of this area was recognized by the Experimental Ecology Reserve Project, TIE, which rated it at 98% for site quality. The North Inlet system was also the first marine site selected to participate in the National Science Foundation's Long-Term Ecological Research Program (LTER).

However, North Inlet Estuary faces future pollution pressures from two primary sources: Winyah Bay and coastal development activities. The Winyah Bay watershed is approximately 18,000 mi². Freshwater input into Winyah Bay estuary ranges from 2,000 to 100,000 cubic feet per second (cfs), with a mean runoff of 15,000 cfs. Water quality is influenced by the City of Georgetown through the Sampit River, which receives discharges from waste treatment plants, a pulp mill, and a steel mill. Pollutant loadings from the Pee Dee, Waccamaw, and Black rivers into Winyah Bay are dominated by agricultural runoff, with additional inputs from wastewater treatment plants. Most importantly, however, about 20% of the water exchange in North Inlet is through tidal creeks associated with Winyah Bay. Wind direction and river discharge influence the quality and quantity of water entering North Inlet from the bay. Because of Winyah Bay's proximity to and influence upon North Inlet, it was added to the study.

The second potential source of pollutants which could affect the North Inlet system may come from increased coastal development. Several years ago, approximately one-quarter of the North Inlet watershed was zoned for urban development. About 2,300 dwelling units will be constructed, along with one or two golf courses. Surface water drainage has been significantly modified and plans are being considered to modify existing wetlands on the property zoned for urban development. Additionally, modification of existing tidal creeks has been proposed. These actions may have visible effects on the hydrology, chemistry and biota of North Inlet. Increases in anthropogenic chemicals (pesticides, herbicides, petroleum hydrocarbons, etc.) have been projected.

The choice of these systems was based on the fact that most estuaries have been altered by human activity either through direct impacts (e.g., dredging, filling, and pollution) or indirect impacts (e.g., alteration of watershed characteristics and freshwater discharge), and these changes have modified their structure, function, and temporal dynamics. Because the understanding of anthropogenic effects and the resistance and resilience of estuarine systems is poor, some insights might be gained by comparing estuarine systems which exhibit varying degrees of human intervention. This study was an attempt to compare and contrast three estuarine systems with quite different histories to gain a better understanding of how human influence can impact critically important systems.

These estuarine systems were also chosen for study because they represent the more thoroughly studied systems in South Carolina. For instance, many of the more than 900 scientific papers and books that have been published by the Baruch Institute focus on research conducted in North Inlet and adjacent habitats, such as Winyah Bay. Studies have dealt with the functional dynamics of coastal environments from the molecular to the ecosystem level of organization, with a goal of understanding the temporally and spatially complex interactions between biotic and abiotic components of this estuarine system. Information available on Charleston Harbor Estuary has been developed primarily in response to the many activities and manipulations that have occurred in and around the harbor; the sources are many.

GEOGRAPHIC SETTING

The watershed areas of Charleston Harbor, North Inlet, and Winyah Bay estuaries lie entirely within the South Carolina Coastal Plain and represent extensive estuarine-marsh systems. The Coastal Plain slopes downward toward the sea, accounting for high stream flows. It consists of Pleistocene sedimentary deposits of sand, gravel, clay, marl and limestone resting upon a basement of ancient rocks. Underlying sediments of the Coastal Plain are metamorphic and igneous rock. Above this are sediments of consolidated and unconsolidated materials from marine and alluvial deposits. Overlying these deposits is a thin blanket of unconsolidated sand, clay and shell comprising the Pleistocene and Recent formations. This material is 3 m to 5 m thick with maximums reaching 15 m. The area is dissected into terraces as a result of former sea level episodes.

Charleston Harbor Estuary

The Charleston Harbor watershed is the second largest watershed in South Carolina. Classified as a 2b estuary (according to Hansen and Rattray 1966), Charleston Harbor has the third largest estuarine drainage area and the second largest inflow of freshwater from all sources in the state.

The estuary is located midway along the South Carolina coastline at the junction of three rivers — the Cooper, Wando, and Ashley. The lower harbor basin is bound on the north by residential communities of Sullivans's Island and Mt. Pleasant, on the south by James Island and the undeveloped Morris Island, and on the west by the peninsula of Charleston city. The lower harbor meets the Ashley River at the Intracoastal Waterway and meets the Cooper River at its junction with the Wando River.

Portions of the watershed containing the Ashley River, Wando River, and the lower harbor basin drain an extensive area of marsh and lowlands. The Ashley River, with its origin in Cypress Swamp in Berkeley County, drains a 900 km^2 area in Berkeley and Charleston counties. The Wando River flows from headwaters in the Iron Swamp in Charleston County and drains 310 km^2. The lower harbor basin covers an area of 65 km^2 and drains an additional area of 104 km^2.

Due to environmental engineering projects completed by the US Army Corps of Engineers (USACOE) within the watershed, the amount of area drained by the Cooper River has fluctuated dramatically. Prior to 1942, the area drained totalled 3,625 km^2. After completion of the Santee-Cooper Hydroelectric Project in 1942, which diverted waters from the Santee River into the Cooper River, the total drainage area increased to 41,000 km^2 and freshwater flow increased to approximately 428 m^3/s. However, due to continued problems with increased shoaling and higher dredging costs as a result of the extra flow, the USACOE completed the Cooper River Rediversion Project in 1985. The Rediversion Project diverted approximately 70% of the Santee-Cooper drainage back into the Santee River in the vicinity of St. Stephens, South Carolina. Subsequently, the monthly mean flow in the Cooper River has been reduced to approximately 128 m^3/s. Since information included in this report was limited to the period 1970 to 1985, the data used to characterize the watershed and determine long-term trends reflect conditions preceeding the Rediversion Project of 1985, unless otherwise stated. Available information generated after rediversion is now available in Van Dolah et al. (1990).

Throughout the history of the Charleston Harbor, sea level has risen and fallen, periodically inundating the Coastal Plain, layering sediments and dividing the plain into terraces. The estimated rate of sea level rise is 2.5 mm per year. This rate creates concerns over the greenhouse effect and its influence on global temperatures, sea level rise and weather conditions.

Presently, the climate in the area is relatively mild compared with inland temperatures. The winters are mild and temperate, while the summers are warm and humid. The estuary receives an annual average precipitation of 124.87 cm, which is almost exclusively rainfall.

Charleston Harbor has served as a strategic shipping port ever since 1670 and is, in fact, the second largest container port along the Atlantic seaboard. The area is a popular tourist attraction due to its history and culture, and more importantly, is a great economic resource. The lands surrounding the estuary are largely developed and support a population of more than one-half million people within the tricounty area of Charleston, Dorchester and Berkeley counties. Within the 3,000 km^2 area are the area's largest municipalities — Charleston and North Charleston. Land use patterns in the area are 56% forested, 14% agricultural, 10.3% rural, and more than 6% each urban and open water.

Economic activity and population growth within and around the Charleston Harbor watershed has placed many demands on the estuarine system. For example, the Cooper River is home to military facilities which rank as the third largest home port of the US Navy. In addition, numerous marina, industrial, and municipal wastewater facilities are situated in the watershed's rivers. Some of the largest municipal dischargers include the Charleston Commissioners of Public Works, North Charleston Sewer, Berkeley County Water and Sewer Authority, and the Town of Summerville. WestVaco is the largest industrial discharger in the area. The lower harbor basin, surrounded by city and urban developments, boasts many commercial port facilities and receives effluent from a number of point sources. Nonpoint source runoff from low-lying areas and periodic flooding of the drainage system adds to the point-source discharges in the area.

North Inlet and Winyah Bay Estuaries

North Inlet Estuary is a bar-built class C type estuary (Pritchard 1955) located 70 km northeast of Charleston, South Carolina. The watershed drains a 24.8 km² area of mostly forest to the east and west and a moderately developed residential watershed to the north. The North Inlet Estuary is composed of numerous winding tidal creeks and is considered a pristine tidal estuary due to minimal anthropogenic impacts. The marsh is bounded by sandy barrier islands to the east and is connected to the coastal ocean by way of the tidal inlet of Town Creek through which 79% of all water exchange occurs. North Inlet is bound to the south and southwest by Winyah Bay and is connected to it by three creeks: South Jones, No Man's Friend, and Haulover.

The Winyah Bay watershed is one of the largest estuarine ecosystems on the Eastern Seaboard and is classified as a B type estuary by Pritchard (1955). It is located 14.4 km south of North Inlet. The entire basin drains an extensive area of approximately 46,736 km² and is composed of the lower Winyah Bay, which enters into the Atlantic Ocean, and the subbasins of six major rivers: Pee Dee, Lynches, Little Pee Dee, Black, Waccamaw, and Sampit. The drainage originates in the Blue Ridge Mountains of North Carolina and enters the Yadkin-Pee Dee River system, which accounts for more than 41,451 km² of the basin. Of the remaining total area, the Lynches River basin composes 3,549 km², the Little Pee Dee River 2,849 km², the Black River 5,298 km², the Waccamaw River 2,578 km², and the Sampit River 622 km². Most of the area drained is rural except for the marsh and cypress and hardwood swamps in the Waccamaw River and Sampit River areas, which are closest to the lower bay.

The lower Winyah Bay is oriented in a northwest-southeast direction and is 29 km long with a surface area of 155.4 km². This estuary is widest at its center, 7.2 km, and is a narrow 1.2 km at its entrance. The mean depth is 4.2 m; however, a navigation channel is maintained at 8.2 m and is 29 km long, extending from the Port of Georgetown to the jetty at the entrance. Several islands occur within the bay and a very shallow area, called Mud Bay, is centrally located. The Winyah Bay Estuary and its six subbasins together comprise 20.1% of North Carolina's and 25.3% of South Carolina's total land area, draining through the Piedmont regions and Coastal plains. The area includes the South Carolina counties of Chesterfield, Darlington, Florence, Marlboro, Marion, Dillon, Georgetown, Williamsburg, Lancaster, Kershaw, Lee, Sumter, Horry and Clarendon.

Winyah Bay is a true coastal plain estuary, and receives its freshwater from the Pee Dee, Waccamaw and Sampit rivers. Two major factors influence the current geomorphology of this estuary: jetty construction and maintenance of a navigable commercial boat channel. The area is dredged due to extensive shoaling and sand trapping caused by the jetty.

North Inlet is very dynamic with the formation of spits and swash bars. A well-developed ebb-tidal delta was present by 1963 as well as a lengthening main ebb-channel. The low elevations and coastal location of the watershed produce a temperate to subtropical climate with moderate temperatures. The mean annual temperature is 18°C and ranges from an average 8.4°C in January to 26.9°C in July. Precipitation averages 130 cm per year, with summer being the wettest season. Climate and precipitation are influenced by two major factors affecting the southeast coastal environment: large rainfall deficits (droughts) and rainfall excesses (tropical storms and hurricanes).

The entire Pee Dee-Yadkin Basin of South Carolina supported a 1980 population of 619,800 people, with the majority of people residing within the Yadkin-Pee Dee and Black subbasins. The projection for 1990 wa that more than 2,500,000 people would reside in this area. Urban and developed areas comprise a relatively small portion of the basin, however. Forestry resources dominate, making up 12,144.4 km² of the basin. The dominant economic activity of the Pee Dee subregion is agriculture, accounting for 7,629.3 km² of the subregion. Tobacco and soybeans are the primary cash crops.

The Waccamaw Region Planning District, which includes Winyah Bay and North Inlet estuaries, includes the counties of Georgetown, Horry, and Williamsburg. Wetland areas comprise 29% of the total land area, forest 45.6%, agriculture 21%, and urban areas 2.5%. East of the Waccamaw River is a popular tourist area, the Grand Strand, made up of residential and commercial developments. The North Inlet area is primarily forest or undeveloped (89.6 km²), wetlands (52.6 km²), and the remaining area (1.1 km²) is residential and recreational (e.g., golf courses).

PHYSICAL AND CHEMICAL PROPERTIES

Charleston Harbor

The operation of the Pinopolis hydroelectric plant on the Cooper River influences freshwater flow and salinity in Charleston Harbor. Before diversion of the Santee River the monthly average flow was 11.8 m³/s; after diversion the number significantly increased to 455 m³/s. Since the Rediversion Project, the flow from the Cooper River into Charleston Harbor has become more stable with a monthly mean of 122 m³/s.

The estuary experiences semidiurnal tides. Prior to rediversion the mean tidal amplitude range was 1.6 m, and during a spring tide the range increased to 1.8 m. Effects of the Rediversion Project on the tides are not yet well-documented. The reversals of surface and bottom currents over a single tidal cycle determine the circulation patterns in the harbor. The estuary is stratified with a net downstream flow in a relatively freshwater surface layer, a net upstream flow in the bottom saline layer, and a net bottom to surface flow of water.

After diversion of the Santee River, sedimentation in Charleston Harbor averaged approximately 7,645,350 m³/y. The Rediversion Project was undertaken to reduce sedimentation rates in Charleston Harbor, but post-rediversion rates have not yet been documented. The three major sources of material entering the harbor include offshore coastal material, Holocene deposits within the Cooper River basin, and material transported from the upper Santee River basin through lakes Marion and Moultrie.

Basic water quality parameters, including temperature, salinity, dissolved oxygen, nutrients, and pollutants, have been measured extensively throughout the estuary. The water temperature averaged 19.8°C and ranged from 6.2°C to 29.9°C. The difference between surface and bottom temperatures ranged between 0.5°C and 2.0°C, and seasonally ranged from a low of 1.5°C to a high of 35.0°C throughout the entire estuary.

Salinity regimes are controlled by freshwater flow and tidal stages. At high river discharges the estuary is strongly stratified; conversely, at lower freshwater flows the estuary is less vertically stratified. Prior to rediversion, the mean harbor salinity was 16.8 parts per thousand (‰) with a range of 7.7 ‰ to 29.5 ‰ prior to rediversion. Within the watershed the salinity ranged from 0 ‰ to 35.6 ‰. The average salinity at the mouth of the Cooper River varied from 4.5 ‰ to 5.3 ‰, and at the mouth of the harbor from 16.0 ‰ to 18.5 ‰.

Dissolved oxygen levels in the estuary, which are affected by such factors as temperature, presence of phytoplankton, magnitude of river flow, and seasonal fluctuations, ranged from 0 mg/l to 17.05 mg/l and averaged 7.46 mg/l. Dissolved oxygen (DO) levels were higher in surface waters and in colder months. The percent saturation of DO in bottom waters of the upper harbor is 52%, the lower harbor 77%, near the mouth of the harbor 80%, and at the mouth 90-95%. Studies examining the effects of the Rediversion Project on DO content in Charleston Harbor Estuary are reported by Van Dolah et al. (1990).

Nitrates, phosphates, and ammonia are several of the nutrients monitored during the study period. Kjeldahl nitrogen was found to range between 0.04 mg/l and 19.90 mg/l. Total ammonium concentrations ranged between 0.02 mg/l and 13.0 mg/l. Nutrients found in lower amounts include nitrate-nitrite (0.0-6.65 mg/l), orthophosphate (0.0-1.56 mg/l) and, total phosphate (0.02-4.6 mg/l).

Pollutants were monitored throughout the estuary. Metals were detected in maximum amounts of 10,310 µg/l for iron, 2,000 µg/l for copper, and 1,080 µg/l for chromium. The range of biochemical oxygen demand was 0.15 mg/l to 11.0 mg/l, of chemical oxygen demand 0.00 mg/l to 930 mg/l, and of fecal coliform 1 to 31,500 colonies/100 ml.

Winyah Bay and North Inlet Estuaries

Of the freshwater inflow into Winyah Bay Estuary, 90% originates from the Pee Dee River and the remainder from the Waccamaw and Sampit rivers. Freshwater inflow occurs at a rate of 26.9 m^3/s at low flow and 7,884 m^3/s during major floods. The greatest flow occurs in the winter. In contrast, there is little freshwater input into North Inlet Estuary. Inflow occurs at a rate of 1-5 m^3/s from groundwater input and upland runoff. Half of the volume is a result of rainfall.

The mean tidal amplitude of Winyah Bay is 1.0 m at Georgetown Harbor and 1.2 m at the mouth of the bay. Aside from freshwater input, the semidiurnal tide is the dominant factor influencing circulation patterns. The bay is partially stratified for most of the year with the greatest stratification occurring during high freshwater discharge. North Inlet has a tidal range of 1.1 m for neap tides and 2.5 m for spring tides. The average flow of tidal currents is 1.3 m/s. Circulation is driven by tidal pumping and those factors influencing tidal variation. Sheet flow plays a minor role. The estuary is well mixed; no significant vertical stratification of salinity or density occurs.

Sedimentation in Winyah Bay is extensive. Approximately 25,509,943 tons of soil per year are eroded throughout the watershed. Silt and clay characterize the majority of the sediments in the upper third of the harbor and estuary, while more than 59% of the sediments in the lower bay consist of sand. Surface sand formations are deposited on marls, sands, clays, and limestones formed by sedimentation. The interridge of marsh along the perimeter of North Inlet is sand, with evidence that this marshland has evolved from a forest environment. Sedimentation rates of

1.3 mm/yr to 2.5 mm/yr in North Inlet are minimal compared to Winyah Bay.

A number of water quality parameters have been studied in these systems. Water temperature averaged 19.2°C in Winyah Bay during the reporting period, with a mean monthly average of 6.3°C in January and 28.2°C in July. These temperature extremes occurred in Mud Bay. No vertical stratification in temperature was found. In the North Inlet estuary, the average temperature was 18.7°C with a monthly average of 8.3°C in January and 27.2°C in July.

Spatial and temporal variation in salinity occurred in both Winyah Bay and North Inlet estuaries. Strong vertical stratification was present in the upper bay with ocean-dominated bottom water, whereas little vertical stratification was present in the lower bay due to tidal mixing. Salinity in the bay ranged from 3.5 ‰ to 15 ‰ with a mean salinity of 7.4 ‰. Within North Inlet Estuary the highest salinity (33.3 ‰) existed at Town Creek. Due to high flushing of the inlet, salinity is spatially homogeneous over the year. Mean monthly salinities ranged from 29.5 ‰ in May to 34.4 ‰ in October.

Monthly dissolved oxygen concentrations in Winyah Bay exhibited an inverse relationship to temperature; the lowest concentrations coinciding with maximum productivity. The mean monthly concentration ranged from 5.2 mg/l to 10.9 mg/l with greatest variation occurring in July. In North Inlet, the DO range was 1.5- 7.4 ppm. The highest concentrations occurred during daylight and at high tide.

In Winyah Bay, total phosphorus averaged 3 μg-at/l. Seasonal variation in total phosphorus was positively correlated to temperature. The highest concentrations were found in June and the lowest in winter. Phosphorus concentrations increased with increasing depth. The Sampit River contained the highest total phosphate concentrations. Much of the data indicates that concentrations of total phosphorus were from river sources. Orthophosphate averaged about 22% of total phosphorus and exhibited little variation with depth and season. The overall mean orthophosphate concentration was 0.55 ug-at/l.

Within the North Inlet Estuary, particulate phosphorus comprised 56% of total phosphorus, which averaged 1.03 μg-at/l. The lowest total and orthophosphate concentrations (0.74 μg-at/l and 0.018 μg-at/l, respectively) occurred at Town Creek, while the waters adjacent to Winyah Bay contained the highest concentrations (up to 2.89 μg-at/l and 2.58 μg-at/l, respectively). Particulate phosphorus concentrations were found to be highest near the forest and lowest toward the mouth of the inlet. Seasonal variations in total, orthophosphate and particulate phosphorus were present, with highs in August and lows in winter.

Nitrogen was also monitored in Winyah Bay. Total Kjeldahl nitrogen averaged 75.78 μg-at/l, nitrate-nitrite averaged 16.57 μg-at/l, ammonia 14.07 μg-at/l, and dissolved organic nitrogen 61.71 μg-at/l. Higher dissolved organic nitrogen concentrations were found to occur during the early summer months and October. The highest concentrations of and variations in total nitrogen were measured in October and May, whereas ammonia and nitrate-nitrite were highest in summer and winter. Significant temporal and spatial variations in nitrogen concentrations occurred in Winyah Bay. Nitrate-nitrite and total nitrogen decreased along the main channel from the upper bay to the ocean during spring. A strong linear relationship of total nitrogen with salinity suggests that the river waters entering the bay are significant sources of nitrogen. The average total concentration in these rivers was 20% greater than the average concentration in the bay.

Within North Inlet Estuary the mean total nitrogen concentration was 33.67 μg-at/l. Of this, 60%

was dissolved organic nitrogen, 34% particulate nitrogen, 5% ammonia and less than 1% nitrate-nitrite. The highest concentrations of total nitrogen were found near Winyah Bay and the lowest near Town Creek. Total nitrogen exhibited a strong seasonal pattern which co-varied with primary production and the annual temperature cycle, primarily as a result of variation in particulate nitrogen. Concentrations were highest in summer months and lowest in January.

In contrast to Winyah Bay, nitrogen patterns in North Inlet Estuary were more closely related to the temperature cycle than to freshwater runoff. Increased concentrations in nitrate during May, June, and July in Winyah Bay were similar to the peaks in North Inlet Estuary; however, the winter peak coincident with freshwater input in Winyah Bay was not evident in North Inlet. Peaks in nitrate-nitrite in January, March, and June exhibited a strong relationship with salinity. Ammonia had the opposite relationship to salinity in Winyah Bay, with highest ammonia values corresponding to the lowest salinities. In North Inlet Estuary highest ammonia concentrations occurred with high salinity peaks (June, August, and September). Ammonia tracks temperature in North Inlet Estuary, unlike in Winyah Bay. Total nitrogen showed a strong seasonal pattern, tracking temperature, in North Inlet Estuary but an erratic pattern in Winyah Bay.

BIOLOGICAL CHARACTERISTICS

Charleston Harbor Estuary

The productive Charleston Harbor watershed sustains a vast array of biological communities. Marsh acreage exceeds 21,000 ha and includes brackish and salt marsh, freshwater marsh, and coastal impoundments. The distribution of intertidal vegetation is influenced by salinity conditions and the duration of tidal flooding. The predominantly marine and brackish waters of the Ashley and Wando rivers support *Juncus romerianus* in large quantities. The Cooper River contains a diversity of freshwater and saltwater types. The most common genera are *Juncus*, *Spartina*, *Sagittaria*, and *Scirpus*. Total annual production of a freshwater marsh at Dean Hall Plantation was 1,600 g/m^2.

The watershed does not support extensive subtidal seagrass beds or benthic macroalgae communities except for the *Egeria* beds in the upper Cooper River. The minimal amount of subtidal vegetation is probably due to high turbidity levels and a lack of suitable shallow water substrate in the subtidal zone. Epiphytic algae is dominated by chlorophytes, diatoms, and cyanophytes. The abundant populations of dominant taxa occurring at many locations may be a reflection of the eutrophic water quality. Species diversity is found to be low in contrast to other South Carolina estuaries.

Four hundred fifty-one species of phytoplankton were found in a 1984 study of Charleston Harbor. The genus *Skeletonema* dominated the area. The highest abundance of phytoplankton was found in areas of high salinity. Diatoms tended to dominate during the spring and fall, whereas cyanophytes and flagellates dominated during the summer and winter. The overall abundance of zooplankton, however, was found to be lowest compared to other river systems studied in South Carolina. In a 1976 report on the Cooper River, the zooplankton types observed in decreasing order of abundance were amphipods, isopods, and pelecypods.

A diverse assemblage of benthic invertebrate species is found in the Charleston Harbor watershed.

but detailed studies of macrofaunal communities were limited prior to 1984. No studies were found on meiofauna in the estuary for the study period.

For the macrobenthos, one limited study in 1976 suggests that polychaete worms were most abundant in high salinity locations, whereas, at low salinity locations, many more amphipods, isopods, and bivalves were found. Oligochaetes and amphipods comprised 49% of total abundance.

More studies of the larger invertebrate species have been conducted which show that the Charleston Harbor system supports large populations of penaeid shrimps and blue crabs. *Penaeus setiferus* tended to peak in abundance in September through October, while *Penaeus aztecus* peaked in June and July. The latter species occurred in smaller numbers and in higher salinity areas in the lower estuary. *Callinectes sapidus* was highest in abundance in October and was least abundant upstream. Shellfish beds of *Crassostrea virginica* and *Mercenaria mercenaria* are also abundant in the estuary.

The diverse finfish assemblage has value to recreational and commercial fisheries. The finfish were found to be most abundant in spring and winter. Common genera included *Leiostomus*, *Micropogonias*, *Cynoscion*, *Sciaenops*, *Paralichthys*, *Morone*, *Ictalurus*, *Stellifer*, *Anchoa*, and *Brevoortia*.

North Inlet and Winyah Bay Estuaries

North Inlet Estuary contains 2,260 ha of salt marsh, 86% of which is low marsh and 13% of which is high marsh. The low marsh is dominated by the species *Spartina alterniflora*, while the high marsh contains a mix of species. Common genera include *Spartina*, *Juncus*, *Borrichia*, *Distichlis*, *Salicornia*, *Iva*, and *Fimbristyplis*. Winyah Bay has a diverse plant community due to its broad range of salinities. Of the total area of marsh habitat (12,730 ha), freshwater marshes compose 81%, brackish marshes 18%, and salt marshes less than 1%. Many of the same genera that occur in North Inlet are present in Winyah Bay; the bay does harbor several more varieties.

Diatoms dominate the 229 species of phytoplankton found in North Inlet Estuary. The genera *Thalassionema* and *Skeletonema* were continually present and dominant in all seasons. Total phytoplankton productivity generally follows the annual temperature cycle with highs (234 mg C/m^2/hr) in summer and lows (6.4 mg C/m^2/hr) in winter. In Winyah Bay, the average chlorophyll-*a* concentration was 5.16 mg C/m^3, with highest concentrations in surface waters.

Benthic microalgae production during the period 1973 to 1975 was 2.5 times greater than phytoplankton production for that same period. Benthic macroalgae species, particularly the genus *Enteromorpha*, dominate the winter months, being a significant source of energy and carbon. The greatest number of species occurs at North Inlet and declines toward Winyah Bay, where significantly less biological information exists.

More information exists concerning benthic communities. Benthic infauna in Winyah Bay were highly diverse compared to similar sites in other southeastern states. The number of polychaete species dominated the benthic infauna, while pelecypods were high in abundance. The relative abundance of major taxa at sites adjacent to Winyah Bay differed from Charleston Harbor in which polychaetes (37%) were more abundant than pelecypods (7%), cephalochordates (20%), and sipunculids (5%). The number of species and species richness was greatest during the summer. The highest diversity occurred at the most seaward stations.

Sessile epibenthic species occurred in low numbers in the bay. Cnidarians and arthropods made up the largest number of species (21 each), followed by mollusks (15) and bryozoans (12); species common to abundant in other South Carolina estuaries. The mean number of total epibenthic organisms was highest in the Pee Dee River. Mysid shrimps were the dominant epibenthic organism, averaging approximately 42% of the catch.

In North Inlet, the highest biomass and density values for zooplankton were measured at locations with less variable salinities. Copepods, including their larval stages, were the most dominant, comprising 64% to 69% of total zooplankton numbers and biomass. The most common genus was *Parvocalanus*. Major species in North Inlet are representative of those found in Florida waters. Peaks in zooplankton density occurred in the summer. In Winyah Bay the highest number of zooplankton were collected at high salinity locations, with lowest densities found at riverine locations. Copepods tended to be most abundant in the warmer months.

North Inlet contained a diverse fish fauna with over 100 species. Common genera included *Anchoa, Menidia, Brevoortia, Fundulus, Leiostomus, Alosa, Dorosoma*, and *Mugil*. Shrimps and crabs also were present, with crabs (*Callinectes* spp.) most dominant.

Fish fauna in Winyah Bay Estuary was diverse, with up to 75 species collected. Generally, high and variable salinity locations had the highest number of individuals and species, while locations with the lowest and most stable salinities had the lowest numbers. The numbers of fish species were positively correlated with bottom temperature and salinity and negatively correlated with oxygen and depth. The most dominant species were seasonal inhabitants and abundant in specific areas.

Decapod crustaceans were not as abundant as fishes in Winyah Bay. Penaeid shrimp were numerically dominant, comprising 50% to 53% of the decapod catch with *P. setiferus* comprising about 42% alone. Blue crabs were also found year-round with the largest catches from September to December. Species found in the upper reaches of Winyah Bay were primarily freshwater genera, including *Macrobrachium* and *Ictalurus*.

LONG-TERM TRENDS

Long-term trends for Charleston Harbor, North Inlet, and Winyah Bay estuaries were difficult to identify. The data available for character analysis were mostly derived from short-term studies and were not collected for a sufficient period of time for trends analyses. The lack of consistent and standardized sampling procedures from one study to the next, as well as gaps in the data, further compounded the difficulty in determining long-term trends. These problems also precluded detailed comparisons among the estuaries. Thus, the characterization of conditions, in addition to the trends outlined in this report, represent the best attempt to compile, organize and highlight the pertinent information that was available.

Land and Water Use Trends

Charleston Harbor Estuary

One of the most significant trends affecting resource use is the increase in population within the Charleston Harbor watershed area. The population of the tricounty region increased steadily throughout the 1970 to 1985 survey period, with primary growth in Berkeley and Dorchester counties. Total residential acreage increased, resulting in the urbanization of rural areas and development of additional infrastructure to accommodate this growth. Both the recreational and commercial use of Charleston Harbor increased substantially. Recreational boat registrations increased by 45%. Additionally, 10 marinas and 13 public boat landings were developed within the time frame considered in this report. Commercial vessel traffic increased from 1,400 ships and barges to more than 1,800 as container cargo increased from 168,000 tons to 2.8 million tons. Expanding port facilities as well as the major addition of the Wando River Terminal accommodated the increases. The US Navy also expanded its port facilities and stepped up its dredging operations.

The number and volume of municipal and industrial discharges in Charleston Harbor Estuary, surprisingly, decreased from a total of 115 in 1969 to a total of 78 in 1986. The volume of the discharges dropped from 212.4 million gallons per day (MGD) to 92.9 MGD. The most significant decrease in discharges over the period occurred in the Ashley River. The Ashley River originally received discharges from 51 sources at a volume of 149.9 MGD, but the volume decreased to 32.9 MGD from 28 sources by 1985. The Cooper River, lower harbor, and Wando River, in order of decreasing importance, also received less discharge volume to a lesser extent. The largest municipal discharges originate from the Charleston Commissioners of Public Works and North Charleston Sewer, each with volumes of 18.0 MGD. The Berkeley County Water and Sewer Authority I and the Town of Summerville discharge less, with 10.0 MGD and 6.0 MGD, respectively. The largest industrial discharger is WestVaco with a volume of 20.0 MGD. Mobay Chemical and DuPont Chemical are also major contributors with discharge volumes of 6.5 MGD and 1.2 MGD, respectively.

North Inlet and Winyah Bay Estuaries

The major land use trends are those which accompany increases in population. The trend of converting forested and agricultural land to primarily residential-urban and commercial development is expected to continue through 1995. Within the Yadkin-Pee Dee River Basin, forests have declined by over 3,800 ha per year since 1970. Agriculture has declined by 2,000 ha per year. Urban land use increased 4% since 1970 by 4,800 ha per year. A major land use change in the Waccamaw subregion was a conversion of 3,440 ha of forested land to residential communities. Agriculture decreased by 1,020 ha. By 1995, residential area is expected to increase by 2,400 ha and forests to decline by 6,490 ha. Projections within Georgetown County for 1985 indicated that forested lands would decrease by 1.4%, forested wetlands by 0.6%, nonforested wetlands by 0.6%, and agriculture by 0.1%. Residential, industrial, and commercial land use will increase by 0.6%, although commercial use of Winyah Bay itself has not increased during the study period. However, growth in recreation and tourism has occurred along the Grand Strand, and industrial growth occurred in and around Georgetown, Sumter, and Florence.

The national trend of population migration and business and industry location in the Sunbelt states is evident in the Yadkin-Pee Dee Basin. The population in the basin has increased by more than 30% from 1970 to 1985, with the largest increase occurring in the Waccamaw subarea (Georgetown, Horry, and Williamsburg counties). Over the next 30 years, the population of the Yadkin-Pee Dee Basin in both North and South Carolina is expected to increase by 53%. The major impact will occur along the lower Waccamaw Neck and is expected to increase drinking water demands and sewage wastewater treatment. Water demands for power, industry, irrigation and consumption will also increase.

Public water supplies increased by 88 MGD for the 15-year study period. Municipal and industrial demand increased from 251 MGD in 1970 to approximately 319 MGD in 1985; a 4.5 MGD increase per year. Irrigation use within the basin was 36.3 MGD in 1977 and is expected to increase to 83.5 MGD by the year 2010. The lower Waccamaw River subbasin is being subjected to increasing amounts of industrial and private domestic effluents from point-source discharges. In 1969, there were eight industrial, municipal, and private domestic dischargers into the lower Waccamaw River subbasin with a total discharge of slightly more than 95 MGD; by 1976, five additional dischargers were sited, adding an additional permitted discharge of 41.18 MGD and 22,422 lbs/day BOD_5. The major trend in wastewater discharge into the Winyah Bay system is an increase in the number of municipal sewage treatment plants to accommodate population growth and urban development. There are no municipal or industrial wastewater discharges into North Inlet estuary.

In South Carolina, over 36% of the total tourist trade occurs in the Grand Strand. Myrtle Beach State Park in Horry County and Huntington Beach State Park in Georgetown County are two of the state's major park facilities. Recreational use has, as a result, increased from less than 9.5 million travelers and visitors in 1972 to over 13 million in 1985. Boat registrations in Georgetown County have increased from 1,124 in 1965 to 5,785 in 1985. However, no additional public boat landings have been constructed in Winyah Bay Estuary to handle the increase.

TRENDS IN PHYSICAL CONDITIONS

Charleston Harbor Estuary

Large changes in several water quality parameters occur in the Charleston Harbor basin over a tidal cycle. Distinct seasonal trends in water temperature and dissolved oxygen are evident.

The mean dissolved oxygen values for locations within the estuary ranged from 1.40 mg/l to 7.43 mg/l, except for the Goose Creek Reservoir and the upper Ashley River whose mean values were lower. The individual chemical oxygen demand values range from 1.4 mg/g to 150 mg/g during the survey period and the average COD ranged from 0.4 mg/g to 62.25 mg/g. COD was highest for the lower Ashley and the lower harbor sediments than in any other areas of the estuary. Overall COD levels decreased in all areas measured between the period 1975-1979 to the period 1980-1985.

Salinity fluctuated with freshwater flow and the tides. Salinity was highest during summer months when freshwater flow was lowest. The highest salinity occurred in the lower harbor and high salinity in the lower rivers, especially in the Cooper and Ashley rivers. Salinity was lowest in the Goose Creek Reservoir and in the upper Cooper River.

The average turbidity values ranged from 6.31 FTU to 20.67 FTU throughout the estuary. The highest turbidity value occurred in the upper Ashley River, due most likely to the high impact of stormwater runoff. The values for other areas in the estuary are fairly similar in magnitude.

Mean orthophosphate values ranged from 0.04 mg/l to 0.46 mg/l; higher orthophosphate concentrations were found in the upper Ashley River and the Goose Creek Reservoir, while lower levels were measured in the upper Cooper River. Average total phosphate values ranged from 0.08 mg/l to 0.43 mg/l, and the mean Kjeldahl nitrogen values ranged from 0.6 mg/l to 1.38 mg/l during the study period with higher concentrations in the upper Ashley River and Goose Creek Reservoir than in other areas of the estuary. The mean nitrite-nitrate values ranged from 0.06 mg/l to 0.26 mg/l, with higher levels in the upper Ashley River. Mean total ammonia values ranged from 0.12 mg/l to 0.33 mg/l and suggest a lower concentration of ammonia in the upper Cooper River.

North Inlet and Winyah Bay Estuaries

No significant trends in freshwater inflow occurred. Low flows occurred in 1978, 1980, and 1984 due to below-average precipitation. No significant trends in temperature or salinity were found.

Only one long-term data set was available to evaluate water quality in Winyah Bay, and water quality sampling was not standardized by tidal stage, river discharge, time of day, day of month, or month of the year. In general, water quality in Winyah Bay has improved since 1972. Some violations of SC Water Quality Standards occurred and were associated with point source and, to a lesser extent, nonpoint source discharges. However, by 1984 and 1985 more than 99% of the salt water area in the lower Waccamaw subbasin met SC Water Quality Standards. The major problem was DO contraventions due to municipal discharges into White's Creek (City of Georgetown) and the industrial discharge from International Paper into the Sampit River. Dissolved oxygen concentrations significantly increased over the 10-year period, and were related to freshwater discharge. DO values ranged from 3.5 mg/l to 15 mg/l in Winyah Bay, and from 1.5 mg/l to 7.4 mg/l in North Inlet. Monthly BOD_5 values significantly declined during the 10-year period.

In North Inlet, nitrate and total phosphorus showed no significant trend, but total Kjeldahl nitrogen and ammonia significantly increased during the 1975 to 1985 period. In general, concentrations of total nitrogen and total phosphorus in North Inlet Estuary are decreasing, while inorganic nitrogen significantly increased at Town Creek. Ammonia and nitrate-nitrite had significant interannual variation in seasonal patterns, which was linked to salinity. Turbidity exhibited a significant seasonal pattern,which was related to salinity as well. This variation indicates a loading associated with freshwater discharge.

TRENDS IN POLLUTANT LOADINGS AND AMBIENT POLLUTION CONCENTRATIONS

Charleston Harbor Estuary

The inorganics monitored during the study period included mercury, copper, chromium, cadmium, and lead. The samples taken were analyzed during two study periods: 1975-1979 and 1980-1985. The average mercury concentrations in sediments ranged from 0.11-0.40 µg/g in the upper Ashley River during the 1975-1979. The average maximum values for mercury in sediments were comparable with mid-range values for mercury in sediments obtained from other estuaries throughout the US. Mercury levels increased in the lower harbor basin and in the lower and upper Cooper River area in the 1980-1985 period vs the 1975-1979 period. Mercury levels decreased in the upper Ashley River and changed only slightly in the Wando River and lower Ashley River areas.

The average concentrations of copper in sediments ranged from 6.75 µg/g in the upper Ashley during the 1975-1979 period to 34.40 µg/g in the Wando River during the 1980-1985 period. The average concentrations of copper found in the Charleston Harbor Estuary were low in comparison with other estuaries; however, individual measurements did range up to the higher levels found in some of the nation's more polluted estuaries. Copper levels increased from the 1975-1979 period to the 1980-1985 period in the areas of the upper and lower Ashley River, the Wando River, and the upper Cooper River. Levels in the lower Cooper River and lower harbor basin showed only slight changes.

Average chromium concentrations in sediments ranged from 8.20 µg/g to 32.00 µg/g during the review period, and were higher in the Ashley River, lower Cooper River, and lower harbor areas, particularly during the 1980-1985 period. Values were low in comparison to other estuarine areas. Values increased from the 1975-1979 period to the 1980-1985 period in the lower and upper Ashley River, the lower harbor basin and the upper Cooper River. Values decreased in the Wando River area and remained relatively consistent in the lower Cooper River.

Average cadmium concentrations in sediments ranged from 0.68-5.09 µg/g during the review period. Cadmium levels in the lower Ashley River were significantly higher than other areas in 1975-1979 but were substantially lower during 1980-1985. Other values remained fairly consistent between the two time frames. Average values were comparable to mid-high values from other estuarine areas.

The average lead concentrations in sediments ranged from 18.40 µg/g to 96.65 µg/g in the estuary. Higher levels existed in the upper Ashley River area during 1975-1979. The average values were comparable to mid-range values in other estuaries. Other than the significant decrease in concentrations from the 1975-1979 period to the 1980-1985 period in the upper regions of the Ashley River, the other areas of the estuary exhibited increases in lead concentration.

PCBs, DDTs, and coliform bacteria were among the organic pollutants monitored. Concentrations of PCBs in the sediments were a great deal higher in the Wando River and somewhat higher in the Cooper River during the 1975-1979 period than other areas of the estuary. The maximum average concentration of PCBs was 47.9 µg/g. The highest PCB concentrations found in the harbor exceeded the maximum values for other areas throughout the country. During the 1980-1985 survey period PCBs were found at the Wando River stations.

The maximum average concentration of DDT was 1.93 µg/g, which was high when compared with available data from other estuaries. Increased levels of DDT were found in the lower Cooper and lower Ashley rivers during both time periods, as well as in the upper Cooper River during the 1975-1979 time period.

The SCDHEC has classified the waters of Charleston Harbor as "SC," which allows average fecal coliform levels of up to 1,000 colonies/100 ml on an annual basis, and represents fairly low water quality. Mean coliform values ranged from 15 colonies/100 ml to 410 colonies/100 ml during the survey period, while median values ranged from 7 colonies/100 ml to 143 colonies/100 ml. Several stations in the Ashley River, lower harbor, lower Cooper River, and Goose Creek Reservoir had relatively high fecal coliform values, with mean values exceeding 200 colonies/100 ml. Consistently lower concentrations of fecal coliforms were found in the upper Cooper and Wando rivers than in other areas of the estuary.

North Inlet and Winyah Bay Estuaries

Heavy metals were analyzed in the water, sediments, and fish for Winyah Bay. Several metals (Cd, Cu, Ni, Cr) have over 75% of their reported concentrations below the analytical detection limits. For Pb, Zn, and Hg more than 50% of the analyses were above the detection limit. Concentrations of heavy metals dissolved in the water column in general were very low. Only lead and zinc were detected at levels above SCDHEC criteria. When comparing heavy metal concentration averages of 1975-1980 and 1981-1985, chromium significantly decreased. Mercury decreased at most stations.

Sediment heavy metal concentrations in Winyah Bay vary spatially as a function of sediment type and point source discharges. Data on mercury (0.2µg/g to 0.3 µg/g), copper (1 µg/g to 10.9 µg/g), chromium

(5 µg/g to 26.2 µg/g), lead (5 µg/g to 26 µg/g), nickel (5 µg/g to 100 µg/g) and zinc (8 µg/g to 40 µg/g) were collected for one station in the bay. Higher concentrations of lead and zinc were detected in the Sampit River adjacent to Georgetown Steel, where the major heavy metal problem occurs. Concentrations of lead, copper, chromium, and zinc were greater in the upper bay than in the lower bay or Sampit River. Only copper significantly declined over the study period. No other metals showed any significant trends.

The Winyah Bay watershed has one of the highest reported pesticide use rates in the United States, ranked second nationally in overall and annual pesticide use and ninth in annual pesticide use per area. Winyah Bay ranked fifth in toxicity-normalized pesticide use, meaning that it is not only a high use area, but also a high-toxicity pesticide use area. Even with this heavy use, relatively few pesticides have been detected in Winyah Bay waters, sediments, shellfish, or fish tissue. The only organic compounds which have routinely been detected are Dieldrin, DDT, DDD, DDE, and PCBs.

As with Charleston Harbor Estuary, the waters of Winyah Bay are classified SC; therefore shellfish harvesting is prohibited. Only one location is monitored for coliform bacteria; during the period 1970 to 1985, the long-term average for coliform was 28.5 + 18.1/100 ml, with a range of 0/100 ml to 2,000/100 ml. Seasonal variations are great, with the highest averages of 60.3 colonies/100 ml and 61.9 colonies/100 ml for May and November, respectively, and 11.1 colonies/100 ml in early spring for the low.

Sources for fecal coliforms in Winyah Bay include municipal point sources and numerous non-point source contaminations from septic systems. Fecal coliforms significantly declined during this 15-year study period. The major fecal coliform input originates in the Sampit River and in areas of municipal discharge. The lack of high coliform measurements can be partially attributed to lower loading and the relatively undeveloped nature of the lower basin compared to other estuaries like Charleston Harbor.

Portions of North Inlet Estuary have been restricted or conditionally restricted for shellfish harvesting due to high fecal coliform levels; nevertheless, most of North Inlet is classified "SB" or "SA" by SCDHEC. Coliform measurements are taken at 11 locations throughout the inlet, with long-term averages ranging from 26 colonies/100 ml to 91 colonies/100 ml. The lack of significant trends during the 15-year period reflect the absence of increased development pressures in this area.

TRENDS IN BIOLOGICAL RESOURCES

Very few data sets are available that provide long-term (>5 years) data on biological resources for these estuarine systems, and much of it exists as landings of commercially important species.

Charleston Harbor Estuary

Estimates of fisheries landings from Charleston Harbor generally showed patterns similar to those observed state wide, suggesting that production of shrimp and crabs from this estuary is typical of other South Carolina estuaries. Reduced landings of white shrimp, *P. setiferus*, most likely due to a decreased number of spring spawners after unusually cold winters, occurred in 1977, 1978, 1981, 1984, 1985, and 1986. Highest landings of brown shrimp, *P. aztecus*, which were less variable during the study period, were noted in 1980, 1981, and 1987. Blue crab, *C. sapidus*, landings were relatively low from 1975 to 1977 compared with later years, unlike patterns observed in state wide landings. Very little change occurred in dominant finfish and decapod crustacean species composition between collections taken in 1984 and during the period 1973-1977.

North Inlet and Winyah Bay Estuaries

Commercial landings data on shad, blue crab and most shrimps taken in Winyah Bay suggest that commercial landings increased significantly over the 15-year study period, although reduced landings were observed from 1973-1977. Landings of penaeid shrimp, *P. aztecus* and *P. setiferus*, showed little variation over the study period.

Landings in Georgetown during 1979 did not follow the state wide trend, but during the mid-1980s landings were similar. Over the study period there was an increase in blue crab landings. An apparent increase in sturgeon landings in Winyah Bay occurred. An increase in landings data may be a direct result of the increased fishing effort and not necessarily a reflection of increased fishery resources.

HUMAN HEALTH IMPLICATIONS

Charleston Harbor Estuary

Shellfish populations are abundant in the Charleston Harbor Estuary; however, essentially all oyster and hard clam grounds are closed to shellfish harvesting due to high bacterial counts. In 1982, some 7.5 ha of oyster grounds existed in the Wando River, 2.0 ha in the Ashley River, 5.6 ha in the lower harbor, and less than 0.5 ha in the Cooper River. Large beds of the hard clam, *Mercenaria mercenaria*, also exist in the lower portion of the estuary. There are no data sets available for analysis of the potential human health impacts due to inadvertant consumption of polluted shellfish or diseased finfish.

North Inlet and Winyah Bay Estuaries

Shellfish grounds found in Winyah Bay and North Inlet estuaries, as in other water bodies of the state, are classified as prohibited, restricted or approved by SCDHEC according to the quality of the overlying waters . Most of Winyah Bay is classified as prohibited or restricted. Water quality is influenced by the City of Georgetown through the Sampit River, which receives discharges from waste treatment plants, a pulp mill, and a steel mill. Pollutant loadings from the Pee Dee, Waccamaw, and Black rivers into Winyah Bay are dominated by agricultural runoff, with additional inputs from wastewater treatment plants. High levels of organic pollution have resulted in the closing of the Sampit River to shellfish harvesting. Shellfish closures, however, had little effect on recreation since most recreation involves swimming, golf, and boating (primarily fishing).

North Inlet Estuary, on the other hand, has been classified into three zones: the Mud Bay area adjacent to Winyah Bay as restricted; an interface zone as conditionally restricted; and the rest of the inlet as approved. Again, there are no data available for analysis of the potential human health impacts due to inadvertant consumption of polluted shellfish or diseased finfish.

SUMMARY

The Charleston Harbor, North Inlet, and Winyah Bay estuaries, located only 70 miles apart along the South Carolina coast, are very distinct in terms of anthropogenic influences. Charleston Harbor is an urban estuary with a controlled source of freshwater flow. Its quality has actually improved over the last 15 years due primarily to the upgrade of wastewater treatment facilities (to secondary treatment). However, the Charleston metropolitan area continues to grow at a significant rate so that recent improvements in resource quality are once again in jeopardy without adequate and holistic planning and management.

The North Inlet and Winyah Bay estuarine system is also subjected to human influences, particularly from inland agricultural activities and nonpoint source runoff. North Inlet, historically isolated from the direct influences of man, faces pressures from rapid residential and resort development on adjacent lands. Winyah Bay is also somewhat removed from the direct effects of pollutants, being buffered by large expanses of marsh, but is influenced by river discharge and agricultural runoff.

It was apparent from the outset that a characterization of these estuarine systems (including trends analysis) utilizing extant data from existing information resources would pose a great challange. This project provided added evidence that comparisons of long-term trends or comparisons among major estuaries is often not feasible unless comparable methodologies are used.

Not surprising, the major constraint facing the project investigators was in the analysis and synthesis of datasets from diverse sources; datasets which first had to be identified, located, and qualified. Generally, no standard protocols or processes were followed among the various studies in the collection of data in these estuarine systems. Much of the data found in published reports and "grey" literature was reported in a multitude of fashions, rendering direct comparisons and trends analyses difficult, if not impossible. This was particularly true for the water quality datasets acquired through the STORET files of the US Environmental Protection Agency. Water quality data collected during the study period (1970 to 1985) was not standardized to tide stage or river discharge; prominant factors influencing water quality conditions. Therefore, while spatial trends could be detected, temporal trends were most difficult to identify. More recently, a SCDHEC study attempted to evaluate trends in the Charleston Harbor Estuary using nonparametric procedures.

Secondly, many of the studies conducted in Charleston Harbor, North Inlet, and Winyah Bay estuaries were of relatively short duration (three years or less), making attempts to correlate resource trends to the health of the systems tenuous. This is less true for North Inlet, where the Long-Term Ecological Research program staff has been collecting estuarine data for more than 10 years. However, environmental studies examining the relationship between resource use and health remain few in number and limited in duration.

Nevertheless, several benefits have resulted from this investigation. Obviously, no study of this type had ever been performed for the Charleston Harbor, North Inlet, and Winyah Bay estuaries. This report should prove to be a useful reference to scientists, graduate students, resource managers, and state and local government officials. For instance, the Office of Coastal Resources Management (NOS-NOAA) has recently initiated the development of a Special Area Management Plan (SAMP) for Charles-

ton Harbor; a copy of this report was immediately requested by the SAMP staff. Interest in the North Inlet and Winyah Bay characterization has been expressed by a number of environmental consulting firms as background material for the development of proposals in response to a call by the South Carolina State Ports Authority to identify potential dredge material containment areas in that region of South Carolina. The literature cited offers a valuable source of bibliographic references on refereed and grey literature available for these systems.

The study also highlights the limited amount of data available for Charleston Harbor, North Inlet, and Winyah Bay. Additional effort will be necessary to collect physical, chemical, and biological data on a time frame useful for trends analysis. Most data collected now, with the notable exception of those collected in North Inlet, are associated with short-term, single objective studies. Multi-objective and multidisciplinary investigations into the relationships between land use trends and the health of the estuarine ecosystem may be necessary. Unfortunately, significant gaps in the data can be found for almost all attributes of the estuarine systems studied.

A standardized method for collecting water quality data is necessary for meaningful temporal trends analyses. Water quality data provide a legitimate means for assessing the health of an estuarine system, identifying "hot spots" and analyzing temporal trends. Until such a protocol is established, the water quality data will be of limited use for detailed trend analyses that are sensitive to detecting changes in the estuary before they become significant problems.

The study of estuarine systems has been ongoing for some 25 years. As is often the case with scientific investigations, the gain in knowledge is offset by the number of new questions that are raised. It will take many more years of study and significant financial support to unravel and understand the complex processes that drive estuarine systems and the influences of man's activities on those processes. However, resource managers and policy-makers do not have the luxury of time on their side. It is the use of existing information, compiled and synthesized, that provides the basis for the development of many policies and plans; thus lies the value of this systematic characterization of Charleston Harbor, North Inlet, and Winyah Bay estuaries.

LITERATURE CITED

Hanson, D.V. and M. Rattray, Jr. 1966. New dimensions in estuarine classifications. *Limnology and Oceanography* 11: 319-326.

Kjerfve, B. 1976. The Santee Cooper: A study of estuarine manipulations. p. 44-56 In: M.E. Willey (ed). Estuarine Processes Vol. I. Uses, Stresses, and Adaptation to the Estuary. Academic Press.

Mathews, T. D., F. W. Stapor, Jr., C. R. Richter, J. W., Miglarese, M. D. McKenzie, and L. A. Barclay. 1980. Ecological Characterization of the Sea Island Coastal Region of South Carolina and Georgia. Vol. I: Physical features of the characterization area. US Fish and Wildlife Service, Office of Biological Services, Washington, D.C. 212 p.

National Research Council. 1983. Fundamental research on estuaries: The importance of an interdisciplinary approach. Studies in Geophysics, National Academy Press, Washington, D.C. 79p.

Pritchard, D.W. 1955. Estuarine Circulation Patterns. Proceedings of the American Society of Civil Engineers 81(717): 1-11.

Research Planning Institute. 1980. Evaluation of the Santee-Cooper Rediversion Project. Research Planning Institute Publ. No. RPI/R/80/2/4-4. Columbia, SC..

Sandifer, P. A., J. V. Miglarese, D. R. Calder, J. J. Manzi, and L. A. Barclay. 1980. Ecological Characterization of the Sea Island Coastal Region of South Carolina and Georgia. Vol. III: Biological Features of the Characterization Area. US Fish and Wildlife Service, Office of Biological Services, Washington, D.C. 620 p.

Van Dolah, R.F., P.H. Wendt, and E.L. Wenner. (eds.) 1990. A physical and ecological characteristic of Charleston Harbor Estuary System. Final Report to the SC Coastal Council, Charleston, SC. 634 p.

Characterization of the Physical, Chemical and Biological Conditions and Trends in Winyah Bay and North Inlet Estuaries: 1970-1985

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SETTING

Watershed Characteristics

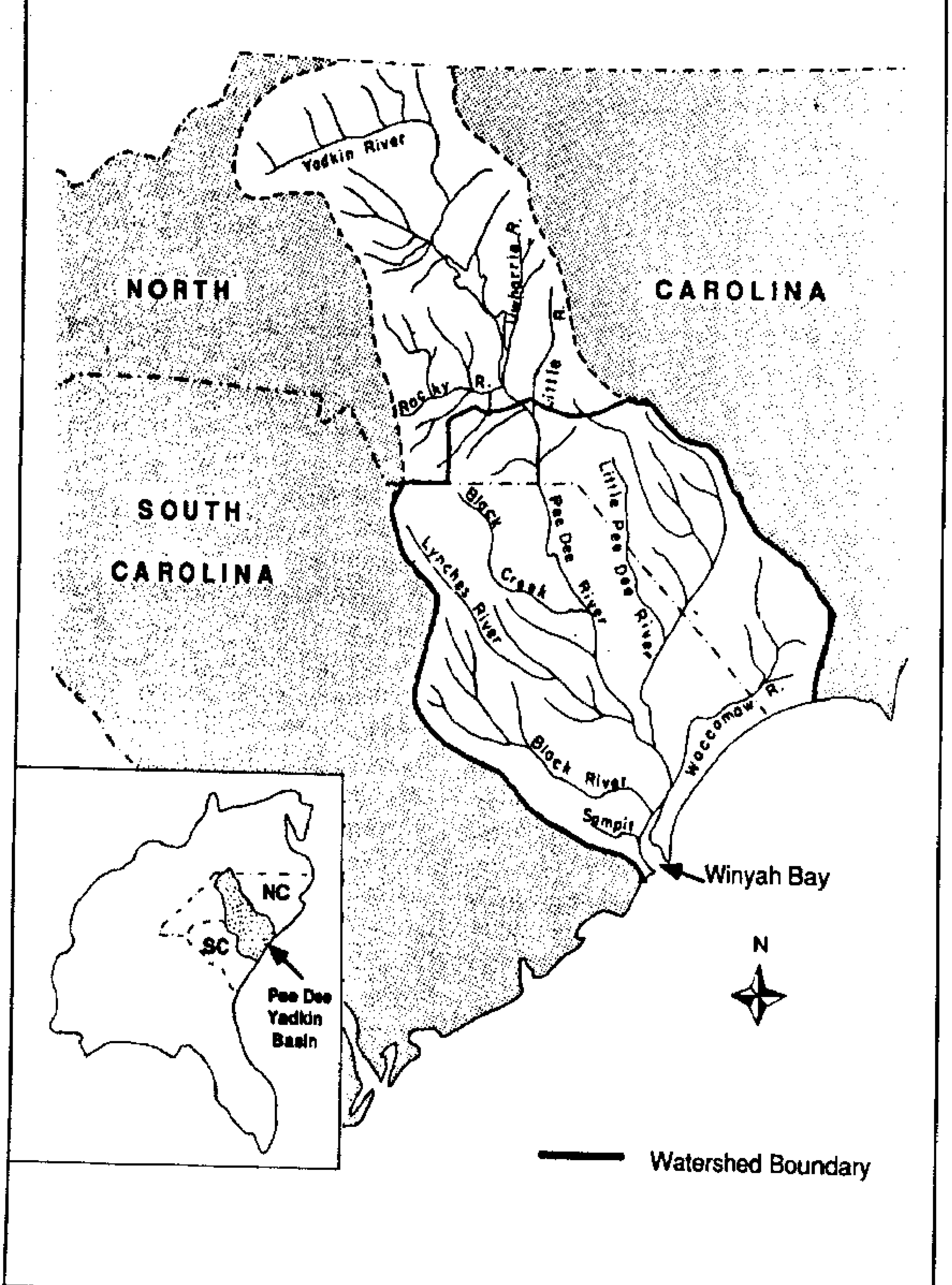
The entire drainage basin associated with Winyah Bay is approximately 46,736 km^2 and encompasses 20.1%, 23%, and 1% of the total land area of North Carolina, South Carolina, and Virginia, respectively (Fig. III-1). The drainage of this diverse basin originates on the eastern slope of the Blue Ridge Mountains in North Carolina and Virginia, travels through the Piedmont regions of North and South Carolina and the Coastal Plain of eastern South Carolina to Winyah Bay where it is then discharged into the Atlantic Ocean. Of this area, approximately 25,232 km^2 lies in North Carolina and encompasses parts of 28 counties, whereas in South Carolina it encompasses parts of 14 counties (Chesterfield, Clarendon, Darlington, Dillon, Florence, Georgetown, Horry, Kershaw, Lancaster, Lee, Marlboro, Marion, Sumter, and Williamsburg) and is 21,026 km^2. The Yadkin River originates in North Carolina and flows 327 km to the southeast where it junctures with the Uwharrie River and becomes the Pee Dee River. Several other major rivers are tributaries of the Pee Dee River as it travels to the ocean. These rivers include the Lumber, Lynches, Little Pee Dee, Black, Waccamaw, and Sampit (Brooks et al. 1977). This is a predominantly rural area.

The Pee Dee River is the major hydrologic feature of the subbasin. It originates in North Carolina and receives most of its flow from drainage within that state. In South Carolina, the dominant tributaries are Black Creek, Catfish Creek, Jefferies Creek, and Thompson Creek. In the upper portion of the basin, the streams either originate within or traverse the upper Coastal Plain. Most of these creeks are associated with extensive swamps. Average annual stream flow of the Pee Dee River is 269 m^3/s at Pee Dee, SC. The Pee Dee River has a large and well-sustained streamflow all year, with flows ranging from 20 m^3/s to 6,230 m^3/s (Brooks et al. 1977).

The Lynches River subbasin is long and narrow. It has an areal extent of 3,549 km^2 that covers portions of eight counties (Chesterfield, Lancaster, Kershaw, Florence, Lee, Darlington, Sumter, and Williamsburg) and comprises 4.4% of South Carolina's land area. Rural areas dominate this subbasin. The Lynches and the Little Lynches flow from the lower Piedmont of North Carolina and South Carolina through the upper Coastal Plain (dendritic drainage) into the lower Coastal Plain (trellis drainage). In the lower Coastal Plain, Bay Swamp, Lake Swamp, and Sparrow Swamp are moderately sized tributaries (Snyder 1983). Flows range from less than 3 m^3/s to 708 m^3/s, with a 45-year average flow of 28.5 m^3/s (Brooks et al. 1977). The Lynches River basin encompasses counties in North Carolina and includes portions of Dillon, Marion, Horry, and Marlboro counties in South Carolina. The areal extent in South Carolina is 2,849 km^2 which is 3.5% of the state's predominantly rural land area. The major watercourses are the Little Pee Dee and the Lumber rivers which originate in the Sandhills of North Carolina. Extensive swamplands are associated with this system; an 87 km section of the Little Pee Dee beginning at the confluence with the Lumber is eligible for the state's Scenic Rivers Program (Brooks et al. 1977). The 33-year average flow at Galivants Ferry, SC, is 91.8 m^3/s (range 4-782 m^3/s).

The Black River subbasin drains 3,724 km^2 (areal extent, 6.6% of South Carolina's land area) that encompass parts of seven counties (Kershaw,

Fig. III-1. Yadkin-Pee Dee drainage basin (Conservation Foundation 1980).



Lee, Sumter, Clarendon, Florence, Williamsburg, and Georgetown). It has a northwest-southeast orientation. The Black River is the dominant watercourse draining the subbasin. The primary tributaries draining into the Black River are the Pocotaligo River, Scape Ore Swamp, Pudding Swamp, and Black Mingo Creek. Most of these streams are located in the middle and lower Coastal Plains except the Scape Ore Swamp which is located in the upper Coastal Plain. This is a predominantly rural area (Brooks et al. 1977). Flows at Kingstree, SC, range from less than 1 m^3/s to greater than 1,642 m^3/s, with a 45-year average of 26 m^3/s.

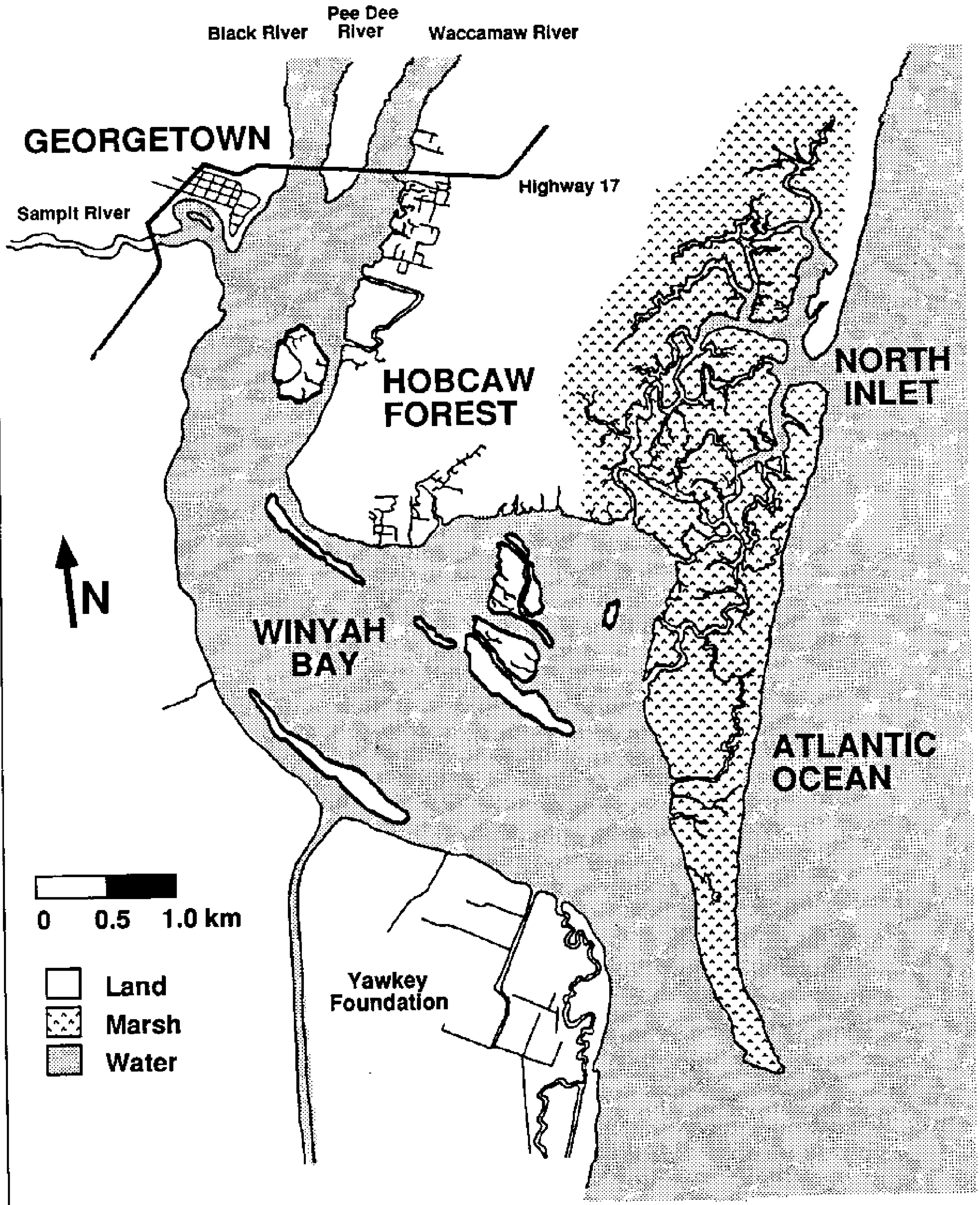
The Waccamaw River also originates in North Carolina. In South Carolina, it runs parallel to the coast where most of Horry County and a part of Georgetown County make up this subbasin. The areal extent is 2,875 km^2 with approximately 44% of the basin within South Carolina (Brooks et al. 1977). Much of this basin is covered by cypress and hardwood swamps. The eastern edge of this subbasin (the Grand Strand) is a very popular tourist area in the summer months with a large transient population. The 24-year average flow at Longs, SC, is 34 m^3/s, with flows ranging from essentially no flow to 314 m^3/s.

The Sampit subbasin, which drains approximately 622 km^2 originates in Georgetown County, SC, approximately 19 km upstream from its entry into Winyah Bay. The lower portion of the Sampit River has been dredged to form Georgetown Harbor's turning basin. Extensive marshes and swamps are adjacent to the upper portion of the Sampit River. The lower portion of the river receives wastewater from a pulp paper mill, Georgetown municipal sewage treatment plants, and steel mill discharges as well as other sources of pollution. The Sampit River is the most polluted river entering Winyah Bay (Snyder 1983; USACOE 1984).

Winyah Bay is one of the largest estuarine ecosystems on the Eastern Seaboard and is classified by Pritchard (1955) as a B-type estuary (Fig. III-2). It is located 14.4 km south of North Inlet. Winyah Bay is 29 km long and extends from the US Highway 17 bridge to the Atlantic Ocean. The surface area of Winyah Bay is 155.4 km^2 (Moore et al. 1977). Winyah Bay and its drainage basin are surrounded by 124 km^2 of marshes; 87% of these are tidally influenced. Freshwater marshes dominate (92 km^2) and comprise 35% of the state's freshwater marshes. A substantial portion of the estuary is surrounded by lands that have been set aside for research, conservation, and education. The Belle W. Baruch Foundation's Hobcaw Barony and the Thomas Yawkey Wildlife Center border the bay (Conservation Foundation 1980).

Winyah Bay is oriented in a northwest-southeast direction. It has a mean depth of 4.2 m and a mean tidal amplitude of 1.0 m. It is widest at the center (7.2 km) and narrowest at the entrance to the ocean (1.2 km). Most of the freshwater inputs are from the Pee Dee and Waccamaw rivers. Due to these freshwater inputs the bay is partially stratified for most of the year. Georgetown area inputs to the bay are the primary influences on the water quality of the bay, which has a "SC" water classification and whose shellfish beds have been restricted since 1964. The Sampit is the most polluted river entering the bay, while pollution from the Pee Dee, Black, and Waccamaw rivers is dominated by agricultural runoff. A prominent feature of Winyah Bay is the long rock jetties that project for more than a kilometer into the ocean from North and South islands. In addition, there are several islands within the bay and a very shallow area in the middle of the bay (Mud Bay). A navigable channel 8.2 m deep, 140-200 m wide, and 28.8 km in length runs along the axis of the bay and is maintained for commerce from the ocean to Georgetown Harbor (Johnson

Fig. III-2. Map of study area including Winyah Bay Estuary and North Inlet Estuary.



1970; USACOE 1976, 1984; Conservation Foundation 1980).

North Inlet Estuary is a bar-built class C type estuary (Pritchard 1955) located on the southern extreme of the arcuate strand and the transition from the strand to the cuspate forelands of the Santee Delta and Cape Romain. It is 70 km northeast of Charleston, South Carolina. The watershed is 24.8 km^2, with 14.9 km^2 to the north draining a moderately developed residential watershed into the upper portion of North Inlet Estuary and 9.9 km^2 draining a forested watershed to the west (M. Pennys personal communication; Williams unpublished data). The basin for North Inlet drains primarily forested watershed to the west and a moderately developed watershed to the north. Residential development including a golf course is less than 2% of the land area (Waccamaw Regional Planning and Development Council 1985).

North Inlet is considered a pristine tidal estuary in that it has minimal anthropogenic impacts. It consists of *Spartina alterniflora* marsh (75.2%), exposed mudflats (2.5%), and tidal creeks (22.0%). The marsh is bounded to the east by sandy barrier islands, the north and west by forested uplands, and the southwest and south by Winyah Bay. North Inlet connects with the coastal ocean via a tidal inlet (Town Creek) on the eastern boundary and connects to Winyah Bay through three creeks (South Jones, No Man's Friend, and Haulover) to the south. The primary water exchange occurs through Town Creek (79%) with inputs from Winyah Bay occurring with southwesterly winds and during periods of high river discharge. The North Inlet system is composed of numerous tidal creeks with average channel depths of 3 m. The greatest depth exists (7.4 m) in Town Creek adjacent to the inlet (Kjerfve et al. 1982). There is very little freshwater input to the system; it is less than 1% of the tidal prism which contributes to a salinity range of 30-34 ‰. North Inlet is influenced by a semidiurnal tide with a mean range of 1.4 m and has tidally pumped circulation. There is no significant vertical stratification of salinity or density (Kjerfve 1982).

Sedimentary Regimes and Geological History

Geological History

More than 95% of the Winyah Bay watershed lies in the Coastal Plain province of South Carolina. Underlying the sediments of the Coastal Plain is an irregular surface of metamorphic and igneous rocks formed about 345 to 500 million years ago (Hatcher 1972 in Snyder 1983). These deposits dip to the south and southeast. During the Cretaceous to Quaternary periods, sediments consisting of consolidated and unconsolidated material from marine and alluvial origin were deposited on the crystalline rocks. The Coastal Plain province is further divided into the upper, middle, and lower physiographic regions. The upper Coastal Plain slopes eastward from the fall line to the Citronelle Escarpment; the Middle Coastal Plain lies between the Citronelle and Surry escarpments; and the Lower Coastal Plain between the Surry escarpment and the present coastline. The Coastal Plain exhibits moderate to low relief (Snyder 1983).

Stratigraphy

Three formations of the late Cretaceous age occur in the Coastal Plain: the Middendorf, Black Creek, and Pee Dee. The Middendorf is composed of light-colored laolinitic sands with lenses of laolinitic clays. The thickness of the formation ranges from a few meters at the fall line to 238 m north of Georgetown. The top of the Middendorf is 15 m to 35 m below the surface in the northern portion of the Coastal Plain and 400 m along Winyah Bay. The Black Creek formation lies from 0.3 m to 10 m beneath Pliestocene deposits in the northwestern portion of the Coastal Plain to 150 m to 170 m below Winyah Bay. The formation is composed of light gray sands inter-bedded with marine clays and green sands. Thin continuous layers of impervious calcareous sandstone are abundant in the upper third of the formation. The thickness of the formation ranges from 240 m to 255 m along the coast to less than 25 m in the northwestern portion of the Coastal Plain at Darlington (SCDHEC 1976). The Pee Dee Formation outcrops in Florence, Williamsburg, Horry, and Georgetown counties. The top of the formation ranges from 35 m below mean sea level in Orangeburg to less than 14 m in Georgetown County. The thickness of the formation ranges from a few meters at the upper lip to 120 m in the Georgetown area. The Pee Dee is composed of dark-gray, fine, clayey sand with loose, coarse, and shelly limestone horizons (SCDHEC 1976; Brooks et al. 1977; Snyder 1983).

Tertiary formations include Black Mingo, Santee Limestone, Duplin Marl, and Waccamaw. Sediments of the Black Mingo underlay the central part of the Coastal Plain. The basement of the Black Mingo Formation is black shale, with the remaining portion composed of fine sand, silty clay, sandstone, fuller's earth, and beds of limestone. The Santee Limestone is composed of yellow to white fossiliferous and calcarious limestone. The Duplin Marl of the Pliestocene age consists of deposits of shell, sand, clay, and marl that extend as erosional remnants over a large part of the Coastal Plain. The formation is generally less than 17 m thick. The Waccamaw Formation overlies these deposits and is generally less than 3 m thick and parallels the coast from North Carolina through Horry County to Georgetown. It consists of blue-gray to yellow and brown sandy shell marl (Snyder 1983). In the area directly adjacent to Winyah Bay and North Inlet the geologic formations are characterized as follows (Snyder 1983). The Waccamaw formation ranges from surficial to 31 m in thickness; Blank Mingo is located at 31 to 91 m and is approximately 91 m thick; the Black Creek averages 198-229 m thick and starts at 137-168 m; and finally, the Middendorf which has an average thickness of 213 m and is located at 335-366 m.

Origins and Morphology of Sediments

Overlying these deposits is a thin blanket of unconsolidated sand, clay, and shell composing the Pleistocene and Recent formations. The average thickness of the material is 3 m to 5 m with a maximum of 15 m (SCDHEC 1976). Former sea levels dissect this area into eight progressively higher terraces (Brandywine, Coharie, Sunderland, Wicomio, Penholoway, Talbot, Pamlico, and Recent). Parent material in Georgetown County is unconsolidated material from marine or fluvial deposits. The parent material was deposited during the Pleistocene Epoch as Talbot and Pamlico formations. The Talbot Terrace is 8 m to 15 m above sea level and encompasses a portion of the Winyah Bay watershed. The remaining portion of the watershed is located in the Pamlico Terrace, which has a shoreline less than 9 m (USACOE 1984).

Geomorphology

The average depth in Winyah Bay varies considerably with location and tidal stage. Depths range from shallow mud flats to natural channel depths of 7.6 m at the lower end of the bay (USACOE 1984). Two major factors influence the current geomorphology of the bay. Jetty construction and maintenance of a navigable commercial boat channel (8.2 m deep) have stabilized the geomorphology of Winyah Bay. In 1857 Winyah Bay varied in depth from 6 m (below mean low water) at the mouth of the bay to less than 2 m on the large ebb-tidal delta associated with the entrance to the bay. The entrance to the bay extended seaward in a southerly direction. In 1899 the main ebb-channel was realigned to a more eastwardly direction consistent with the jetty construction. The 5.9 km jetty constructed in 1899 was a significant factor contributing to bathymetric changes. Sand trapping resulted in extensive shoaling just south of the jetty and the disappearance of the main ebb channel. By 1925 the area was transformed into a large intertidal sand flat with a long subaerial sand spit attached to the north end of the jetty. These deposits had accumulated into barrier-like islands by 1964. Navigational dredging was initiated in 1948 and completed in 1952 (USACOE 1976). A 29-km-long channel was dredged from the Port of Georgetown to the jetty and maintained to an average depth of 8.2 m with varying widths of 140 m to 200 m (Little 1974; Hinde et al. 1981; Zarillo et al. 1983).

North Inlet

The current inlet within the North Inlet Estuary is very dynamic. Presently, it is approximately 650 m to 850 m wide, has a maximum depth of 8 m, and has been fairly stable since 1940. In 1878, the main ebb channel was located approximately 1.5 km north of the current channel. In 1916, a breach of North Island occurred at approximately the position of the current channel. By 1925 the island created by the breach eroded into a broad shoal and a wide shallow inlet persisted. A 1925 hydrographic survey showed two distinct channels with a combined area of 1,300 m². As the southern channel became more efficient, recurved spits grew southward from Debidue Island and the northern channel was abandoned. During this period, the ebb-tidal delta shifted more than 1.5 km southward. Between 1925 and 1964, the southern channel enlarged to approximately the same combined areas of the 1925 channels. The main-ebb channel increased in length (extending seaward by more than 1,350 m) and the ebb-tidal delta increased in area. By 1963, a well-developed ebb-tidal delta was present. This area continued to be very dynamic with the formation of spits and swash bars (Zarillo et al. 1985).

Climatology

The temperate to subtropical climate encompassing North Inlet and Winyah Bay estuaries is controlled by their low elevations and coastal locations. Temperatures are moderated due to the proximity of the Atlantic Ocean and the Gulf Stream, giving rise to both relatively lower temperature maxima and higher temperature minima than would be found farther inland. Two major factors affecting southeastern coastal environments are the recurrence of large rainfall deficits (droughts) and rainfall excesses (tropical storms and hurricanes). Tropical storms or hurricanes impact the South Carolina coast approximately once every 2.6 years (Gentry 1971), contributing on average about 10-15% of the total annual precipitation at North Inlet but up to 25% of the area's annual rainfall (LTER unpublished data). Droughts in the southeast have occurred 17 times in the past 100 years (Guttman and Plantico 1987).

The mean annual temperature (1951-1980) is 18°C. Temperatures range from an average of 8.4 °C in January to 26.9 °C in July. The record high temperature of 40.6 °C was recorded July 10, 1977, and the record low of -11.7 °C on December 11, 1962 (Fig. III-3). The mean number of days with temperatures 32.2 °C and above average 45 per year and days with temperatures below 0 °C average 35 days (NOAA 1985). The average number of frost-free days is 25, extending from mid-March to mid-November. No long-term trends in average temperature were observed.

Wind direction and speed varies with season. Northeasterly (fall and winter) and southwesterly (summer) winds are the most common (each accounting for 34%). Spring winds are the most variable but predominantly from the southwest. Northwesterly and southeasterly winds are less frequent (19% and 13% respectively). Winds speeds are generally less than 24 mph with gusts to 56 mph not uncommon (Newell 1985). Highest seasonal wind velocities originate from northeast (averaging 4 m/s). Lowest seasonal velocities originate from the southeastern quadrant (averaging 2.7 m/s) (Michener et al. 1990).

Precipitation in the study area averages 130 cm per year (NOAA 1985a). Annual precipitation patterns are highly variable due to the episodic occurrence of tropical storms and hurricanes (Figs. III-4, III-5, III-6). On an annual basis, over 30% of the storms account for less than 1 cm of the annual rainfall input. Because of the high probability of tropical storms, the return frequency for storms with >10 cm rainfall in 24 hours is only 2 years (Purvis and McNab 1985). The greatest monthly rainfall occurred in August 1971 (49.51 cm), with the greatest 24-hour total occurring on October 15, 1954 (22.35 cm) (NOAA 1985). Storm size and frequency for a given season are quite variable. Winter and spring are drier (20% and 21% of annual precipitation) and average 4.8 and 4 storms per month, respectively. Fall is wetter (24% of annual precipitation) with 4 storms per month. Summer is the wettest season (35% of annual precipitation) with the greatest variation in storm frequency and size due to the frequent occurrence of tropical storms and hurricanes. The average (1935-1986) water budget for Georgetown portrays a slight deficit (1 mm to 17 mm) from April to August (Fig. III-4).

There was significant year-to-year variation in the water budget over the past ten years. Rainfall excess over the period 1970-1986 averaged 90.3 cm, with a range of -6.5 cm to 88.9 cm (Sklar unpublished data). Three years (1978, 1980, and 1986) had significant deficits of 2.5 cm to 6.1 cm during summer months.

From 1901 to 1985, twenty-two tropical storms or hurricanes made landfall on the South Carolina coast (Purvis et al. 1986); only eight of these were category 2 to category 4 intensity. No category 5 hurricanes hit the South Carolina coast during this period. Two storms (September 17, 1945, and September 29, 1959, Gracie) were classified category 3

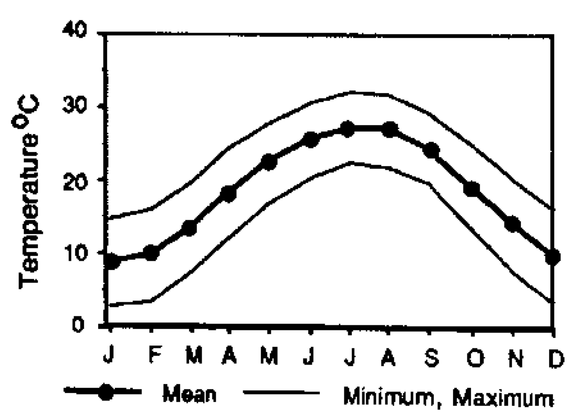


Fig. III-3. Mean monthly minimum and maximum air temperatures for 1951-1980 for Georgetown, SC (NOAA 1985).

and Hazel on October 15, 1954, was a category 4 storm. Hazel had 171 mph winds and tides up to 5.2 m. Gracie maintained hurricane strength more than 160 km inland. Damage occurred from Beaufort to Charleston with heavy rains.

Hurricanes or tropical storms are an annual threat to Georgetown County. For any particular year there is a 46% chance of a tropical storm and a 13% chance of a storm with wind speeds greater than 34 knots (Purvis and McNab 1985). The occurrence and rainfall amount for storms with wind speeds greater than 34 knots are presented in Figure III-5. The hurricane season for the South Carolina coast is June to October with the maximum storm occurrence during September 24-30. The predominant storm direction is from the southwest.

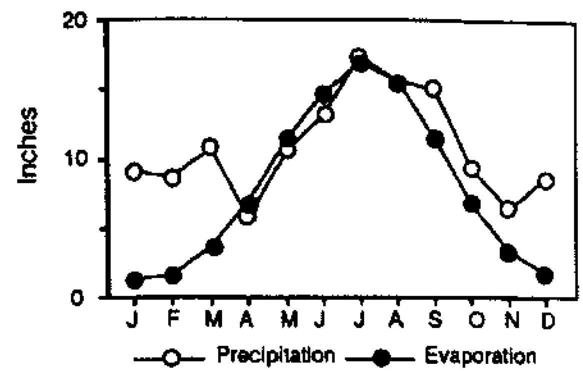


Fig. III-4. Water budget for Georgetown, SC. Mean monthly precipitation for 1951-1980 (NOAA 1985). Evaporation was calculated from the Thronthwaite equation.

Droughts are a normal part of the southeastern climate. The southeast has experienced 17 droughts in the last 92 years (Guttman and Plantico 1987). Drought conditions occurred in 20% to 25% of all months from 1895 to 1986 (Fig. III-6). Droughts in South Carolina last from a year and a half to seven years. Major droughts occurred in the 1920's, 1930's, 1950's, and late 1980's. The most persistent drought lasted from 1952 to 1957. The end of the 1950's drought was marked by a rapid shift to wet conditions which persisted until the late 1970's. The 1980's brought a return to drier conditions. The 1986 drought, while not unusually long (one year), was the most severe on record.

Adjacent Land Use Patterns

In 1980, 619,800 people resided in the entire Pee Dee-Yadkin Basin of South Carolina (Snyder 1983). Table III-1 gives the 1980 population by subbasin and the major urban areas within each subbasin in the region. No data were available for the entire North Carolina and South Carolina portions of the Pee Dee-Yadkin Basin for 1985 but projections for 1990 estimated that 2,544,200 people would reside in the basin (Yadkin-Pee Dee River Basin 1979). Population in the North Carolina counties of the basin was approximately 2.5 times greater than the South Carolina counties.

Land use in the Pee Dee subregion of South Carolina is primarily agricultural (7,629.3 km^2) and forested (9,422.7 km^2), comprising 81.8% of the basin (SC Land Resources Commission 1989). Agriculture is the dominant economic activity within the Pee Dee River basin; 87% of the state's tobacco production occurs in this region. Additional crops include soybeans (46.6%), corn (15%), cotton (5%), grains (16%), and fruit orchards (< 1%) (Pait et al. 1989). Forestry resources within the entire basin total 12,144.4 km^2, with 57% in private farm ownership, 23% in forest industry, and 6% in federal, state, or county control. Within the basin the dominant

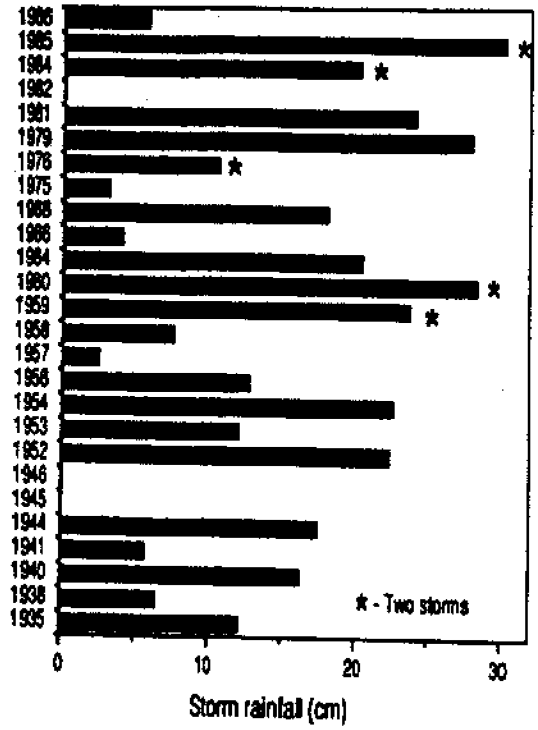


Fig.III-5. Hurricane (winds > 34 knots) frequency and associated total rainfall (Purvis and McNab 1985).

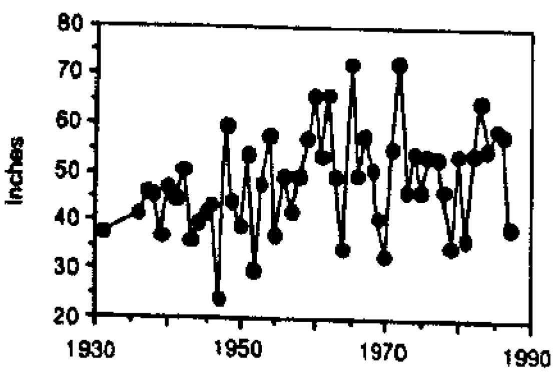


Fig. III-6. Total annual rainfall for Georgetown, SC (NOAA 1985).

forest types are loblolly-shortleaf pine (28%), oak-gum-cypress (22%), oak-hickory (21%), and oak-pine (18%). Longleaf-slash pine (9%) and elm-ash-cottonwood (2%) make up a minor portion of the forest types (Brooks et al. 1977). In this subregion, urban areas are 3% (617.7 km^2) and barren areas (76.9 km^2) and water (133.2 km^2) encompass 1% of the land area. Forested wetlands (2,719.8 km^2) dominate the wetland areas (14.2% of the area) in the subregion with nonforested wetlands only 1.1% of the area (SC Land Resources Commission unpublished data).

The Waccamaw Region Planning District includes Georgetown, Horry, and Williamsburg counties. These counties form the lower portion of the Pee Dee subregion. The total land area for these counties is 7,517 km^2. In this region wetland areas (forested and nonforested) significantly increase, accounting for 29% of the land area (Fig. III-7). Forests occupy 45.6% of the area and are predominantly (43% of total area) forest lands managed for timber and pulp wood. Agriculture is also a significant activity (21%). Urban (2.5%), commercial (0.2%), and industrial (0.3%) activities are minimal (3% of the total land area) (Waccamaw Regional Planning and Development Council 1978).

The lower portions of the Waccamaw, Pee Dee, Black, and Sampit rivers, as well as Winyah Bay Estuary, are located in Georgetown County. Therefore, land use activities in the county directly affect Winyah Bay Estuary and North Inlet Estuary.

Table III-1. Population distribution by subbasin within the Pee Dee-Yadkin Basin for 1980. Populations of major urban areas in each subbasin are included (Snyder 1983).

Subbasin	1980 Population (% State Population)	Major Urban Areas
Yadkin-Pee Dee	202,400	Florence -30,145
		Bennettsville - 8,841
	7%	Darlington - 7,978
		Marion - 7,622
		Hartsville - 7,616
		Cheraw - 5,681
Lynches	83,200	Lake City - 6,739
	3%	Lancaster - 9,547
Little Pee Dee	77,600	Dillon - 7,065
	<3%	Mullins - 6,038
Black	154,500	Sumter - 24,688
	5%	Manning - 4,727
		Kingstree - 4,095
		Bishopville - 3,466
		Andrews - 2,935
Waccamaw	102,100	Georgetown - 10,115
	3%	Myrtle Beach - 17,351
		Conway - 10,219

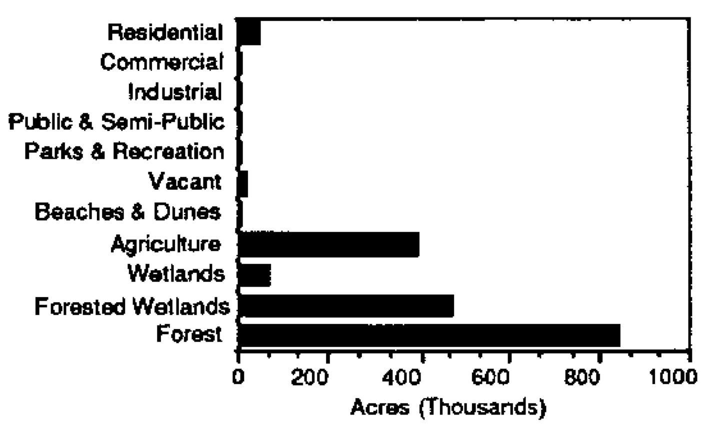


Fig. III-7. The 1985 projected land use for the Waccamaw region based on 1978 survey (Waccamaw Regional Planning and Development Council 1978).

In 1986, slightly more than 2% of Georgetown County was developed. Of the undeveloped land (2,087 km²), 53% was forested, 7.2% agriculture, 27% forested wetlands, and 12% non-forested wetlands (Tansey 1987; USDOC 1987).

The Waccamaw subdivision of Georgetown County directly affects North Inlet Estuary, the Waccamaw River, and the eastern portion of Winyah Bay Estuary. The land within the subdivision was primarily undeveloped with 164.3 km² in forests and 77.2 km² in wetlands. Within the subdivision less than 8% of the land area was developed. Of the total developed area in the Waccamaw subdivision over 46% was residential, 22% golf courses, 22% roads, and less than 6% commercial.

Land use within the North Inlet Estuary basin was primarily forest or undeveloped land (89.6 km²) with wetlands occupying 52.6 km². The remaining 1.1 km² are residential and golf courses (Waccamaw Regional Planning and Development Council 1985).

Freshwater Flow

Winyah Bay

Freshwater inflow to Winyah Bay ranged from 5.7 m^3/s at low flow to 2,832 m^3/s during major floods. During periods of average flow the discharge was 424.8 m^3/s (Snyder 1983). This freshwater inflow originated primarily from the Pee Dee (90%), Waccamaw (10%), and Sampit (< 1%) rivers (USGS, ten-year average for the Pee Dee River; Mathews et al. 1980, Waccamaw River; Lawler et al. Engineers 1977 in USACOE 1984, Sampit River). At the entrance to Winyah Bay the freshwater inflow from the Pee Dee resulted from discharges of the Pee Dee, Lynches, Little Pee Dee, and Black rivers; approximately 65% of this combined flow came from the Pee Dee River (SCDHEC 1976; Snyder 1983). Flow from the Pee Dee, Waccamaw, and Sampit rivers varied seasonally (USACOE 1984) with the greatest flow occurring during the winter months (Table III-2).

A salt wedge occurred in Winyah Bay with the normal freshwater interface varying about 6.4 km between high and low tide (Allen et al. 1984). The interface penetrated to about 8 km above km 0.0 of the Pee Dee and Waccamaw rivers under average freshwater flow conditions but was 26 km above during periods when freshwater inflow was less than 85 m^3/s (Johnson 1970; USACOE 1976; Hinde et al. 1981). The interface at high tide reached km 3.2 on the Black River and km 8.0 on the Pee Dee and Waccamaw rivers under average flow conditions (USACOE 1976; Hinde et al. 1981).

North Inlet

Freshwater inflow to North Inlet varied from 1 m^3/s to 5 m^3/s due to groundwater input and upland runoff (Kjerfve 1984). Rainfall inputs averaged 1.3 m/yr^2. On a volumetric basis approximately 50% of the freshwater input came from rainfall. The freshwater contribution from Winyah Bay was unknown. Freshwater inflow to North Inlet varied seasonally with little or no flow during the summer and early fall (Fig. III-8).

Tides

Winyah Bay

Superimposed on the unidirectional riverine flow was a semidiurnal tide. Tides in Winyah Bay varied from 1.2 m at the mouth of the bay to 1.0 m

Table III-2. Ten-year average river discharge for the Pee Dee, Waccamaw, and Sampit rivers (USGS ten-year average for Pee Dee River; Mathews et al. 1980 for Waccamaw River; Lawler, Matuskey, and Skelly Engineers 1977 in USACOE 1984 for Sampit River).

	Pee Dee River m^3/s	Waccamaw River m^3/s	Sampit River m^3/s
Winter	800	34	1.1
Spring	530	34	1.1
Summer	305	34	1.1
Fall	305	34	1.1
Annual Average	480	34	1.1

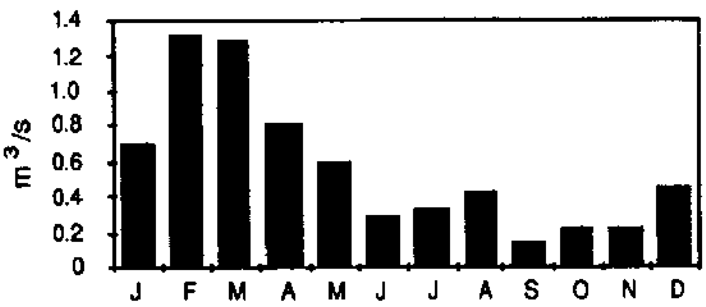


Fig. III-8. Monthly freshwater inflow to North Inlet Estuary, averaging data for 1978-1985 (Williams unpublished data)

at Georgetown Harbor. Tidal variation increased on the average by 0.2 m during spring tides (Trawle 1969 in Allen et al. 1984; USACOE 1984). Far-field forcing resulted in higher tides during the early fall months and lower than average tides during the winter months (Kjerfve and McKellar 1980). Meteorological events such as northeasterly blowing winds increased tidal amplitude and influenced longshore currents in the coastal boundary zone (Schwing et al. 1983).

Exchange with North Inlet

Flow between Winyah Bay and North Inlet occurred through South Jones, No Man's Friend, Haulover, and Sign creeks. Twenty-one percent of the water exchange in North Inlet occurred through South Jones and No Man's Friend (Kjerfve et al. 1982). Of that water, 80% of the exchange between the two systems occurred through South Jones (Kjerfve 1978 in Allen et al. 1982). Haulover Creek is narrow and shallow and flow was restricted to within a few hours of high tide (Allen et al. 1982). Water exchange between North Inlet and Winyah Bay was restricted by a nodal point located approximately 0.5 km to 1.5 km from the Winyah Bay entrance (Schwing and Kjerfve 1980; D.Chestnut SCDHEC personal communication). Only during high freshwater discharge into Winyah Bay or with the dominance of southwesterly winds was the nodal point overridden and net flows traverse from Winyah Bay to North Inlet (Allen et al. 1982). The temporal variability (total flux) of freshwater via this exchange has not been quantified.

North Inlet

The semidiurnal tidal range was 1.4 m and ranged from 1.1 m during neap tides to 2.5 m during spring tides. The tidal prism measured 2.1 x 10^7 m^3. The average residence time for water in North Inlet was 5.65 days, ranging from 7.26 days during the fall to 4.03 days during the winter (Childers and McKellar 1986). Tidal velocities were typically 1.3 m/s but occasionally exceeded 2.0 m/s (Kjerfve 1984). Because of limited freshwater input, flows within North Inlet were dominated by tidal pumping and water level variation. Water level variation was apportioned into semidiurnal (73%), diurnal (13%), weather-induced (4%), and seasonal (7%) fluctuations (Kjerfve et al. 1982).

Seasonal variation in sea level resulted in a seasonal variation in net water exchange between North Inlet and the coastal ocean (Fig. III-9). During the fall, maximal net discharge of water from North Inlet was ebb directed, coinciding with falling sea levels. North Inlet imported water from December through April, some of which was stored or exported through Winyah Bay (Kjerfve and McKellar 1980). Wind-induced low frequency continental shelf waves varied water level with-in the estuary. Northeasterly winds caused southerly coastal currents and Ekman flux shoreward. This

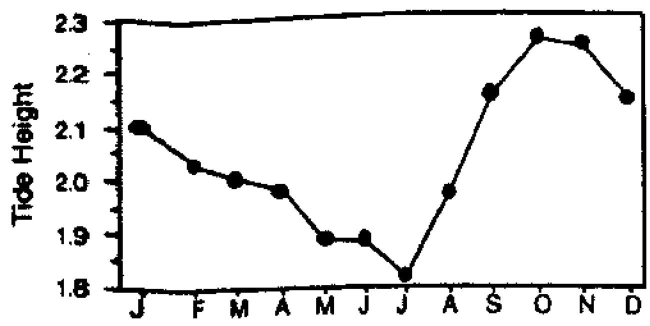


Fig. III-9. Mean monthly tidal height measured at Oyster Landing for 1981-1985 (LTER unpublished data).

flux increased water levels by 0.8 m within North Inlet Estuary. Southeasterly winds decreased water levels by driving coastal currents offshore (Kjerfve 1984).

Circulation Patterns

Winyah Bay

Circulation patterns in Winyah Bay were affected by freshwater discharge, tidal forcing, coastal currents, meteorological factors, density gradients and topographic features. Detailed measurements of surface currents in Winyah Bay were not available. In general, the dominant factor influencing currents in Winyah Bay was the semi-diurnal tide. During flood tides, currents were directed up the bay. In deeper channels, currents were not only affected by the tidal rise but flow was enhanced by density gradients caused by higher salinity water. Tidal influence occurred as far as km 131.2 on the Waccamaw River, km 73.6 on the Black River, and km 60.8 for the Pee Dee River (SCDHEC 1976). Ebb tides reversed the direction of most surface currents and an increase in net velocity occurred with the addition of river current components. Bottom currents had a net velocity up the Bay due to density gradients (USACOE 1984).

North Inlet

More detailed information was available for current patterns in North Inlet. Studies by Kjerfve and Proehl (1979), Palmer et al. (1980), Schwing and Kjerfve (1980), Kjerfve et al. (1981), Kjerfve et al. (1982), Kjerfve (1984), Dame et al. (1986), and Eiser and Kjerfve (1986) have detailed current dynamics within the estuary and exchanges between North Inlet and the coastal ocean and Winyah Bay. Due to limited freshwater input to North Inlet, the estuary is well-mixed and lacks salinity stratification; therefore, two-layered estuarine gravitational circulation does not exist. Flow varies laterally from a non-inear interaction between tidal currents and estuarine bathymetry. This mode of circulation is referred to as tidal pumping. Circulation is driven, therefore, by the same factors which influence the tidal variation (lunar cycle, winds, far-field forcing, Eckman pumping, etc.) (Kjerfve 1984).

Tidal currents dominate with flows averaging 1.3 m/s. Velocities as high as 2.3 m/s have been measured. Velocities were tidally asymmetric with maximum ebb velocities significantly greater then peak flood currents. The net current was uni-directional with depth but varied in direction laterally. It was not uncommon to have net flow lateral reversal within a channel cross section (Kjerfve 1978). Residual circulation was small when integrated over a given channel cross section. Because of lateral flow variation within a cross section, depth-integrated residual flow may vary by 25 cm/s (Kjerfve et al. 1982). Kjerfve et al. (1982) found large lateral variation in tidal currents in transects across Town Creek.

Net ebb currents occurred in the main channel and net flood currents in the secondary channel. These patterns result in a net export of water through Town Creek. Similar patterns were noted in transects across creeks near the inlet mouth. A bimodal bathymetric profile was apparent with the deeper channel experiencing net ebb currents and the secondary channel having net flood currents (Kjerfve 1978). These tidally-driven circulation patterns introduce large spatial variations as tides interact with local bathymetry (Kjerfve et al. 1982). Similar studies conducted in South Jones and North Jones creeks showed different patterns. In North Jones the main channel flows were flood directed and the secondary regions were ebb directed. South Jones has no tidally averaged current reversal. The lack of complex bathymetry in South Jones Creek may contribute to differences in circulation (Kjerfve et al. 1982).

Topographic variation may be an important factor as well in determining the significance of sheet flow to North Inlet's circulation patterns. Sheet flow occurred when non-channelized water floods the marsh surface. Estimates of the importance of sheet flow varies with location in North Inlet. In the Bly Creek basin, sheet flow accounted for only 1.1% of the tidal prism (Eiser and Kjerfve 1986). In the Oyster Landing basin, Miller and Gardner (1981) attributed as much as 50% of the water flux to sheet flow from the adjacent marsh. The Bly Creek system is a rectangular basin approximately 450 m wide and 1,600 m long with the creek proper occupying a much greater portion (17%) of the 720,000 m^2 watershed. The Oyster Landing basin is 140,000 m^2 with the creek occupying about 2% of the watershed, or approximately 3,307 m^2 (calculated from Miller and Gardner 1981). The apparent differences were due to topographic features of the two systems.

Sedimentary Patterns

Winyah Bay

Terrestrial sediments were supplied to the bay by the dendritic network of streams and tributaries draining the 46,258 km^2 basin of North Carolina and South Carolina. Rivers cross four physiographic provinces in the Carolinas, each having distinctive soil types, slopes, plant cover, and erosion rates (Conservation Foundation 1980). Impounded lakes and ponds trap most sediments originating in the Piedmont region of the Yadkin-Pee Dee system. The sediments that reach the bay originate below the last major reservoir on the Yadkin River north of the North Carolina state line (Conservation Foundation 1980)

The US Soil Conservation Service (1979) calculated that 2.3 x 10^{10} kg of soil were eroded throughout the watershed per year. Although a total of 1.2 x 10^6 m^3 were discharged within the basin, losses due to bank overflow brings the total reaching the bay to 7.6 x 10^5 m^3 (US Soil

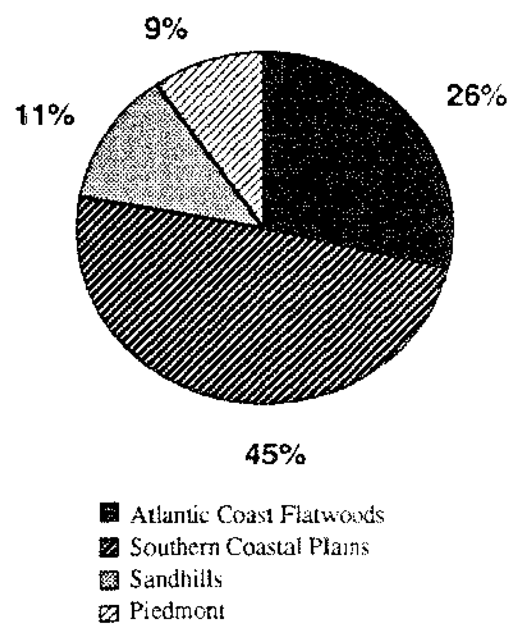


Fig. III-10. Contribution of sediment (1.2 x 10^6 m^3) to Winyah Bay from the various geographical provinces in South Carolina (US Soil Conservation Service 1979). The remaining 9% not accounted for in the diagram is not documented in the publication.

Conservation Service 1979).The South Carolina State Ports Authority reports that this may be an underestimation (Davis and Floyd, Inc. and Little 1983). The origin of the sediments reaching Winyah Bay are depicted in Figure III-10.

The majority of these sediments were silt and clay which predominate bottom sediments in the upper third of the harbor and estuary (Fig. III-11). The bottom sediments in the lower bay reaches have more than 59% sand with the percentage of sand increasing toward the entrance channel. The surface sand formations were deposited on marls, sands, clays, and limestones formed by sedimentation (Colquhoun 1973). The surface sands were angular, fine to coarse in texture, and generally arkosic, containing a high percentage of pure white kaolin. Most of the coastal plain deposits were soft or soluble. Sediments were mostly sand and clayey sand in the deeper channels. Where currents were too weak to transport sand, bottom sediments were primarily clays. The distribution of sand was restricted to areas where currents were greatest such as the head of the bay where major rivers enter and the mouth of the bay where tidal currents were the greatest (Colquhoun 1973).

Shelf sediments in this region appear to be primarily represented by medium to coarse grained sands (Pilkey et al. 1979). Hinde et al. (1981) found that two of three stations located outside the jetties consisted mostly of medium to coarse sands and the third was characteristically mostly silty clays. Mathews et al. (1980) found that the north jetty of the bay entrance channel traps the southerly littoral sediment drift, resulting in deposition at the southern end of North Island. Also, they indicated that the original Winyah Bay ebb-tidal delta has been removed since the completion of the south jetty. Stapor and Murali (1978) noted that between 1925 and 1964 South Island experienced a net deposition rate of 70,000 m^3/yr from onshore sand movement under the influence of waves and tidal currents.

North Inlet

Gardner and Bohn (1980) described North Inlet as a marsh basin in an early stage of evolution under conditions of slow submergence. They suggested that the interridge of the marsh is sand. A narrow area along the main tidal channel is comprised of mud and silt. They also found that the sand areas of the marsh contained tree stumps and roots indicating the area was originally forest that, through succession and salt water intrusion, had evolved to marsh. There was little information on the sedimentary patterns and processes occurring in the inlet. Using Pb 210 sediment profiles, Sharma et al. (1987) have shown that present sedimentation rates (1.4 - 4.5 mm/yr) were comparable to rates over the past 20 years of 1.3 - 2.5 mm/yr. These rates were comparable to local sea level rise (~3.0 mm/yr) in the inlet.

Basic Water Quality Parameters

Only two sources were available for describing seasonal water quality parameters in Winyah Bay Estuary (Fig. III-12). The SCDHEC STORET station MD080 is located near the US Highway 17 bridge at the head of the bay. Data were obtained from surface samples. Allen et al. (1982, 1984) sampled 14 stations bimonthly over a two-year period at two depths (surface and bottom) (Fig. III-13).

The longest continuous data available on water quality parameters for North Inlet was the LTER database with daily measurements at three stations for 1981-1986 (Fig. III-12). Additional shorter studies on specific parameters (dissolved oxygen, pH, nutrients) have been conducted at a number of locations in North Inlet Estuary (Gardner 1973, 1975; Erkenbercher and Stevenson 1977; Kjerfve and McKellar 1980; Gardner and Gorman 1984; Dame et al. 1986; Whiting et al. 1987; Wolaver et al. 1988).

Fig. III-11. Map showing sediment distribution in Winyah Bay (USACOE 1984).

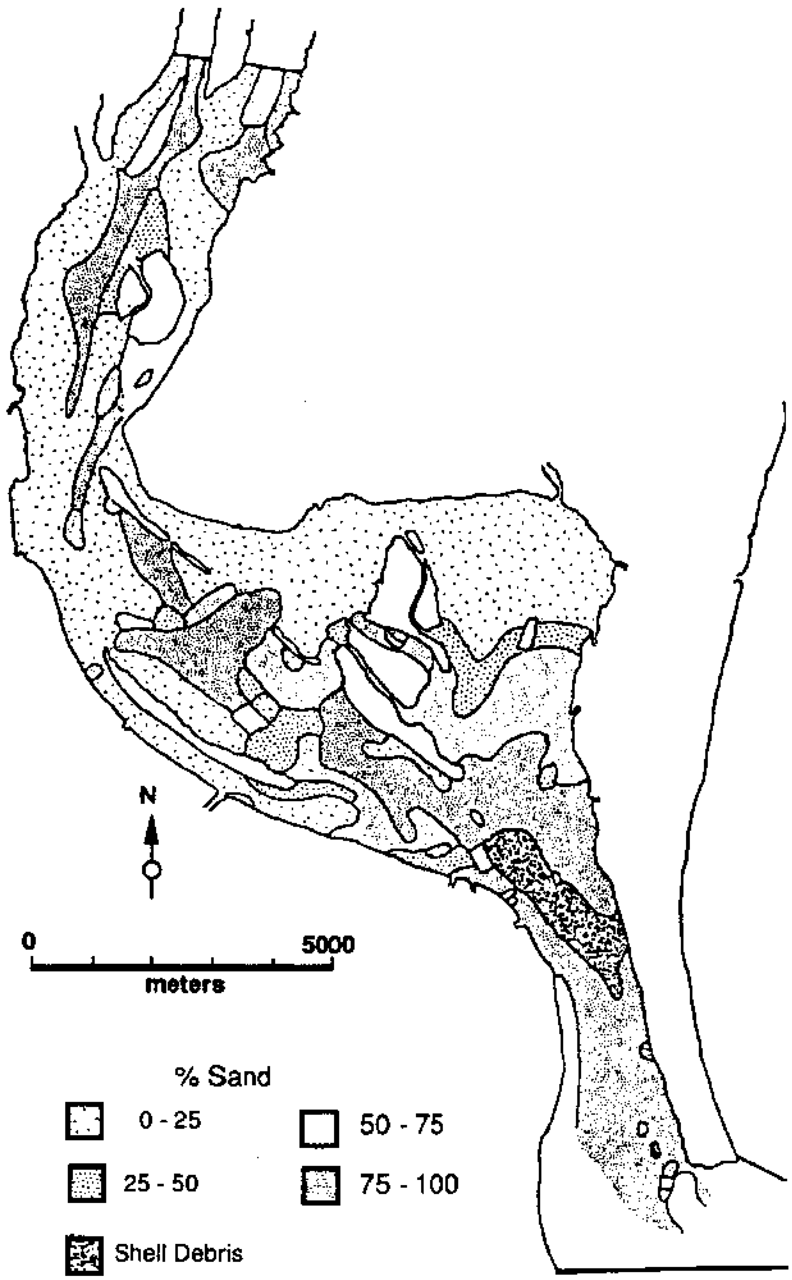


Fig. III-12. **Map of water quality** stations in Winyah Bay Estuary and North Inlet Estuary (1 - Allen et al. 1982, 1984; 2 - SCDHEC STORET database; 3 - LTER unpublished data; 4 - Whiting et al. 1987; Dame et al. 1986).

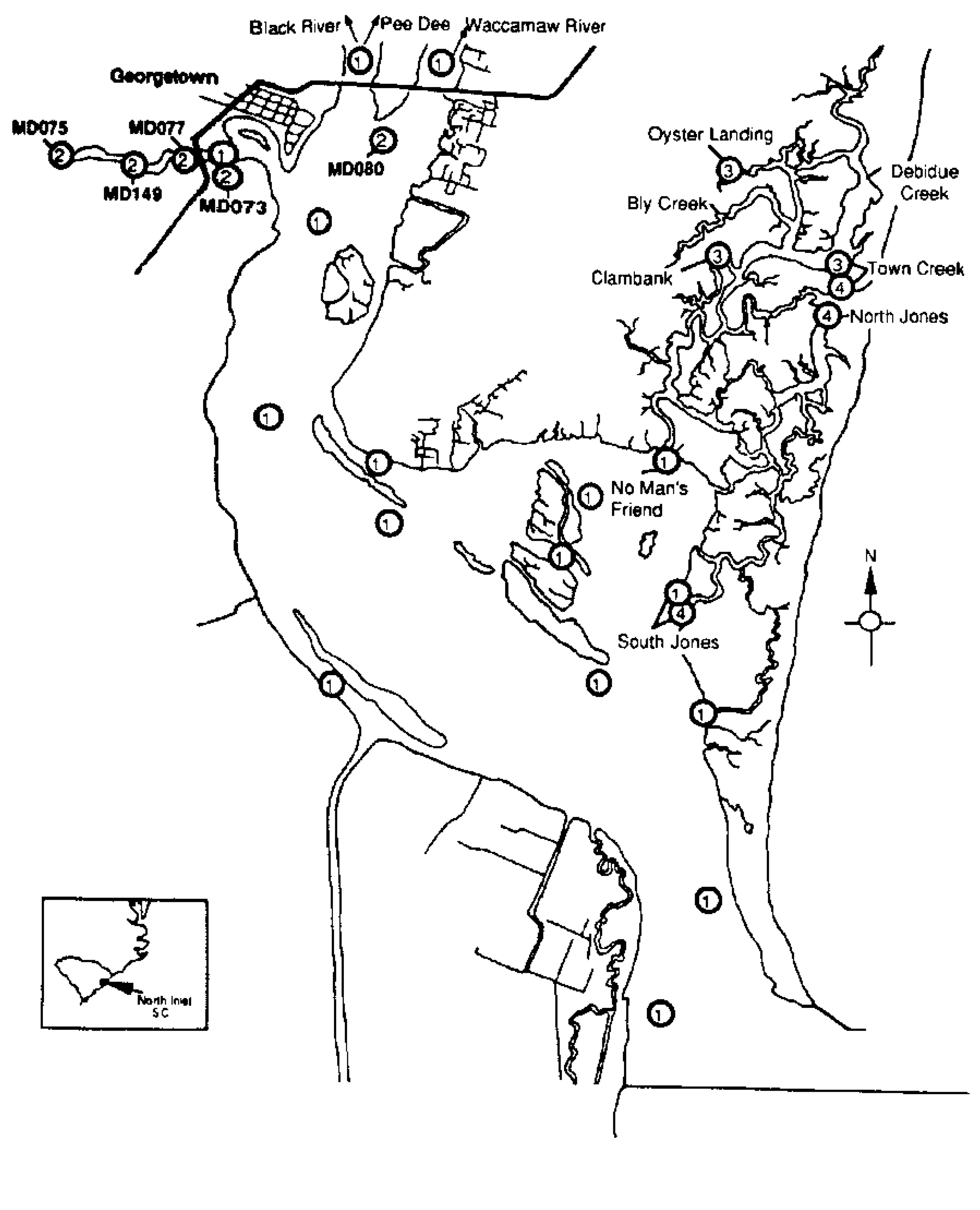
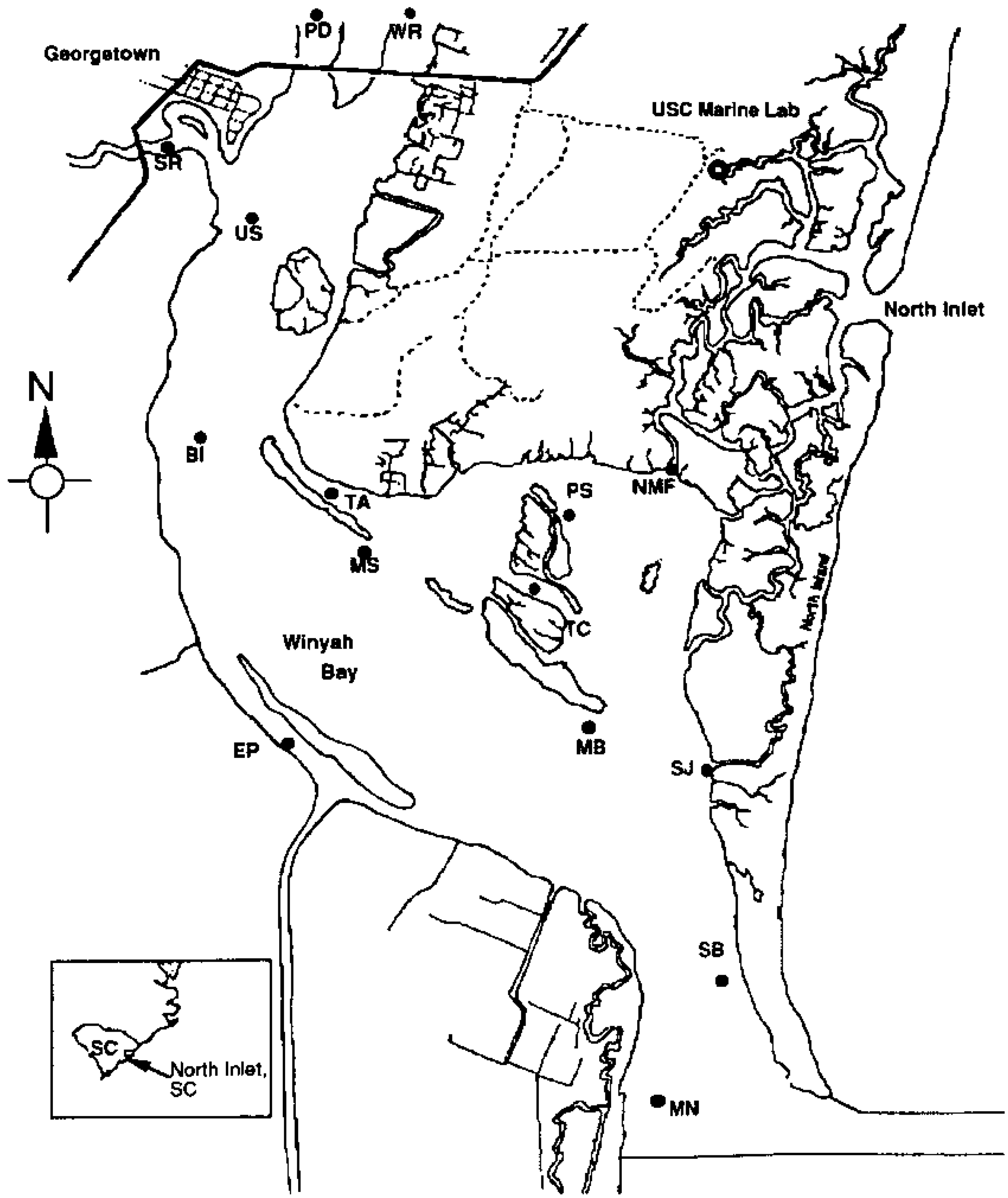


Fig. III-13. Sampling stations identified by station name for studies conducted by Allen et al. (1982, 1984). Station locations are identified by the following codes: Pee Dee River (PD), Sampit River (SR), Waccamaw River (WR), Pennyroyle River (PR), Upper Station (US), Belle Isle Marina (BI), Thousand Acre (TA), Pumpkinseed (PS), Mid Station (MS), The Cut (TC), Esterville Plantation (EP), Mud Bay (MB), Shell Bank (SB), and Lower Station (LS) (Allen et al. 1982, 1984).



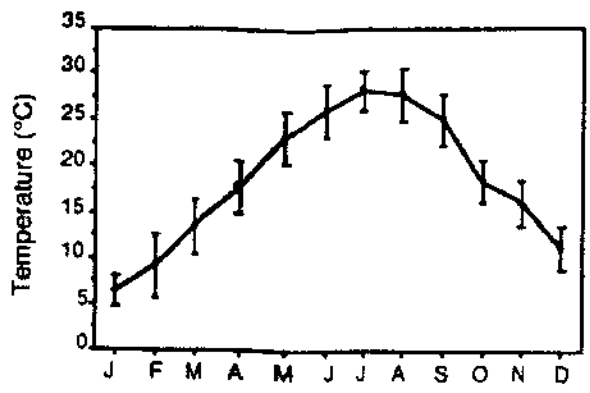


Fig. III-14. Mean monthly temperature (± SD) for 1977-1986 for station MD080 (SCDHEC STORET database).

Temperature

Winyah Bay

The seasonal temperature regime for Winyah Bay is depicted in Figure III-14. The ten-year temperature range was 4°C to 32°C, with an average temperature of 19.2 ± 0.7°C. The mean monthly range was 6.3°C in January to 28.2°C in July. The temperature extremes generally occurred in the shallow areas of Mud Bay (Allen et al. 1984). The work of Allen et al. (1984), which provides more detailed information on the temperature regime, shows no significant spatial temperature variance in the bay for either the vertical or horizontal planes (Fig. III-15). The mean monthly temperature was similar to those for the MD080 station. Johnson (1970) also found little to no vertical stratification in temperature.

North Inlet

North Inlet temperature data covering the period 1981-1985 is shown in Figure III-16. The average annual temperature was 18.7 ± 2.0 °C, with a mean monthly temperature of 8.3 °C in January to 27.2 °C in July. These temperatures were similar to Winyah Bay (MD080) for the same period (mean 19 ± 0.9 °C, range 6.6 °C in January to 27.6 °C in July). No spatial differences in temperature were observed in North Inlet Estuary.

Salinity

Winyah Bay

The seasonal salinity pattern and monthly variability in the bay were primarily determined by the amount of freshwater inflow and tidal intrusion. Lowest salinities occurred during the winter and early spring months coincident with freshwater inflow (Fig. III-17). The range for the ten-year MD080 data was 3.5 ‰ to 15‰, with a mean salinity of 7.4 ‰ (± 2.05). The mean monthly range was 0.6 ‰ to 8.4 ‰, with large variations in all months. High variability occurred during June, August, and October due to interannual variation in freshwater flow induced by tropical storms or hurricanes.

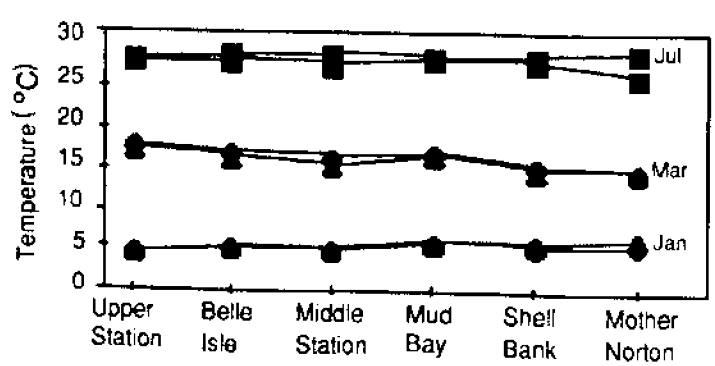


Fig. III-15. Monthly surface and bottom temperatures along a longitudinal gradient from upper (Upper Station) Winyah Bay to the mouth (Mother Norton) of Winyah Bay (Allen et al. 1984).

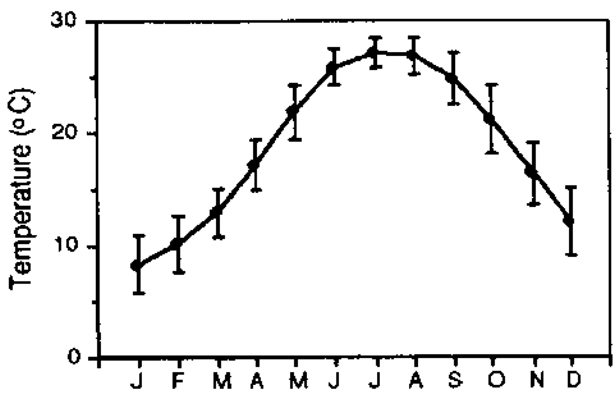


Fig. III-16. Mean monthly temperatures (±SD) for the years 1981-1986 averaging all three stations (LTER unpublished data).

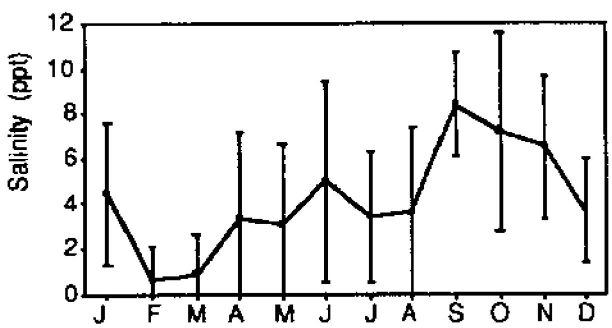


Fig. III-17. Mean monthly salinities (± SD) for years 1977-1986 for station MD080 (SCDHEC STORET database).

The data from Allen et al. (1984) indicate strong spatial and temporal variations of salinity for the bay (Fig. III-18). During periods of high river discharge (January) surface to bottom salinity differences were small, with salinities primarily influenced by freshwater inflow. Tidal salt intrusion was minimal throughout the estuary. The greatest surface to bottom variation occurred at the Middle Station. During March greater spatial variation in salinities occurred. Lower bay stations were influenced by high salinity tidal oceanic waters with little surface to bottom differences. The upper station had very low salinities (little surface to bottom difference) indicating a strong influence by freshwater discharge. The mid bay stations (Belle Isle and Middle Station) had strong vertical stratification, suggesting oceanic influence on the bottom waters and riverine influence on the surface waters. When freshwater discharge was lowest, oceanic waters affected the upper bay. There was strong vertical stratification in the upper half of the bay due to ocean-dominated bottom waters. The lower half of the bay exhibits little vertical stratification, indicating a dominance of tidal mixing during low flow periods.

North Inlet

The data from the Long-Term Ecological Research program in North Inlet show spatial and temporal variations in salinity (Fig. III-19). In general, the highest salinities were found at Town Creek (33.3 ± 0.2 ‰) while Clambank (31.8 ± 0.4 ‰) and Oyster Landing (31.4 ± 0.4‰) have similar salinities. Salinities tend to be spatially homogeneous over a year because of high tidal exchange; however, on a short-term basis (on the order of days) substantial salinity variation occurred. Mean monthly concentrations ranged from 29.5 ± 0.3 ‰ in May to 34.4 ± 0.1 ‰ in October. Oyster Landing salinity was greatly influenced by storm-generated freshwater runoff while Clambank was influenced to a large degree by intrusions from Winyah Bay with high river discharge or wind-driven phenomena. These influences result in lower spring salinities for Clambank and Oyster Landing than found at Town Creek (Fig. III-19). The lower salinities in September were due to the freshwater discharge associated with tropical storms or hurricanes.

Table III-3. Range of pH in interstitial pore water and salt marsh surface waters near Goat Island, North Inlet Estuary, SC (Gardner 1973).	
Margins of tidal creeks	6.55 - 7.30
Interior of marsh	6.60 - 6.75
Sandy margin along Goat Island	5.90 - 6.60
Surface seawater	8.00 - 8.10

pH

Winyah Bay

There were no observable trends in pH with temperature or discharge in Winyah Bay Estuary (Fig. III-20). The pH range was 4.9 to 8.2 for the ten-year SCDHEC data set. The mean monthly range was 6.6 to 7.2, with the greatest variation occurring in August.

North Inlet

Estuarine surface water pH was less variable than interstitial waters. In the summer of 1971, Gardner (1973) profiled the interstitial waters of North Inlet and reported the pH values found in Table III-3. Gardner's (1975) studies, conducted July - August 1972 and June - July 1973, found an average pH of 6.8, with a range of 6.4 to 7.8. Surface pH ranged from 8.0 to 8.1. Erkenbrecher and Stevenson (1977) reported a mean surface water pH of 7.5 with a range of 7.1 to 7.9. Their study was conducted in two tidal creeks over five separate tidal cycles; 130 pH measurements were made.

Dissolved Oxygen

Winyah Bay

Monthly dissolved oxygen concentrations were inversely related to temperature, with the lowest concentrations coinciding with maximum productivity. Monthly dissolved oxygen concentrations range from 3.5 mg/l to 15 mg/l for the ten-year SCDHEC data (Fig. III-21). The mean monthly concentration range was 5.2 mg/l to 10.9 mg/l, with the greatest variation occurring in January. Johnson (1970) reported dissolved oxygen concentrations during the winter months from 8.5 mg/l to 11.8 mg/l, with an average of 10.0 mg/l. These data represent a saturation level of 75-95%. He found little to no variation with depth.

North Inlet

Gardner and Gorman (1984) measured dissolved

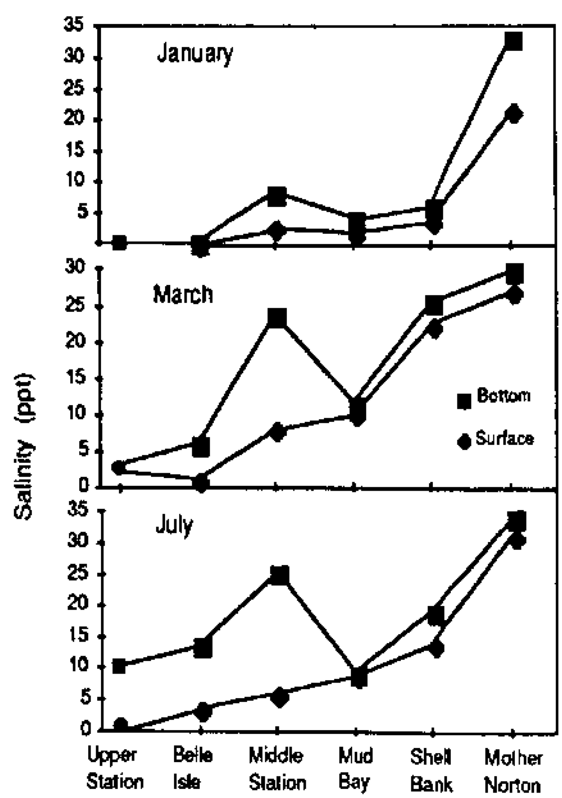


Fig. III-18. Comparisons of surface and bottom salinities along a transect from upper Winyah Bay (Upper Station) to the mouth of Winyah Bay Mother Norton (Allen et al. 1984).

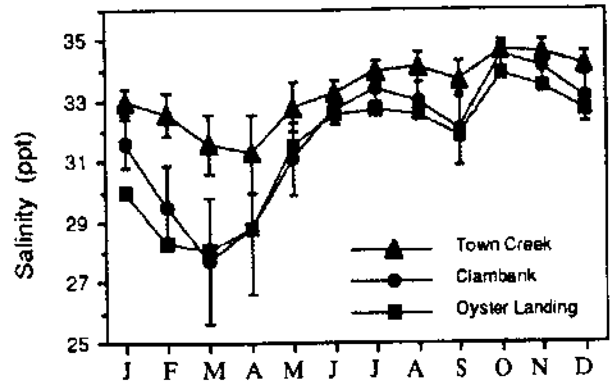


Fig. III-19. Mean monthly salinity (± SD) for station MD080 for 1977-1986 (SCDHEC STORET database).

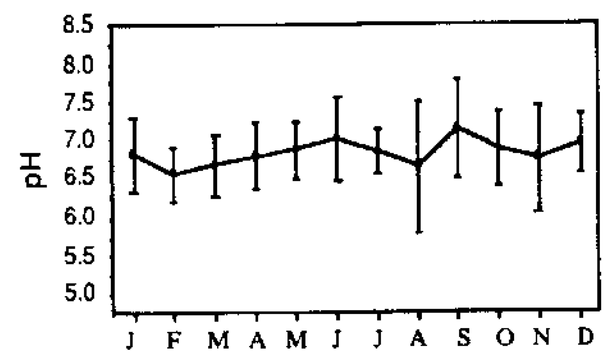


Fig. III-20. Mean monthly pH (± SD) for station MD080 for 1977-1986 (SCDHEC STORET) database.

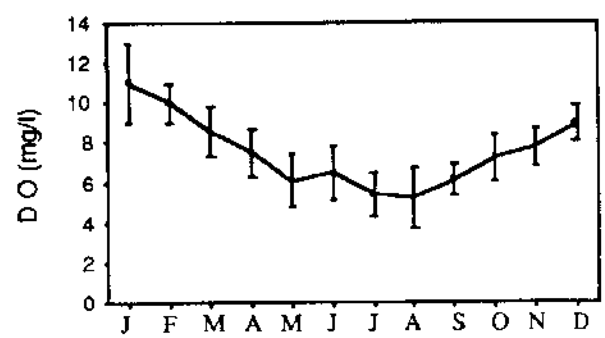


Fig. III-21. Mean monthly average dissolved oxygen (DO) (± SD) for station MD080 for 1977-1986 (SCDHEC STORET database).

oxygen at Oyster Landing Bridge in June 1977. He reported a range of 1.5 ppm to 7.4 ppm. The dissolved oxygen concentrations were closely linked to diurnal and tidal variations. Highest dissolved oxygen concentrations occurred at high tide during the daylight hours and lowest concentrations at low tide prior to dawn. Erkenbrecher and Stevenson (1977) examined DO over five tidal cycles and found that DO ranged from 2.3 mg/l to 8.5 mg/l (n = 96, mean = 5.1).

Nutrients

Phosphorous

Winyah Bay

The only long-term data available for Winyah Bay was total phosphorus at station MD080 (SCDHEC STORET database). Total phosphorus averaged 3.02 µg at/l ± 2.04 (SD 0.63 to 9.68 µg at/l) for the period 1976-1987. Similar concentrations were detected by Allen et al. (1984) for 1981 and 1982, with a mean of 2.65 µg at/l and range of 0.7 - 11.5 µg at/l, for all stations averaging surface and bottom (Fig. III-22). Seasonal variation in total phosphorus (from MD080 station) was positively correlated with temperature. The highest monthly concentration occurred in June (4.37 µg at/l ± 2.41), and lower concentrations occurred during the winter months (October 2.12 ± 1.34 µg at/l). A bimodal seasonal pattern was observed by Allen et al. (1984) during 1982, with maximum surface total phosphorus occurring in January (3.4 µg at/l ± 3.0) and a second peak in concentration during July (3.3 µg at/l ± 1.7) (Allen et al. 1984).

Total phosphorus concentrations increased with depth and bottom samples were always higher than surface samples (bottom 3.08 µg at/l, surface 2.17 µg at/l). The highest concentrations were detected at Esterville Plantation (4.2 µg at/l) which is located approximately mid-bay. The Sampit River had the highest total phosphorus concentrations (Sampit 3.8 µg at/l, Pee Dee 2.2 µg at/l, Waccamaw 2.6 µg at/l). With the exception of January 1982, there was a general decline in concentration from Upper Station to Mother Norton, indicating a river source for total phosphorus. During January this pattern was reversed with highest concentrations located lower in the bay. Esterville Plantation may have been the source of the elevated concentrations in January (bottom total phosphorus concentrations of 14.2 µg at/l, Allen et al. 1984).

Orthophosphate concentrations in Winyah Bay averaged 22% of the total phosphorus (Allen et al. 1984) (Fig. III-23). Overall mean orthophosphate concentration was 0.55 µg at/l ± 0.32. There was little variation with depth or season (maximum concentrations in March of 1.19 µg at/l ± 0.54 at the surface and 0.94 µg at/l ± 0.38 at the bottom and minimum concentrations in January of 0.29 µg at/l ± 0.09 at the surface and 0.32 µg at/l ± 0.10 at the bottom). The rivers were the apparent source of orthophosphate (average river input 0.67 µg at/l ± 0.29). The Upper Station concentrations (0.77 µg at/l ± 0.45) were similar to river input and Mother Norton was lowest (0.24 µg at/l ± 0.12). The remaining stations in Winyah Bay were very similar, averaging 0.55 µg at/l ± 0.32.

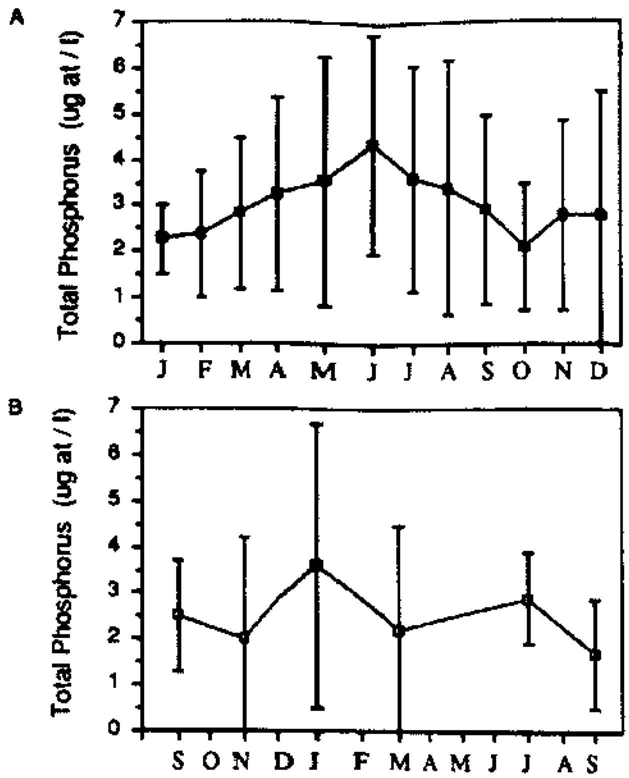


Fig. III-22. Mean monthly average total phosphorus (± SC) for MD080 (A) and averaging all stations sampled during the Allen et al. (1984) study (B).

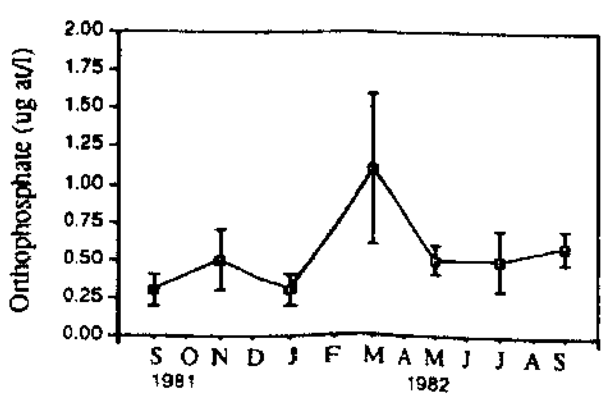


Fig. III-23 Mean monthly average orthophosphate concentrations combining all stations sampled (Allen et al. 1984).

Table III-4. Overall phosphorus concentrations (μg at/l) in water, averaging the three stations sampled daily for 1981-1988 (LTER unpublished data).

	Mean	SE	Minimum	Maximum
Total Phosphorus	1.03	0.012	0	10.60
Particulate Phosphorus	0.58	0.010	0	10.60
Dissolved Organic Phosphorus	0.01	0.005	0	10.13
Orthophosphate	0.03	0.006	0	9.99

Table III-5. Spatial variation in phosphorus in North Inlet Estuary. Means (μg at/l) for stations Town Creek (TC), Clambank (CB), and Oyster Landing (OL) represent an average of daily measurements for 1981-1988 (LTER unpublished data). No Man's Friend (NMF) and South Jones (SJ) means are an average of all data collected by Allen et al. for 1981-1983 (Allen et al., 1982,1984). NA - no data available.

	TC	CB	OL	NMF	SJ
Total Phosphorus	0.74	0.95	1.56	2.21	2.89
Orthophosphate	0.018	0.036	0.06	0.02	0.04
Particulate Phosphorus	0.47	0.52	0.79	NA	NA

North Inlet

Unlike Winyah Bay, the various phosphorus fractions (total, dissolved organic, particulate, orthophosphate) have been investigated for North Inlet (Table III-4). Particulate phosphorus represented 56% of the total phosphorus, with available phosphorus (orthophosphate) comprising less than 3% and dissolved organic phosphorus less than 1%.

Concentrations of total phosphorus, orthophosphate, and particulate phosphorus vary with to station (Table III-5). The lowest total and orthophosphate concentrations were detected at Town Creek. Highest concentrations were detected at the two stations adjacent to Winyah Bay (No Man's Friend and South Jones). Winyah Bay influences not only the phosphorus concentrations present but substantially influences the fractionation. Within North Inlet orthophosphate was less than 3% of the total phosphorus, while waters influenced by Winyah Bay have approximately 88% of the total phosphorus as orthophosphate. Particulate phosphorus concentrations were highest in waters adjacent to the forest and decrease in concentration with station depth (e.g., Oyster Landing > Clambank > Town Creek).

Total phosphorus, orthophosphate, and particulate phosphorus concentrations all showed seasonal variations (Fig. III-24). Total phosphorus concentrations in North Inlet Estuary exhibited a distinct seasonal pattern with maximum concentrations occurring in August (1.97 μg at/l ± 0.95 SD) and minimum concentrations during the winter and early spring (averaging ~ 0.79 μg at/l ± 0.57). Orthophosphate concentrations were very low and showed a slight variation with season with higher concentrations during the summer (0.56 μg at/ ± 0.48) and lowest during the winter (0.23 μg at/l ± 0.33). Particulate phosphorus variation was a major

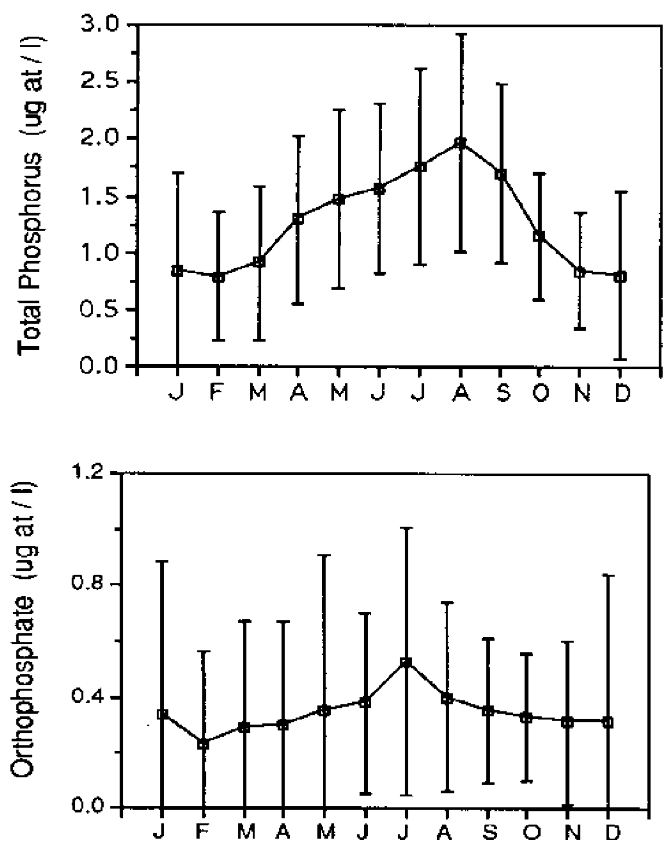


Fig. III-24. Mean monthly concentrations of the various phosphorus fractions in North Inlet Estuary. Monthly means average all samples collected (daily at three stations) for that month for 1981-1988 (LTER unpublished data).

contributor to the total P variation, with maximum concentrations reaching 1.44 µg at/l ± 0.70 in August and minimum concentrations, averaging 0.62 µg at/l ± 0.44 during the winter.

A study focusing on the exchanges with Winyah Bay and the Atlantic Ocean was conducted from 1979 to 1980 (Dame et al. 1986). During this period total phosphorus showed little seasonal pattern while orthophosphate concentrations were higher in the summer and fall (Dame et al. 1986). Concentrations of orthophosphate varied with flow; concentrations increased with ebb flow and decreased with flood tides and were higher on spring tides than neap. Highest concentrations of orthophosphorus were found at low tide in the summer and fall (0.7 - 0.8 µg at/l) (Dame et al. 1986). Highest concentrations of total phosphorus (1.87-2.03 µg at/l) occurred in September and October with an average concentration of 1.37 µg at/l (Kjerfve and McKellar 1980).

North Inlet Estuary exported phosphorus. Phosphorus flux from North Inlet was 3.1 g/m^2/yr with 54% (1.7 g/m^2/yr) exported as orthophosphate and 0.06% (0.2 g/m^2/yr) as ATP. Kjerfve and McKellar (1980) estimated the flux at 2.93 g/m^2/yr during the same period in 1978 and 1979 using daily flux estimates. Greatest flux occurred in September and October. Dame et al. (1986) also found the greatest flux during the fall (16 µg P/l). Estimated inputs were not sufficient to balance the exports reported by Dame et al. (1986) and Kjerfve and McKellar (1980). It was not clear what the additional phosphorus sources were contributing to the reported export. Differences may in part be due to differing time periods for various flux estimates. The phosphorus entering North Inlet Estuary has a very high turnover time. Dame et al. (1986) estimated the turnover of orthophosphate at three days.

Nitrogen

Winyah Bay

In Winyah Bay only four nitrogen fractions were measured: total nitrogen, nitrate, nitrite, and ammonia (SCDHEC STORET; Mathews and Shealy 1978; Allen et al. 1982, 1984). STORET data for one station (SCDHEC MD080) provides the best long-term average nitrogen concentrations for Winyah Bay. Ammonium (NH_4^+) comprised approximately 18% of the total Kjeldahl nitrogen (TKN: 75.78 µg at/l) present

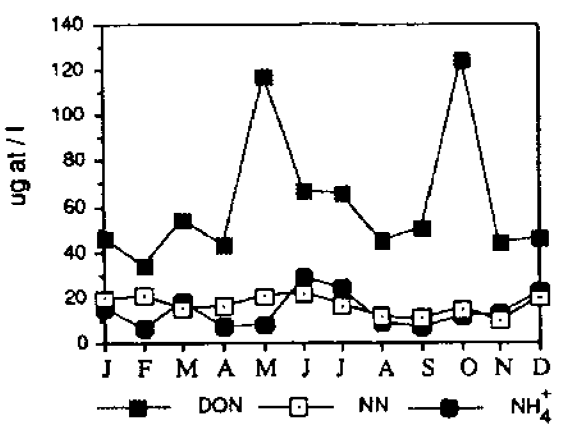


Fig. III-25. Mean monthly concentrations of various nitrogen fractions in Winyah Bay (MD080) for 1975-1985 (SCDHEC STORET database).

ranged from 67.45 to 75.78 µg at/l (Allen et al. 1982, 1984; SCDHEC MD080). Concentrations in the upper bay stations (72.8 µg at/l; Allen et al. 1984) were similar to those determined for the MD080 station.

Seasonal patterns can be assessed from the SCDHEC MD080 data which integrates approximately ten years of variation in flow and concentration measurements (Fig. III-25). Higher dissolved organic nitrogen (DON) concentrations occurred during May and October. The highest concentrations and variation (standard error) in total Kjeldahl nitrogen occurred in October (124.29 µg at/l ± 75) and May (117.15 µg at/l ± 64.14). Both ammonium and nitrate-nitrite displayed a bimodal concentration pattern with high

(SCDHEC MD080). Nitrate-nitrite concentrations (16.57 µg at/l) were slightly higher than ammonium (14.07 µg at/l). It was not known how much nitrogen was particulate; however, dissolved organic nitrogen (TKN-NH_4^+) averages 61.71 µg at/l.

Differences in nitrate-nitrite average concentrations for a given study resulted from differing temporal and spatial resolutions. The lower concentrations of nitrate-nitrite (7.00 µg at/l) determined by Mathews and Shealy (1978) reflected their sampling regime (quarterly covering 20 months from 1973 to 1975 at one station) and the more central location of their station in the bay than the SCDHEC station. The nitrate-nitrite concentrations measured by Allen et al. (1984) reflected a shorter period of time than even Mathews and Sealy's study but integrated the bay and its tributaries (14 stations were sampled). Concentrations in the upper bay (16.2 µg at/l bottom and 17.0 µg at/l surface; Allen et al. 1984) were similar to those measured at MD080 (16.6 µg at/l). Slightly higher nitrate-nitrite and total nitrogen concentrations occurred in the surface waters than bottom waters indicating a riverine source (Mathews and Shealy 1978; Allen et al. 1982, 1984). Total nitrogen averages

concentrations in early summer (June: NN = 22.8 µg at/l, NH_4^+ = 28.6 µg at/l) and mid winter (December: NN = 20.0 µg at/l, NH_4^+ = 22.9 µg at/l). The greatest variability in nitrate-nitrite occurred in May (14.42 ± 4.78) and in July (49.07 ± 8.57) for ammonium, suggesting different factors may be responsible for concentrations during a specific month although a similar seasonal pattern was observed.

There was significant spatial and temporal variation in nitrogen concentrations in Winyah Bay (Allen et al. 1984). Overall nitrate-nitrite and total nitrogen decreased along the main channel from the upper bay to the ocean during the spring (Fig. III-26). There was a strong linear relationship of total nitrogen with salinity, suggesting that the river waters entering the bay were significant sources of nitrogen. Average total nitrogen concentrations in these rivers were 20% (72.8 µg at/l) greater than the average concentration for the main channel stations (59.8 µg at/l). Waters exiting the bay to the ocean were 35% lower in nitrogen than waters entering the bay from the rivers. This overall pattern varies seasonally. During periods of high discharge (i.e., January 1982) the bay was fairly homogeneous with concentrations

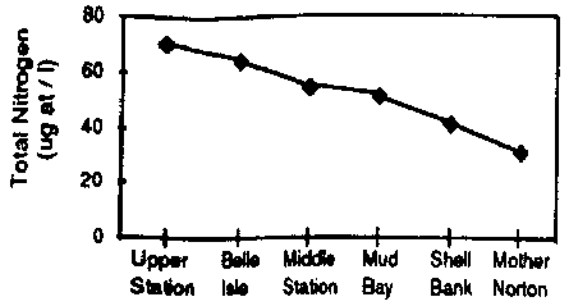


Fig. III-26. March 1982 total nitrogen (averaging surface and bottom) concentrations along a transect from upper (Upper Station) Winyah Bay to the mouth (Mother Norton) of Winyah Bay (Allen et al. 1984).

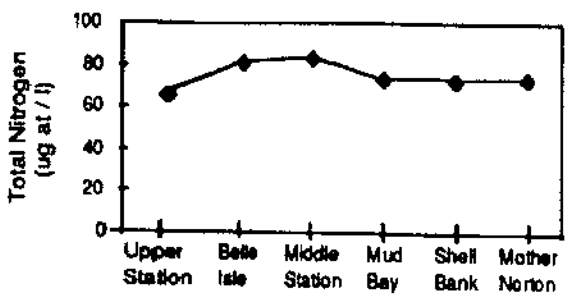


Fig. III-27. January 1982 total nitrogen (averaging surface and bottom) concentrations along a transect from upper (Upper Station) Winyah Bay to the mouth (Mother Norton) of Winyah Bay (Allen et al. 1984).

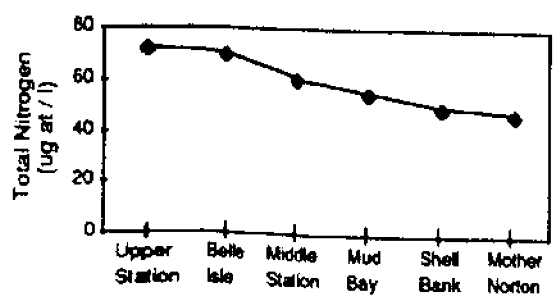


Fig. III-28. June 1982 total nitrogen (averaging surface and bottom) concentrations along a transect from upper (Upper Station) Winyah Bay to the mouth (Mother Norton) of Winyah Bay (Allen et al. 1984).

throughout the bay similar to the levels entering from the rivers (Fig. III-27). During low flow periods stations in the upper bay have higher concentrations than the lower portion of the channel suggesting a riverine source (Fig. III-28).

Using Allen et al.'s (1984) data, USGS runoff estimates for the Sampit, Waccamaw, and Black-Pee Dee rivers and rainfall data for 1984-1985 (LTER unpublished data), it was possible to estimate annual flux of total nitrogen from riverine and atmospheric sources to Winyah Bay. Rainfall inputs were 3.8 kg/ha with total riverine inputs (2,981 kg/ha) dominating the total nitrogen contributions to Winyah Bay. No quantitative outputs from Winyah Bay exist. No studies have been conducted to quantify flow and nutrient concentrations at a transect across the Winyah Bay-ocean interface.

There were several major deficiencies in understanding nitrogen dynamics in Winyah Bay. Important fractions were not quantified either spatially or temporally. No data were available on gaseous forms of nitrogen. No studies have been conducted to estimate important transformations such as nitrification, denitrification, ammonification, and nitrogen fixation. It was not known what role phytoplankton or wetland vegetation play in modifying nitrogen dynamics.

North Inlet

In the North Inlet salt marsh system the predominant nitrogen form was dissolved organic nitrogen (60%), particulate nitrogen also made up a substantial fraction (34%) (Table III-6). It was estimated that approximately 10% of the particulate nitrogen was living biomass

Table III-6. Overall mean (averaging stations 1981-1988) nitrogen fractions (µg at/l) in North Inlet Estuary (LTER unpublished data).

	Mean	SD	Sample Size
Total Nitrogen	33.67	12.65	5079
Dissolved Organic Nitrogen	20.25	9.63	4945
Particulate Nitrogen	11.52	8.02	4979
Ammonium	1.73	2.00	5015
Nitrate-Nitrite	0.55	0.79	5032

Table III-7. Mean station (averaging all data for 1981-1988) nitrogen fractions (µg at/l) in North Inlet Estuary (LTER unpublished data) and averaging all data sampled during the Allen et al. (1984) study (B). (Town Creek - TC, Clambank - CB, Oyster Landing - OL, South Jones - SJ, No Man's Friend - NMF). * Whiting et al. 1987, [1] Allen et al. 1982.

	TC	CB	OL	SJ	NMF
Total Nitrogen	31.36	32.35	37.85	50.72*	48.68[1]
Dissolved OrganicNitrogen	18.69	19.25	23.13		
Particulate Nitrogen	11.46	10.75	12.37		
Ammonium	1.22	1.77	2.29	3.54*	
Nitrate - Nitrite	0.36	0.76	0.56	4.27*	2.50[1]

(Erkenbrecher and Stevenson 1980). Ammonium comprises 76% of the inorganic nitrogen while only comprising 5% of the total nitrogen present. Nitrate-nitrite was less than 1% of the overall nitrogen available in North Inlet Estuary.

The highest nitrogen concentrations (all fractions) occurred at stations proximate to Winyah Bay (South Jones and No Man's Friend) (Table III-7). Nitrate-nitrite in this area of North Inlet Estuary ranged from 4 to 12 times greater than other stations (Clambank, Oyster Landing, Town Creek). Town Creek was greatly influenced by the coastal ocean and had the lowest concentrations of all nitrogen fractions. Runoff from the forested uplands influenced on Oyster Landing total nitrogen, dissolved organic nitrogen, particulate nitrogen, and ammonium. Oyster Landing had higher concentrations of these nitrogen fractions than Clambank or Town Creek. Clambank was influenced by Winyah Bay. However, only nitrate-nitrite was elevated at this station relative to the Oyster Landing and Town Creek stations.

Total nitrogen exhibited a strong seasonal pattern which covaried with primary production (of both phytoplankton and *Spartina*) and the annual temperature cycle. This annual variation was due primarily to seasonal changes in particulate nitrogen (Fig. III-29). Particulate nitrogen maximum concentrations occurred in August (16.49 µg at/l ± 0.34) and minimum concentrations were observed in January (6.83 µg at/l ± 0.26). Dissolved organic nitrogen (mean = 19.21 µg at/l) was a consistent portion of the total nitrogen pool throughout the year. Differences between mean monthly maxima (20.6 µg at/l) and minima (17.5 µg at/l) were 3.1 µg at/l.

Dissolved inorganic nitrogen (both ammonium and nitrate-nitrite) have higher concentrations during the summer months (Fig. III-30). Nitrate-nitrite seasonal variation was similar to particulate nitrogen but the maximum concentrations occurred during the early summer (May 0.88 ± 0.06 μg at/l). The decline in nitrate-nitrite may have been due to utilization by phytoplankton. Phytoplankton biomass increased substantially during the summer months and, therefore, may have contributed to declining concentrations. Other studies have shown that nitrate-nitrite was inversely related to phytoplankton production (Zingmark and Blood unpublished data). Ammonium concentrations were highest during the late summer (July to September) with the maximum concentration (2.42 ± 0.15 μg at/l) in July. However, unlike particulate nitrogen, concentrations were elevated from November through February (consistent with periods of freshwater inflow) and minimal concentrations detected in March (1.02 ± 0.05 μg at/l).

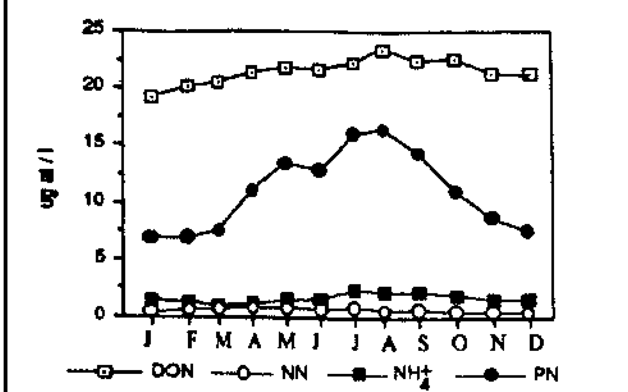


Fig. III-29. Mean monthly (averaging all stations for 1981-1988) nitrogen fractions in North Inlet Estuary (LTER unpublished data).

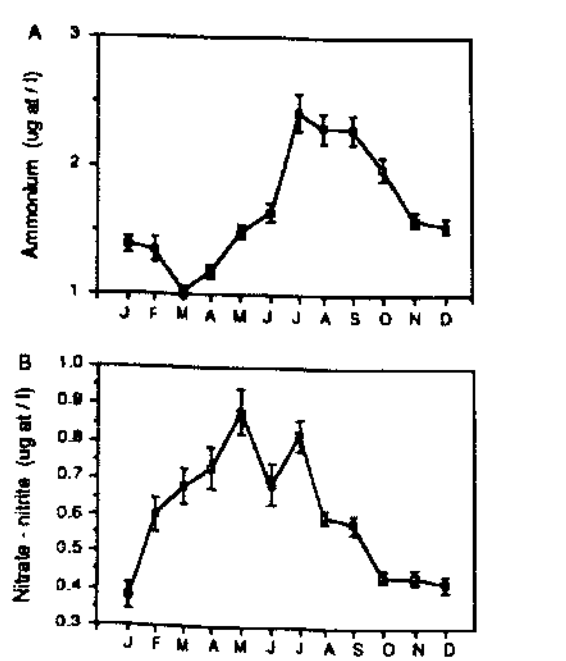


Fig. III-30. Mean monthly (averaging stations 1981-1988) ammonium (A) and nitrate-nitrite (B) concentrations in North Inlet Estuary (LTER unpublished data).

In contrast to Winyah Bay, nutrient patterns in North Inlet Estuary were more closely related to the temperature cycle than freshwater runoff. Increased concentrations in nitrate-nitrite during May, June, and July in Winyah Bay were similar to the peak concentrations in North Inlet Estuary; however, the winter peak coincident with increased freshwater input in Winyah Bay was not evident in North Inlet Estuary. Allen et al. (1984) found peaks in nitrate-nitrite in January, March, and June exhibiting a strong relationship with salinity. Ammonium had the opposite relationship to North Inlet Estuarine patterns with highest concentrations in Winyah Bah occurring during lowest salinities. In North Inlet Estuary highest ammonium concentrations occurred with highest salinities (July, August, and September). Ammonium concentrations were positiviely correlated with seasonal variation in temperature in North Inlet Estuary, but not in Winyah Bay. Total nitrogen had a strong seasonal pattern correlated with temperature in North Inlet Estuary but an erratic pattern in Winyah Bay (March and October were extremely variable).

Macrophytes

North Inlet

North Inlet Estuary had approximately 52 km² of salt marsh of which 49.1 (86%) was classified as low marsh and the remaining 2.9 km² (13%) is high marsh. Low marsh areas were dominated by *Spartina alterniflora* while the high marsh community contained a mix of species including *Spartina alterniflora* (smooth cordgrass), *Juncus roemerianus* (black needlerush), *Borrichia frutescens* (sea ox-eye), *Distichlis spicata* (salt grass), *Spartina patens* (marsh-hay cordgrass), *Fimbristyplis spadicea* salt marsh fimbristylis, *Salicornia* spp. (glassworts), *Iva frutescens* (marsh elder), and others (not identified in publication) (Tiner 1977).

Winyah Bay

Winyah Bay had an extremely diverse plant community arising from the broad range of salinities which occurred in the estuary. Freshwater marshes comprised 90.6 km² (81%), brackish marshes 19.7 km² (18%), and salt marshes less than 1% (0.8 km²) of the total 127.3 km² marsh habitat in Winyah Bay (Tiner 1977). Marshes affected by tides (111.1 km²) are 87% of the marsh area.

Wetland areas within the Winyah Bay watershed were analyzed by the SC Land Resources Conservation Commission using the USFWS Wetlands Inventory (SC Land Resources Commission 1989). The area evaluated (which includes Winyah Bay) encompassed 727 km² of the lower portion of the Pee Dee-Yadkin (Winyah Bay) watershed. Land areas within the evaluated portion of the Winyah Bay watershed were composed of the following: 120 km² estuarine (16.5% of total area, 34.1% of wetland area), 8.4 km² lacustrine (1.1% of total area, 2.4% of wetland area), 3.3 km² marine (0.4% of total area, 1% of wetland area), 198.2 km² palustrine (27.3% of total area, 56.3% of wetland area), 22.3 km² riverine (3.1% of total area, 6.3% of wetland area), and 374.7 km² uplands (51.5% of total area).

Low marsh was dominated by *Spartina alterniflora* (smooth cordgrass), with *Juncus roemerianus* (black needlerush), *Borrichia frutescens* (sea ox-eye), *Distichlis spicata* (salt grass), *Spartina patens* (marsh-hay cordgrass), *Fimbristyplis spadicea* (salt marsh fimbristylis), *Salicornia* spp. (glassworts), *Iva frutescens* (marsh elder), and *Limonium* spp. (sea lavender) in the high marsh (Tiner 1977).

The brackish marsh species included giant cordgrass, *Juncus roemerianus* (black needlerush), *Scirpus robustus* (salt marsh bulrush), *Scirpus americanus* (common three-square), *Scirpus validus* (soft-stem bulrush), *Typha latifolia* (broadleaf cattail), *Typha glauca* (blue cattail), *Pontedaria cordata* (pickerel-weed), *Sagittaria* sp. (arrowhead), *Hymenocallis crassifolia* (spider-lily), *Spartina cynosuroides* (salt reedgrass), *Phragmites communis* (reed), and *Peltandra virginica* (arrow-arum).

In low salinity brackish marshes, *Spartina cynosuroides* (salt reedgrass) occurred. Giant cutgrass (*Zizaniopsis miliacea*) was a common plant in freshwater marshes along with *Pontedaria cordata* (pickerel-weed), *Cladium jamaicense* (sawgrass), *Impatiens capensis* (jewel-weed), *Sium suave* (water parsnip), *Polyfonum* spp. (smart weeds), *Nuphar luteum* (yellow pond-lily), *Cicuta maculata* (water hemlock), *Sagittaria* spp. (arrowhead), *Hibiscus* *moscheutos* (rose mallow), *Scirpus validus* (soft-stem bulrush), *Spartina cynosuroides* (giant cordgrass), *Typha latifolia* (broadleaf cattail), *Thypa glauca* (blue cattail), *Lythrum lineare* (loosestrife), *Nymphaea odorata* (white water lily), and *Alternanthera philoxeroides* (alligator weed). *Alnus serrulata* (tag alder), *Taxodium distichum* (bald cypress), *Carpinus caroliniana* (ironwood), *Gleditsia aquatica* (water locust), *Nyssa aquatica* (tupelo gum) Nyssa *sylvatica* (black gum), *Liquidambar styraciflua* (sweetgum), *Acer ruburm* (red maple), and *Viburnum dentatum* (viburnum) were several tree species which occurred in these freshwater marshes (Tiner 1977; Conservation Foundation 1980). Shrubs present in freshwater marshes included: *Ilex* spp. (hollies), *Vaccinium* spp. (blueberries), *Lyonia lucida* (fetterbush), *Myrica cerifera* (wax myrtle), *Cyrilla racemiflora* (titi), *Cephalathus accidentalis* (buttonbush), and *Smilax* spp. (catbrier) (Conservation Foundation 1980).

No biomass, productivity, or areal extent of individual species have been documented for Winyah Bay marsh vegetation.

Phytoplankton

North Inlet

Phytoplankton have been sampled at a number of locations in North Inlet Estuary (Fig. III-31). Hall (1979) identified 229 species of phytoplankton from samples collected at Town Creek near North Inlet (Appendix III-1). The phytoplankton community was composed of 201 diatoms, 23 dinoflagellates, 1 silicoflagellate, 3 naked flagellates, and 1 cyanophyte. Neritic species were more prevalent than oceanic species. Freshwater forms were negligible. Tychopelagic forms were more prevalent than euplanktonic forms and temperate species were most abundant. High tide was characterized by oceanic species and low tide by resuspended benthic species.

Thalassionema nitzschioides was continually present and dominant in all seasons. *Skeletonema costatum* was the next most abundant; only slightly below *T. nitzschioides*. The two species comprised over 25% of the phytoplankton community while 17 species made up 68% of the community (Table III-8). Some neritic temperate genera (i.e., *Chaetoceros*) usually common in Atlantic estuaries were found in lower concentrations in

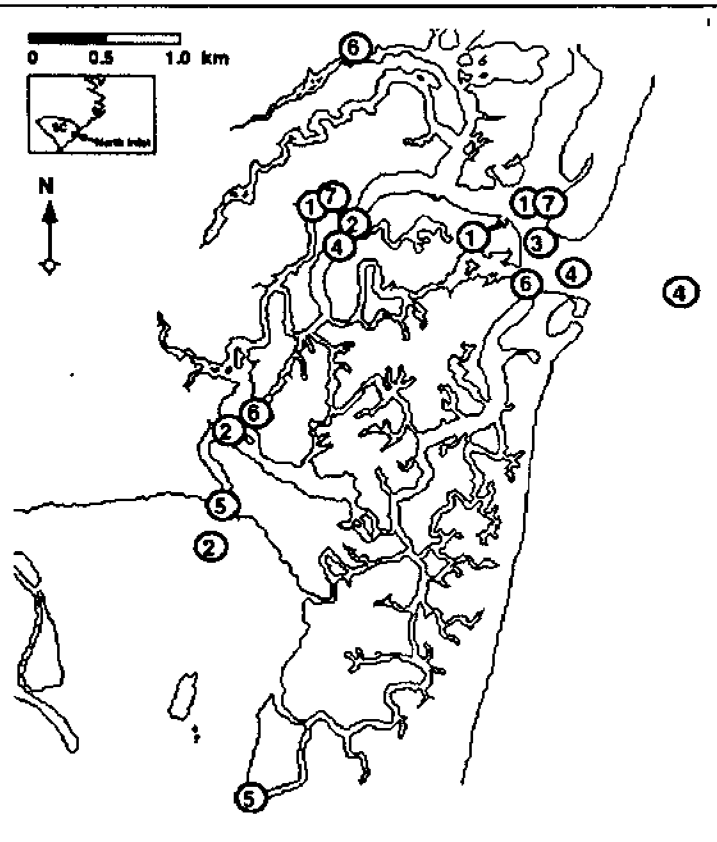


Fig. III-31. Primary production stations in North Inlet, SC. (1 - Sellner 1973; 2 - Vennewitz 1977; 3 - Hall 1979; 4 - Zeeman 1981; 5 - Allen et al. 1982; 6 - Coutinho 1987; 7 - Erkenbrecher and Stevenson 1980).

Table III-8. Relative abundance of phytoplankton species at the ocean- marsh interface. Samples were collected biweekly June 1976 - January 1977 (Hall 1979). * Benthic species

Species	Relative Abundance %
Thalassionema nitzschioides	13.1
Skeletonema costatum	12.2
Melosira sulcata	5.8
Rhaphoneis surirella	5.4*
Cyclotella striata	5.0
Cymatosira belgica	5.0*
Campylosira cymbelliformis	4.1
Thalassiosira sp.	2.9
Biploneis sp.	2.9
Biddulphia aurita	1.5
Coscinodiscus excentricus	1.5
Cymatosira lorenziana	1.4
Cocconeis sp.	1.4
Eunotogramma laevis	1.3
Navicula abunda	1.3
Rhaphoneis amphiceros	1.3
Coscinodiscus lineatus	1.0
Nitzschia seriata	1.0
TOTAL	68.0%

North Inlet Estuary. *Skeletonema costatus* was dominant throughout the year and *Asterionella* spp. was codominant during winter months (Sellner 1973). Year-to-year differences occurred in species dominance. *Asterionella glacialis* found by Sellner (1973) to be abundant were found only in June and July during 1976-1977 (Vennewitz 1977).

Standing crop estimates from cell counts ranged from 1.1 to 3.46 x 10^8 cells/l during 1972-1973 (Sellner 1973). For the study period 1976-1977, the mean cell count was 2.76 x $10^6 \pm$ 2.5 x 10^6 cells/m². Tidal stage differences were noted for both numbers of phytoplankton (high tide: 3.35 x$10^6 \pm$ 3.08 x 10^6, low tide: 2.04 x $10^6 \pm$ 1.65 x 10^6 cells/m²) and community characteristics (Hall 1979).

Resuspension of benthic algae affected species composition, abundance and chlorophyll *a* concentrations (Hall 1979; Erkenbrecher and Stevenson 1980). Three population maxima occurred during the 1976-1977 study period. A major peak occurred in mid- summer, a small peak in mid-winter and an intermediate peak in the spring. These peaks in phytoplankton numbers coincided with the seasonal shifts in phytoplankton dominance as noted by Hall (1979) (Fig. III-32).

Annual phytoplankton production varied from 178 g C/m²/yr (Vennewitz 1977) to 409 g C/m²/yr (Zingmark 1977). Annual phytoplankton production varied spatially with lowest production at Clambank and increasing southward to Winyah Bay or eastward to the plume outside North Inlet (Vennewitz 1977; Zeeman 1981). Annual phytoplankton production in Winyah Bay was approximately twice that measured at Clambank (Vennewitz 1977) while levels offshore were comparable to levels detected at Clambank (Zeeman 1981). The highest total phytoplankton annual production was measured in the North Inlet plume or delta. Zeeman (1981) estimated total annual production for 1980-1981 at 639 g C/m²/yr. Exchanges with Winyah Bay and the coastal ocean indicated a net phytoplankton import to North Inlet from these sources (Dame et al. 1986).

Total phytoplankton productivity generally followed the annual temperature cycle ranging from a low of 6.4 mg C/m²/hr in November to high of 234 mg C/m²/hr in August (Sellner 1973) (Fig. III-33). Studies of phytoplankton chlorophyll *a* and productivity exhibit the same seasonal pattern with maximum concentration occurring during the warmer months and lowest concentration occurring during winter months (Sellner et al. 1976; Vennewitz 1977; Zeeman 1981). Similar seasonal patterns were observed in Winyah Bay (Allen et al. 1984). Lowest concentrations were detected during winter months (1.99 mg C/m^3) and highest concentrations in late summer (13.32 mg C/m^3). These studies indicate that temperature and light were the major factors controlling production and chlorophyll concentrations, exhibiting a positive correlation.

Table III-9. Annual phytoplankton production (g C/m^2) at different locations in North Inlet.

Station	Production	Study
Clambank	151	Vennewitz 1977
Clambank	380	Zeeman 1982
Clambank	259	Sellner 1973
No Man's Friend	205	Vennewitz 1977
Mud Bay	285	Vennewitz 1977
Town Creek	346	Sellner 1973
Town Creek	422	Zeeman 1982
Plume	639	Zeeman 1982
Offshore	346	Zeeman 1982
Unknown	273	Zingmark 1977
Unknown	409	Zingmark 1977

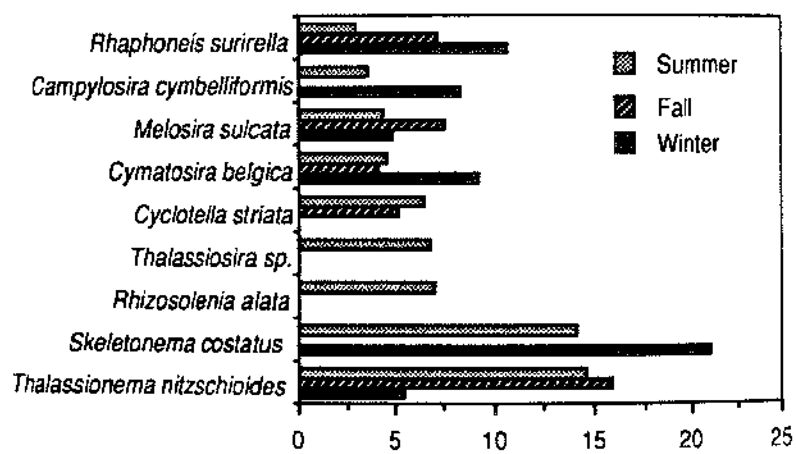


Fig. III-32. Seasonal phytoplankton abundance (number of individuals/species) from Town Creek, North Inlet Estuary, SC (Hall 1979).

Other factors influence phytoplankton biomass and productivity. Zeeman (1981) found chlorophyll *a* related to salinity (-), temperature (+), phosphate (+), current velocity (+), and extinction coefficient (+). However, these factors only explained 30% of the variation, with temperature alone accounting for 24%. Vennewitz (1977) did not find any significant relationships between inorganic nitrogen (ammonium or nitrate) and daily total production, daily nannoplankton production, or total or nannoplankton chlorophyll *a*. Only nannoplankton daily production was positively correlated with orthophosphate. Levels of inorganic nutrients measured during this study were sufficiently abundant so as not to limit production. Erkenbrecher and Stevenson (1980) found tidal forces to be a major influence on the temporal fluctuation in chlorophyll *a*. Higher chlorophyll *a* was found at low tide and following rainfall which they attributed to resuspension of benthic algae. Zeeman (1981) measured greater chlorophyll *a* in bottom waters and also attributed his results to benthic resuspension.

It was unclear what role nutrients play in regulating phytoplankton in North Inlet. Although

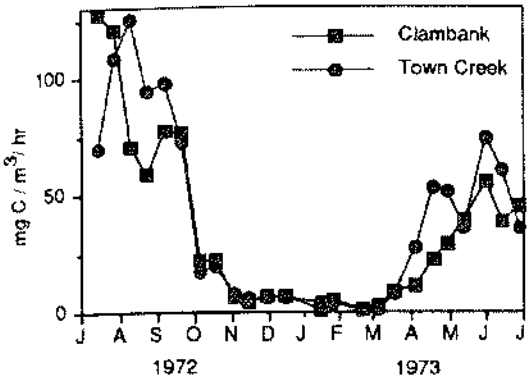


Fig. III-33. Hourly phytoplankton production for two locations in North Inlet Estuary (Sellner 1973).

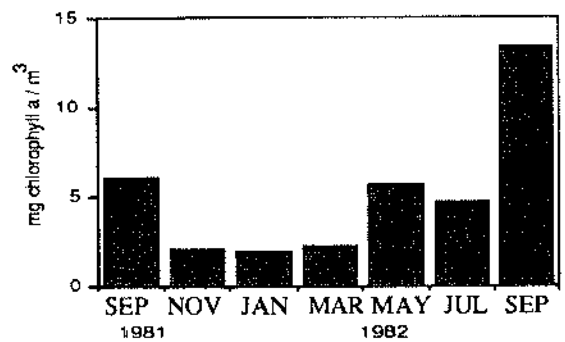


Fig. III-34. Seasonal chlorophyll *a* concentrations averaging all stations ampled during the Winyah Bay study (Allen et al. 1984).

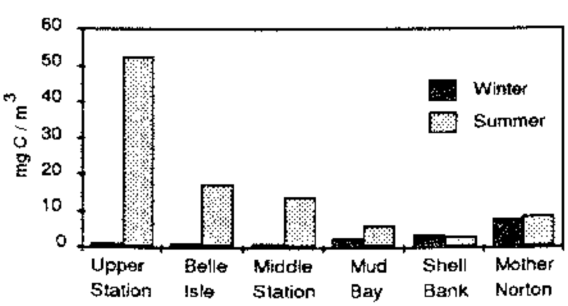


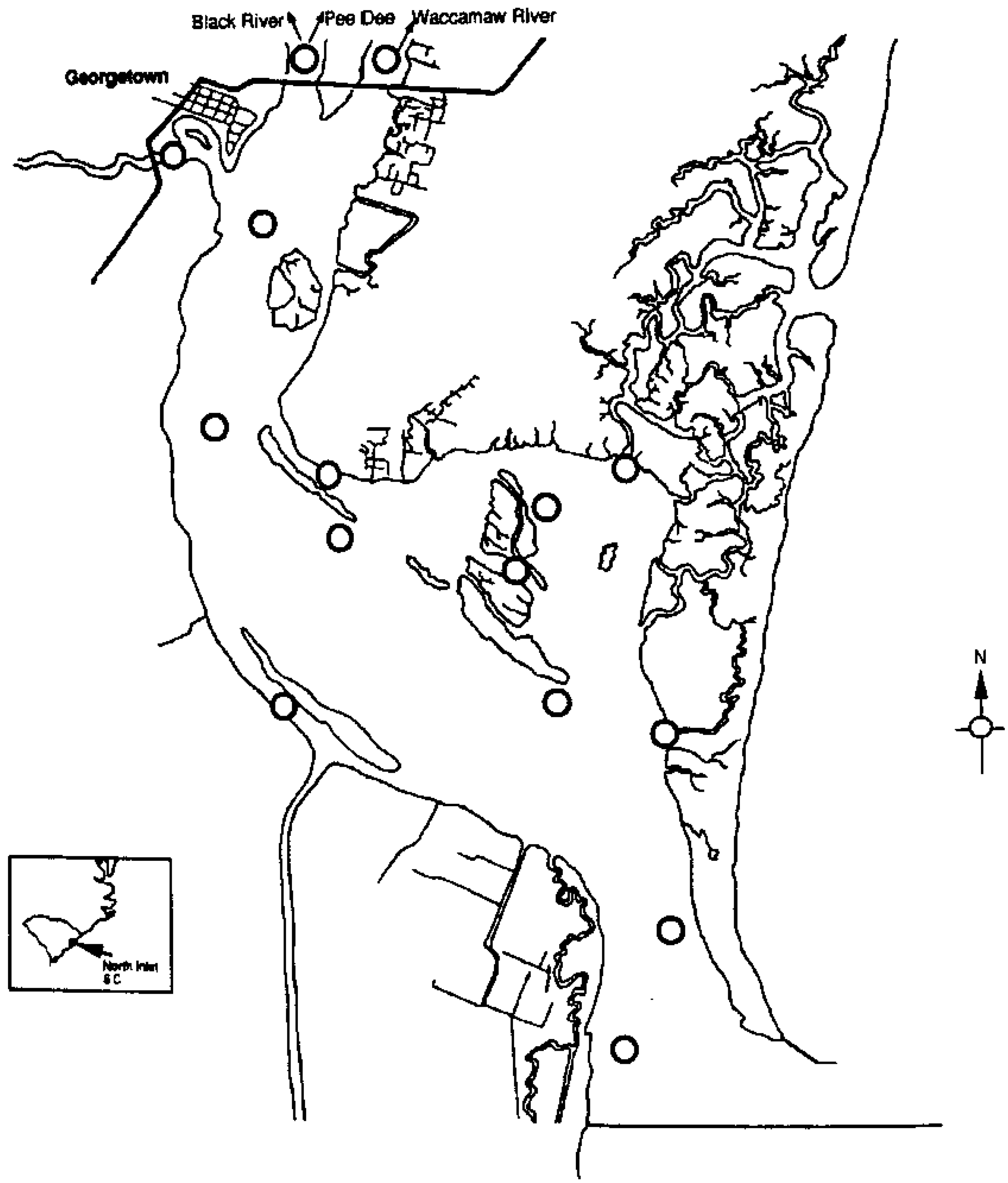
Fig. III-35. Seasonal differences in the spatial chlorophyll *a* concentrations in Winyah Bay. Stations arranged left to right on graph to represent upper bay (fresh water) to lower bay (oceanic water) (Allen et al. 1984).

Vennewitz (1977) studies showed nutrient levels within North Inlet were not limiting, other studies indicate that phytoplankton were restricted or limited within North Inlet. Zeeman (1981) found Pmax = 14.1 (2.6-43) mg C/hr/mg Chl a for North Inlet phytoplankton to be 60% of theoretical maximum. No causative factors were positively identified from parameters measured during the study, but correlations with Pmax and temperature and nutrients suggested they played a role. Species size for North Inlet phytoplankton were found to be in the extreme lower limits, due possibly to nutrient limitation or light limitations (Hall 1979).

Winyah Bay

Only two studies on phytoplankton biomass have been conducted in Winyah Bay (Allen et al. 1982, 1984). The average chlorophyll *a* concentration in Winyah Bay was 5.16 mg C/m³ (0.55 - Waccamaw River; 52.36 - Upper Station mg C/m³). In general, higher chlorophyll *a* concentrations were detected in surface waters. River sources for chlorophyll *a* dominated in the summer and oceanic sources dominated in the winter (Fig. III-35). Spatial differences were observed in Winyah Bay (Fig. III-36). Chlorophyll *a* declined with increasing salinity indicating a river source for phytoplankton within Winyah Bay. Overall, higher concentrations were measured at the Upper Station (10.38 mg C/m³) and declined southward toward the Atlantic Ocean (Shell Bank - 2.78 mg C/m³). Higher levels were detected at Mother Norton (5.19 mg C/m³), indicating potential oceanic sources for the lower bay. Seasonal differences in this pattern were observed. No studies on species composition have been conducted in Winyah Bay Estuary.

Fig. III-36. Sampling locations for phytoplankton studies in Winyah Bay Estuary (Allen et al. 1982, 1984).



Benthic Microalgae

Studies on benthic microalgae were limited. No studies were conducted on microalgae in Winyah Bay. In North Inlet Estuary only production estimates were available. No explicit studies were conducted on community composition in North Inlet Estuary. Benthic microalgae production during 1973-1975 was 2.5 times greater than phytoplankton production for that same period (685 g/m^2/yr, Zingmark 1977). Mean annual abundance of benthic diatom cells at a mud site located in Bread and Butter Creek was 21.0 x 10^6 (± 7.6 x 10^6) diatoms/10 cm^2 and 5.39 x 10^6 (± 2.44 x 10^6) diatoms/10 cm^2 at a sand site in Debidue Creek (Montagna et al. 1983). Bimodal seasonal abundance at the mud site peaked in February-March and July-August. Diatom abundance at the sand site had one peak in July-August.

Benthic Macroalgae

Studies on benthic macroalgae were conducted only in North Inlet Estuary. Benthic macroalgae have been studied in several locations in North Inlet. Ebeling (1982) collected data from January to May 1979 at three sites (Oyster Landing, dock at Clambank, Town Creek toward Winyah Bay from Clambank). Fourteen species were identified, with five species dominating the community (Table III-10; Appendix III-1). Benthic macroalgae dominated during the winter months and were a significant source of energy and carbon during that period. For the major species the average ash-free dry weight/m^2 was 2.59 (0.5-7.08 g afdw/m^2) and had an average caloric content of 2.78 Kcal/g afdw.

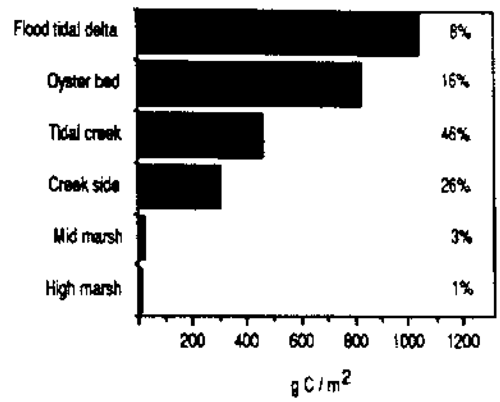


Fig.III-37. Macroalgal production by habitat type within North Inlet Estuary. Percentages were the amount of the total areal production contributed by each habitat type (habitat annual production weighted by habitat area) (redrawn from Coutinho 1987).

Coutinho (1987) evaluated the spatial and temporal macroalgae distribution in North Inlet from 1983 to 1987. He identified 54 species of macroalgae belonging to Chlorophyta (18 species), Phaeophyta (8 species), and Rhodophyta (28 species) (Appendix III-1). North Inlet was not an important boundary for the distribution of species on the East Coast because none of the species were either at their northern or southern limit. The greatest number of species occurred within North Inlet and declined toward Winyah Bay. Both species composition and production varied with substrate type (Fig. III-37).

Table III-10. Dominant macroalgae species weights and caloric content (Ebeling 1982).

Species	Ash-free dry wt/m^2	Kcal/g afdw
Enteromorpha sp.	7.08	3.6
Enteromorpha siliculosus	1.44	3.4
Ulva lactuca	0.50	3.3
Bryopsis plumosa	3.58	0.9
Porphyra leucosticta	0.37	2.7

Species numbers were greatest during the winter with peak reproductive activity occurring in the spring. Mean daily net production of the dominant species ranged from 0.033 to 6.3 g $C/m^2/yr$ with most winter species producing more than 1 g $C/m^2/yr$. Species most productive during the summer months produced less than 1 g $C/m^2/yr$. Eighty-four percent of the macroalgal production occurred between December and April, with one third of the production occurring in March. The average net annual macroalgae production for North Inlet was calculated at 200 g C/m^2, which was equivalent to the amount of phytoplankton production for the same time period. Total annual production was estimated at 316 g $C/m^2/yr$ and respiration calculated to be 118 g$C/m^2/yr$. Annual production was greatest on the flood tidal delta at North Inlet (exceeding 1,000 g $C/m^2/yr$) and lowest (8.7 g $C/m^2/yr$) in the high marsh (Coutinho 1987).

Benthic Infauna

Winyah Bay

Benthic infauna were highly diverse in Winyah Bay (Hinde et al. 1981; Allen et al. 1982, 1984; Van Dolah et al. 1984). Sampling locations are given in Figure III-38. Van Dolah et al. (1984) found that the number of benthic infauna species collected from three sites offshore of the jetties at the entrance to Winyah Bay was considerably higher than that collected for similar sites in Savannah, GA, Charleston, SC, or Wilmington, NC. Samples yielded more than 19,000 individuals representing at least 357 species of invertebrates. Polychaetes represented 43% of the total number of species (Van Dolah et al. 1984). Amphipods (42 species), pelecypods (42 species), gastropods (36 species), and decapods (33 species) together with the polychaetes accounted for 85% of the total taxa. Based on numerical abundance, pelecypods dominated with 34% of the individuals collected. Polychaetes were the next most abundant with 25% of the individuals, followed by amphipods (10%) and bryozoa (9%). The relative abundance of major taxa at these sites adjacent to Winyah Bay differed from Charleston Harbor in which polychaetes (37%) were more abundant than pelecypods (7%), cephalochordates (20%), and sipunculids (5%) (Van Dolah et al. 1984).

Hinde et al. (1981) sampled 12 stations in Winyah Bay and found 16,281 infaunal individuals representing 154 taxa. Polychaetes represented 35% of the species. Amphipods (20 species), pelecypods (16 species), decapods (13 species), gastropods (7 species), isopods (7 species), and echinoderms (5 species) together with polychaetes accounted for 85% of the total taxa. Like the study by Van Dolah et al. (1984), pelecypods numerically dominated and also accounted for a much greater fraction (71%) of the total individuals sampled. Polychaetes were the next most abundant (8%), followed by amphipods (5%) and gastropods (1%). All remaining infauna accounted for less than 10% of the individuals.

Species diversity varied considerably throughout Winyah Bay with the highest diversity occurring at the two most seaward sand stations (proximate to the sites sampled by Van Dolah et al. 1984). The lowest diversity occurred at the southern entrance to Winyah Bay adjacent to South Island due to the dominance of one species. The mussel *Brachidontes exustus* was represented by up to 17,338 individuals/m^2 in this area. High current velocities, large salinity fluctuations, and poor substrate quality contributed to the low diversity in this area. Mid-bay stations had fairly high diversity due to even distribution of individuals among the euryhaline marine and estuarine endemic species (Hinde et al. 1981).

Fig. III-38. Benthic sampling stations in Winyah Bay. (1 - Van Dolah et al. 1984; 2 - Hinde et al. 1981; 3 - Coull 1985; 4 - Grant 1981; 5 - Ivester 1980; 6 - Findlay 1981; Coull 1985; 7 - Fleeger 1979, 1980).

No seasonal data were available for benthic infauna within Winyah Bay (Hinde et al. 1981). Van Dolah et al. (1984) found no overall significant seasonal or spatial variation in total abundance of infauna at the offshore sites. Within a given sampling area, diversity, number of species, and species richness were generally greatest during the summer. Differences among species and sites were observed in this pattern. As an example, of the three most abundant species only one exhibited significant seasonal differences. *Ensis directus*, the most abundant, was more abundant during the winter, probably due to spawning activity during this season. Densities of *Crassinella nartinicensis* and *Cupuladria doma* were not significantly different between seasons.

North Inlet

Published benthic studies were primarily focused on the meiofauna rather than the macrofauna component sampled in Winyah Bay. Detailed information was available on physiology of specific meiofauna (Vernberg and Coull 1975), reproductive periodicity (Coull and Vernberg 1975; Bell 1979; Fleeger 1979), life history patterns (Palmer 1980), feeding activities (Montagna 1984), secondary production (Fleeger and Palmer 1982), spatial heterogeneity (Bell et al. 1978; Coull et al. 1979), and the influence of physical factors (e.g., water current) on meiofauna distribution and resuspension (Grant 1981,1983; Palmer and Gust 1985; Palmer 1986,1988; Palmer and Molloy 1986).

Macrofaunal invertebrates sampled seasonally on an intertidal sandbar were dominated (70% of total number of individuals) by two species of haustoriid amphipods (*Acanthohaustorius millsi* and *Pseudohaustorius caroliniensis*) (Holland and Polgar 1976). Of the 56 species, ten species accounted for 95% of the total number of individuals. These species included deposit-feeding polychaete worms (*Spiophanes bombyx*, *Heteromastus filiformis*, *Haploscoloplos fragilis*, *Polydora* sp., *Nephtys picta*), omnivore amphipods (*Trichophoxus epistomus*, *Monoculodes edwardsi* , *Gammarus palustris*), gastropod (*Terebra dislocata*), and the suspension-feeding bivalve (*Tellina texana*). Seasonal changes were controlled by the population dynamics of these dominant species.

Meiofaunal community structure varied little with habitat within North Inlet (Coull and Fleeger 1977; Bell 1979; Eskin 1980; Fleeger 1980; Ivester 1980; Findley 1981). Meiofauna were dominated by nematodes, copepods, and polychaetes which composed greater than 90% of the fauna at most sites. Nematodes were the most dominant organisms, comprising greater than 70% of the abundance (Appendix III-1) (Bell 1979). Copepods were the second most abundant meiofaunal component. Of the two cyclopid and 19 harpaticoid species, eight comprise 97% of the fauna (Fleeger 1980). Distinct seasonal abundance peaks occurred from the late summer to late fall.

Epibenthic Fauna

Winyah Bay

The number of epibenthic species sampled by Hinde et al. (1981) in Winyah Bay was relatively low; only 83 epifaunal or partly epifaunal macroinvertebrate species were found for the 12 sites. Cnidarians and arthropods accounted for the largest number of species (21 each), followed by mollusks (15) and bryozoans (12). The species collected were not unique to Winyah Bay and were common to abundant in other estuaries in South Carolina. Although estuarine epifaunal invertebrates were strongly influenced by substrate and hydrography, several species were fairly ubiquitous in Winyah Bay. The bryozoan *Membranipora* *tenuis* was found at nine of the 12 stations; the polychaete *Sabellaria vulgaris* at eight; the hydroid *Plumularia floridana*, the bryozoan *Alcyonidium polyoum*, the polychaete *Hydroides dianthus*, and the barnacle *Balanus improvisus* at seven stations; and the hydroids *Clytia cylindrica* and *Obelia bidentata* and the bryozoan *Conopeum tenuissiumum* at six stations.

Areas with shells and rocks available for attachment were sites with the most diverse epifaunal communities. Lower bay stations with such substrate had the highest number of species sampled (31 to 32 species) compared with offshore stations with sandy substrate in which few epibenthic species were found. These sites were typically dominated by non-colonial echinoderms or non-colonial motile species such as decapods and mollusks. In the upper bay epibenthic communities were also poorly developed, with the low numbers attributable to the lack of suitable substrate and high salinity stress (Hinde et al. 1981).

Allen et al. (1982, 1984) used an epibenthic sled fitted with a 365-µm mesh net to collect small motile organisms larger than those collected with zooplankton nets (153 µm mesh) but too small to be retained by fish nets. Developmental stages of shrimps and fishes as well as small cructaceans important in the diets of fishes were sampled with the epibenthic sled. More than 200 species of epibenthic organisms were collected from 14 sites sampled in Winyah Bay. Organisms considered benthic (mollusks, polychaetes, bryozoans, other invertebrates) and soft-bodied invertebrates (chaetognaths, medusae, ctenophores) often dominated the collections but were not enumerated in this study. At most stations densities were generally 10 organisms/m^3 to 100 organisms/m^3. The Pee Dee River had the highest average density (31/m^3) primarily due to the occurrence of high densities of amphipods during the summer and fall. Lowest densities (5/m^3) occurred in the remaining river stations and upper bay where salinity fluctuations were the greatest. Middle bay stations (TA, MS, EP, MB) generally had the highest densities; lower bay stations (SB, LS) had intermediate densities (Fig. III-39).

Mysid shrimps (e.g., *Neomysis americana*, *Mysidopsis bigelowi*) were the dominant epibenthic organisms, averaging approximately 42% of the catch (Fig. III-40). Mysids dominated at all stations except Pennyroyle Creek, Pee Dee River, and Pumpkinseed Island. These stations were dominated by amphipods. Amphipods

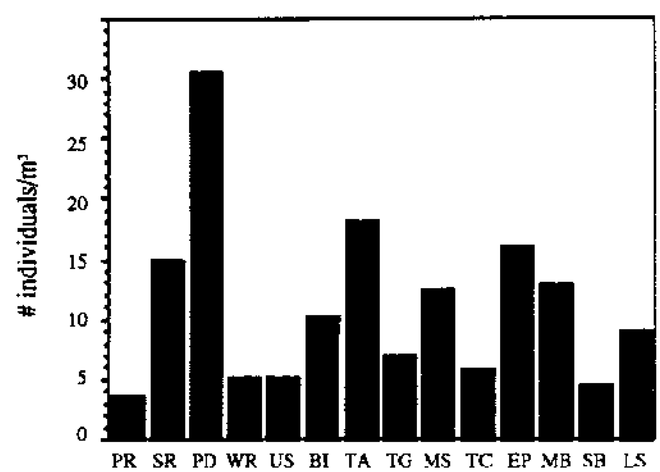


Fig. III-39. Spatial epibenthos data for Winyah Bay. Station means are mean number of total epibenthic organisms for Pee Dee River (PD), Sampit River (SR), Waccamaw River (WR), Pennyroyle River (PR), Upper Station (US), Belle Island (BI), Thousand Acre (TA), Pumpkinseed (PS), Middle Station (MS), The Cut (TC), Esterville Plantation (EP), Mud Bay (MB), Shell Bank (SB), and Lower Station (LS) (Allen et al. 1982, 1984).

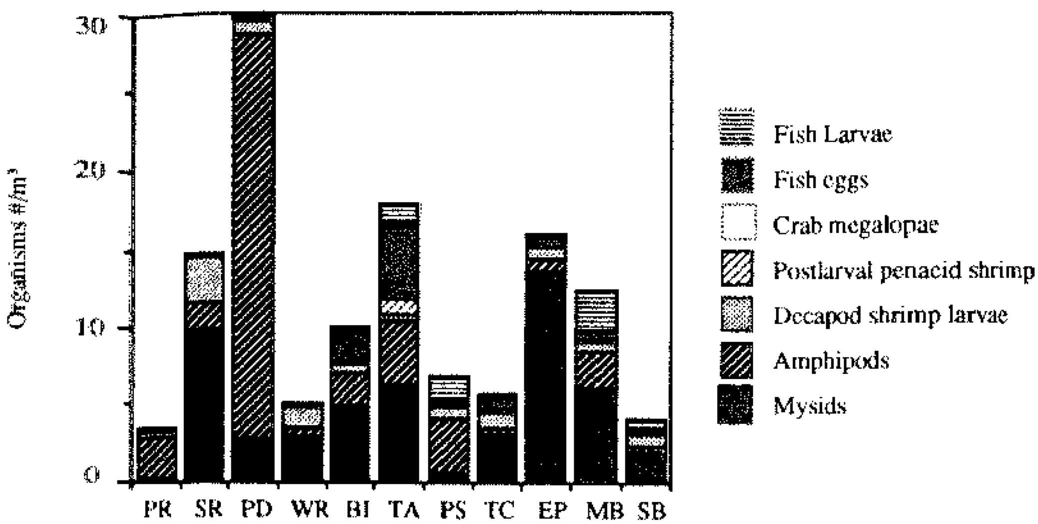


Fig. III-40. Spatial motile epibenthos data for Winyah Bay. Station means are mean number of motile epibenthic organisms per cubic meter for Pee Dee River (PD), Sampit River (SR), Waccamaw River (WR), Pennyroyle River (PR), Upper Station (US), Belle Island (BI), Thousand Acre (TA), Pumpkinseed (PS), Mid Station (MS), The Cut (TC), Esterville Plantation (EP), Mud Bay (MB), Shell Bank (SB), and Lower Station (LS) (Allen et al. 1982, 1984).

(36%) and shrimp larvae (10%) were the next most abundant, and together with the mysid shrimp account for 88% of the epibenthic organisms. Amphipods were comprised of species from the genera *Batea, Corophium, Erichthonius, Microprotopus, Unicola, Gammarus, Listeriella, Elasmopus, Melita, Stenothoe, Synchelidium, Caprella,* and *Paracaprella*. Densities of amphipods were greatest in the Pee Dee River (26/m³) with all other stations having densities less than 4/m³. Fifteen species of decapod shrimp larvae were collected including the penaeids, stomatopods, sergestids, sicyonids, palaemonids, and alpheids. Shrimp larvae averaged 1/m³, with higher densities in the upper bay and river stations. At least seven species of anomuran and 14 species of brachyuran crabs were collected. Anomuran crabs included *Euceramus, Porcellana, Emerita, Pagurus,* and *Hyponconcha*. Among the brachyurans were *Callinectes, Portunus, Ovalipes, Calappa, Libinia, Uca,* and *Cancer*. The lower bay station had the highest density of crabs at 1.3/m³. All other stations had densities of 0.3/m³ or less. Fish larvae and eggs representing over 50 species were identified by Allen et al. (1984). The densities of fish larvae were greater in the mud bay and lower bay area (1-2.5/m³). Densities at No Man's Friend and South Jones creeks were higher than most Winyah Bay stations. All other stations in Winyah Bay had much lower densities.

Relatively low densities of total organisms persisted through the winter with 5-10/m³ from September to March. Total epibenthic organisms reached their highest densities in May (19/m³) and September 1982 (25/m³) (Fig. III-41). The lower density observed in July was probably related to increased freshwater runoff and associated lower salinities further seaward. The lower salinities in July may have displaced the high salinity forms which dominate the summer community toward the ocean. The highest density (147/m³) of total organisms occurred at the Pee Dee River in September 1982. Most

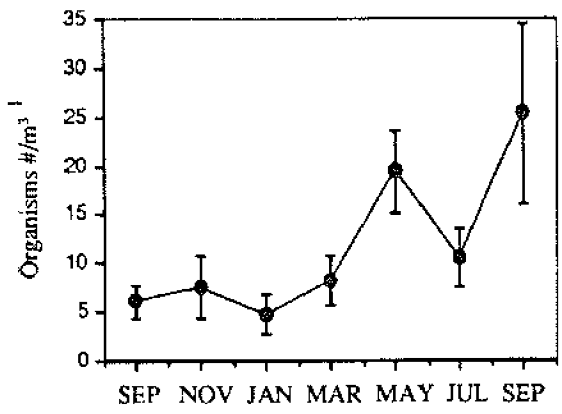


Fig. III-41. Winyah Bay epibenthos monthly means (average of organisms for all stations for each month) (Allen et al. 1982, 1984).

collections had 2-15 organisms/m³, but no motile epibenthic organisms were collected at Pennyroyle Creek in November or Waccamaw River in January.

Mysids comprised more than half of all organisms ranging from 15% in January to 80% in November (Fig. III-42). Highest mysid densities were observed in September 1982 (11/m³) and lowest (1/m³) in January. The highest density of mysids (51/m³) was collected at Esterville Plantation in January. No mysids were collected in the rivers during January or March when water temperatures and salinities were the lowest.

More than half of all organisms collected in January, July, and September 1982 were amphipods. Highest densities occurred in September (13/m³). The highest density of amphipods was obtained at the Pee Dee River in July (33/m³) and September 1982 (134/m³).

Decapod shrimp larvae densities increased during the summer months with May and July averaging 2.4/m³. The highest densities (15.5/m³) occurred in the Sampit River during July. Lowest densities occurred during

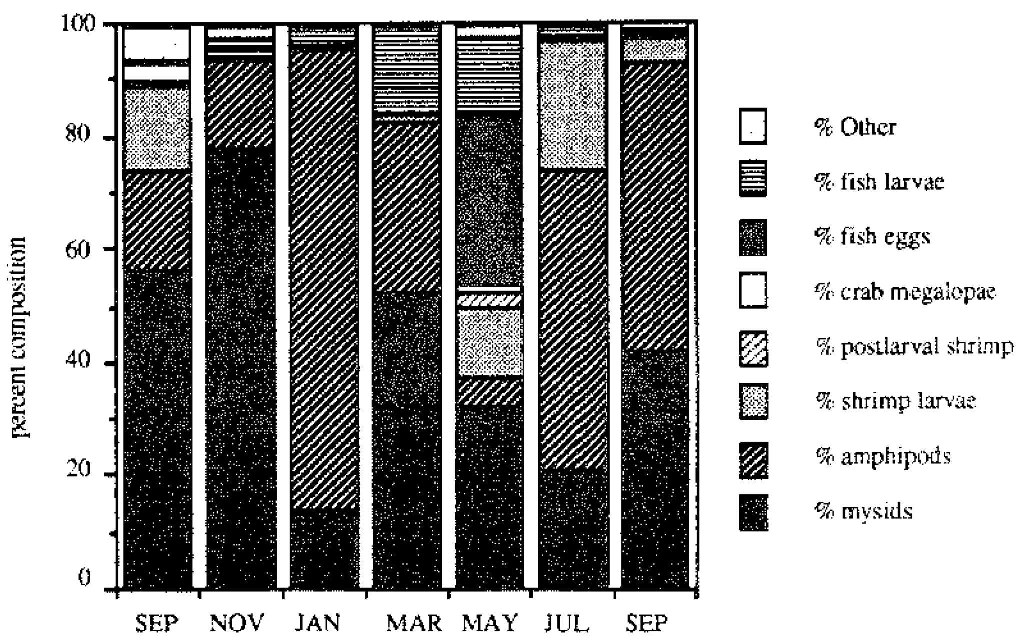


Fig. III-42. Temporal epibenthos community composition for Winyah Bay. Monthly mean percent composition, average of all stations (Allen et al. 1982, 1984).

winter months. No decapod shrimp larvae were collected at the river and upper bay stations in November and at most stations in January. Crab megalopae densities were lowest during the winter. Crab megalopae were not collected in January and only at one station (Mud Bay) during March. Highest overall monthly densities occurred in September ($0.2/m^3$) and the highest density was observed at Shellbank in May ($1.4/m^3$). Megalopae never accounted for more than 2% of the total catch for any sampling period.

Fish larvae were most abundant in May ($2.7/m^3$), lower densities occurred in March ($1.3/m^3$), and less than $0.2/m^3$ was observed during other months. The highest density was sampled in May at Mud Bay ($16/m^3$). River densities were usually less than $1/m^3$ and no larval fishes were collected in January. Highest numbers, in general, occurred in the middle bay in the spring (Allen et al. 1982, 1984).

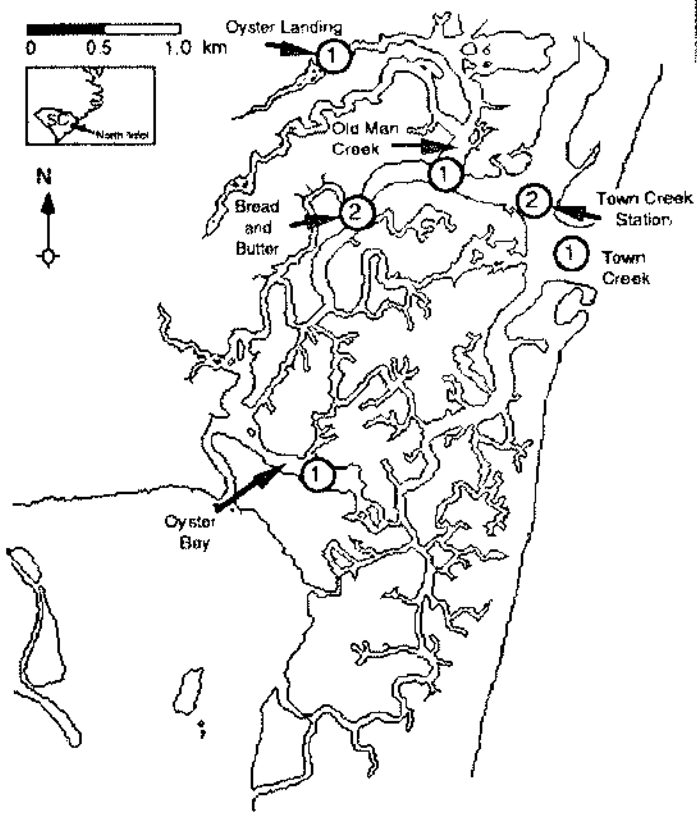


Fig. III-43. Zooplankton sampling stations in North Inlet Estuary. (1 - Lonsdale and Coull 1977; 2 - LTER unpublished data).

Planktonic Communities

North Inlet

Zooplankton have been sampled at four locations in North Inlet (Town Creek, Oyster Landing, Old Man Creek, and Oyster Bay) (Fig. III-43). Samples were collected biweekly from January 1974 to August 1975. Mean total zooplankton density was $9,257/m^3$ and the total standing crop was 16,178 µg dry wt/m^3. Differences in both total zooplankton numbers and biomass varied concurrently among stations. Lower density ($5,107/m^3$) and biomass (8,254 µg dry wt/m^3) was observed adjacent to Winyah Bay (Oyster Bay) and Oyster Landing (7,793 $/m^3$, 14,474 µg dry wt/m^3; respectively). Salinity was most variable at these stations (Oyster Bay: 5-36‰, Oyster Landing: 8-35 ‰). Higher biomass and densities were measured at Town Creek and Old Man Creek ($13,862/m^3$, 23,862 µg dry wt/m^3; $10,204/m^3$, 18,125 µg dry wt/m^3; respectively). Salinities were less variable at these stations (22-36 ‰ and 23-36 ‰, respectively).

Copepods, including larval stages were a dominant category, comprising 64-69% of total zooplankton numbers and biomass (Fig. III-44). The most common species were *Paracalanus crassirostris* (16% of total zooplankton numbers and 13% of the total biomass), *Acartia tonsa* (7% of the total zooplankton density and 20% of the total biomass), *Oithona colcarva* (6% of the density and biomass), and *Euterpina acutifrons* (1.8% of the total number and 2.8% of the total biomass). Less abundant cope-

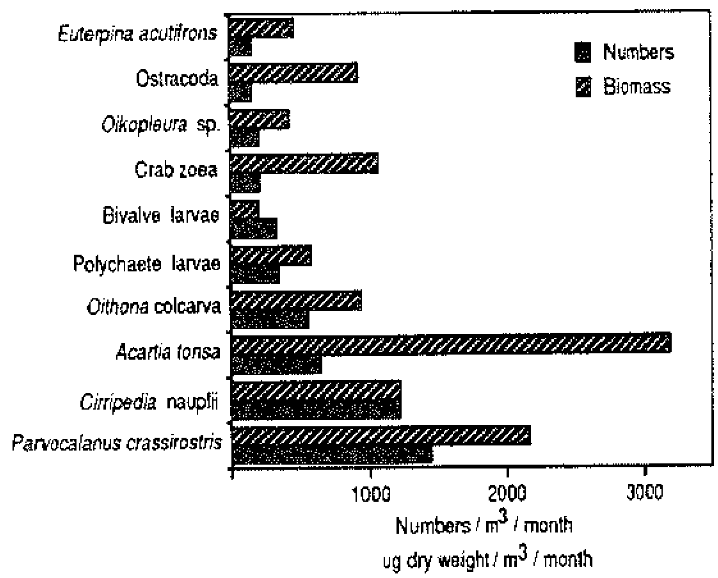


Fig. III-44. Zooplankton dominance in North Inlet Estuary based on density (numbers/m³/month) and biomass (µg dry weight/m³) (Lonsdale and Coull 1977).

pods, included *Saphirella* spp., *Oncaea vensuta*, and *Pseudodiaptomous coronatus*. Comparisons of major species of copepods and their reproductive periodicities suggested that North Inlet Estuary fauna were most closely allied with Florida waters. South Carolina may represent a transition zone between North-Temperate, Mid-Atlantic, and tropical waters of Florida and the Caribbean. The most common meroplankton were barnacle nauplii (*Cirripedia*), which comprised 13% of total zooplankton for the entire sampling period. Other important groups included bivalve (3%), gastropod (2%), and polychaete larvae (4%). Crab (2%) and shrimp zoea were distinctly seasonal in abundance.

Seasonal data for total zooplankton density are presented in Figure III-45. Major peaks in zooplankton density occurred in summer with maximum numbers of individuals and biomass (84,414 /m³ and 140,169 µg dry wt/m³) observed in July 1974 at the Town Creek station. The lowest density and biomass (377/m³ and 640 µg dry wt/m³) occurred in Oyster Bay in October 1974. Distinctly different seasonal patterns were observed for individual species in the North Inlet Estuary (Fig. III-46). *Acartia tonsa* was present throughout the year, with a mean density of 637/m³. *Acartia tonsa* was more abundant during the summer, reaching densities of 2,799/m³ (July 1974), with lower density during the winter months (minimum density 97/m³ in March 1975). *Paracalanus crassirostris* and *Oithona colcarva* exhibited little seasonal variation and were abundant throughout the year. Other taxa such as *Euterpina acutifrons*, bivalve larvae, gastropod larvae, barnacle nauplii, and shrimp zoea showed distinct seasonal variation similar to the pattern of crab zoea (Fig. III-46).

Winyah Bay

Only two studies have been conducted on zooplankton in Winyah Bay (Allen et al. 1982, 1984). Figure III-47 displays station locations for both extensive sampling (14 stations, sampled approximately bimonthly 1980-1982) and intensive sampling (three stations, surface and bottom, bimonthly 1981-1982). Upper bay stations (Waccamaw River, Pee Dee River, and Sampit River) were characterized by low and variable salinities (0.0-19.0‰) while lower stations (Mother Norton, Mud Bay and Esterville Plantation) were characterized by higher salinities (2.0 - 35.2 ‰) (Table III-11).

Zooplankton abundance in Winyah Bay averaged 10,831/m³ (Table III-11). Total zooplankton densities were generally lower in the riverine stations (Waccamaw

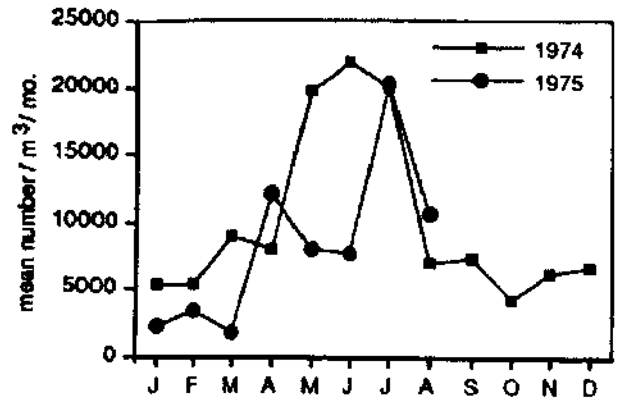


Fig. III-45. Mean number of zooplankton per cubic meter per month in North Inlet (Lonsdale and Coull 1977).

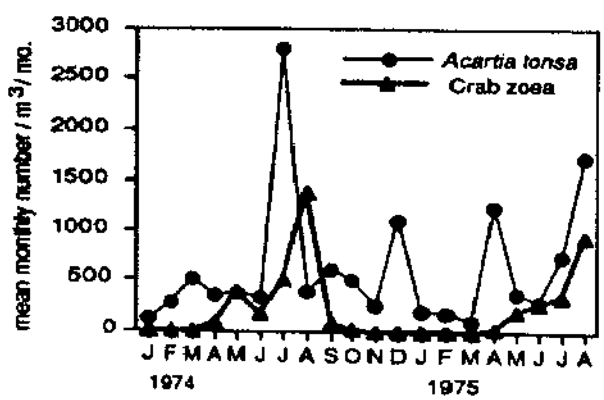


Fig. III-46. Mean monthly numbers of *Acartia tonsa* and crab zoeae in North Inlet (Lonsdale and Coull 1977).

River, Sampit River, Pennyroyle Creek, Pee Dee River), with annual means ranging from approximately 6,000/m^3 to 9,000/m^3. With the exception of the Esterville Plantation site, zooplankton densities in Winyah Bay were generally between 10,000/m^3 to 13,000/m^3. The most oceanic station, Mother Norton, had the highest average density of zooplankton. Each station was usually dominated by only a few taxonomic categories; as few as three categories comprised 70-90% of the total zooplankton organisms present at a given station. The lower stations (Mud Bay, Shell Bank) were more diverse than the upper stations (Waccamaw River, Sampit River, Pennyroyle Creek, Pee Dee River). The mid bay stations had intermediate diversities (Allen et al. 1982, 1984).

The zooplankton community in Winyah Bay was dominated by relatively few copepod and meroplanktonic species. Stations generally had similar dominant species during a given month. Copepods comprised at least 50% of the total zooplankton throughout the year. Total copepods ranged from 53% (Sampit River) to 95% (Pumpkinseed) of total zooplankton (Fig. III-48).

Five copepod species (*A. tonsa*, *P. crassirostris*, *P. coronatus*, *E. acutifrons*, and *O. colcarva*) were year-round residents and accounted for 86% of the copepod catch (Fig. III-49). Other less abundant copepods included *Centropages hamatus*, *Centropages typicus*, *Centropages furcatus*, *Labidocera aestiva*, *Temora turbinata*, and *Eucalanus* spp. *Acartia tonsa* dominated the Winyah Bay system, accounting for 60% of all zooplankton collected and 73% of all copepod species. Mean densities ranged from 1500/m^3 at Shell Bank to 11,000/m^3 at Thousand Acre. Average relative abundance of *A. tonsa* was greatest at the mid bay stations (60% to 90% of all zooplankton species) and lowest at the seaward stations (15-20%). *Eurytemora affinis* comprised 5.5% of total zooplankton species (10% of copepod species) and was most abundant in the riverine stations (e.g., 43% of total copepods in Waccamaw

Fig. III-47. Map of sampling locations for zooplankton in Winyah Bay (Allen et al. 1982. 1984).

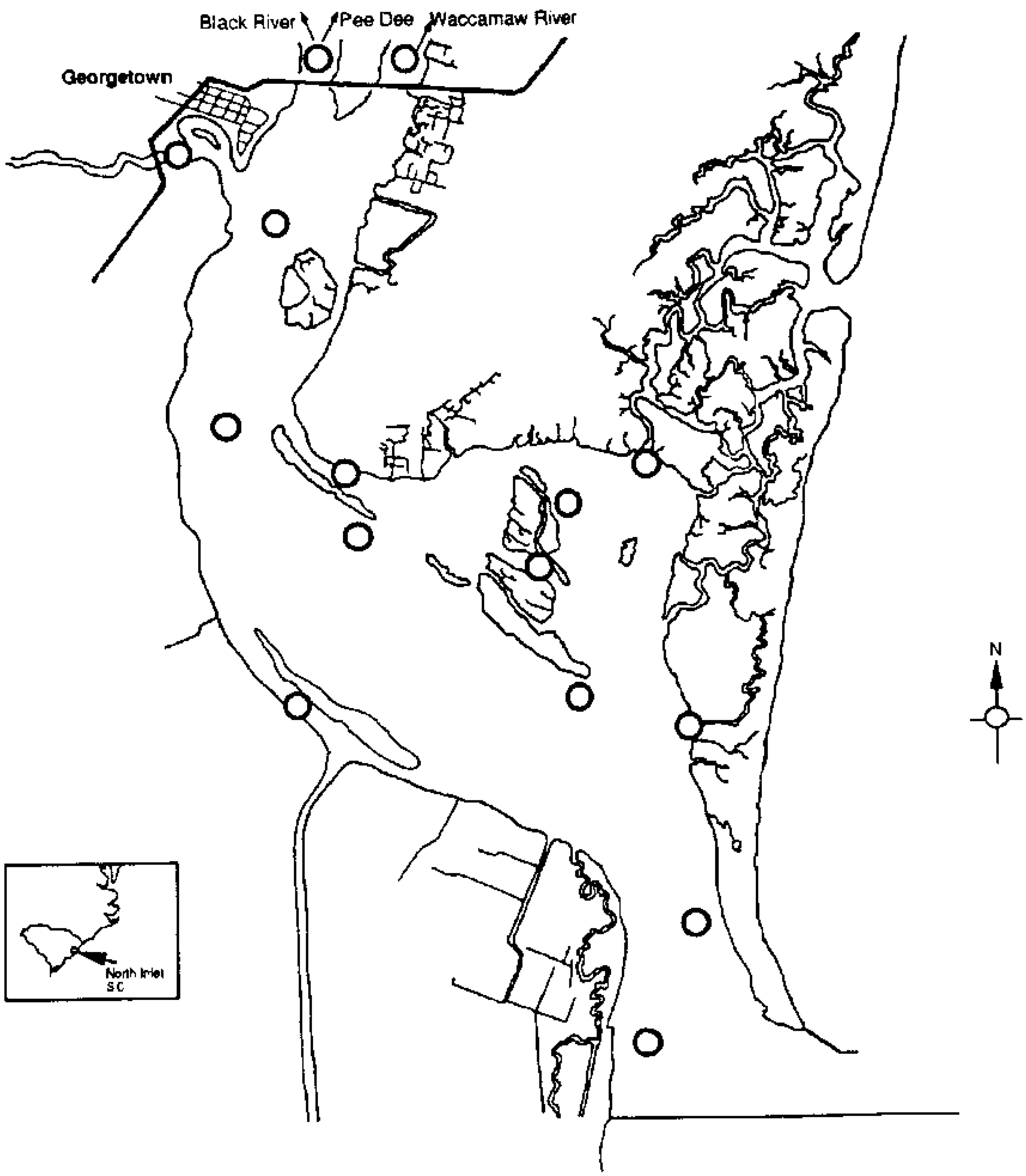


Table III-11. Total average zooplankton abundance (averaging all sampling dates) and salinity (‰) for each station in Winyah Bay (Allen et al. 1982, 1984).

Station	Organisms #/ m^3	Mean	Salinity range
Pennyroyle Creek (PR)	6,036	5.4	0-12
Sampit River (SR)	9,458	7.6	0-19
Pee Dee River (PD)	8,540	5.5	0-14
Waccamaw River (WR)	6,700	3.4	0-12
Upper Station (US)	12,740	6.9	0-17
Belle Isle (BI)	11,287	11.5	0-22
Thousand Acre (TA)	11,852	10.5	0-18
Pumpkinseed (PS)	10,316	13.0	0-24
Mid Station (MS)	10,866	18.8	3-32
The Cut (TC)	12,739	15.1	0-28
Esterville Plantation (EP)	7,687	15.6	2-27
Mud Bay (MB)	12,267	18.2	2-27
Shell Bank (SB)	10,754	25.2	4-33
Mother Norton (MN)	20,398	31.8	22-35

River). *Paracalanus crassirostris* was the third most abundant copepod species (5% of total zooplankton, 6.5% of total copepods), predominating in the seaward stations (43% of copepod species) and rare in the riverine stations. *Pseudodiaptomus coronatus* was generally found in the lower stations where it comprised 3% to 6% of the total copepod species (2% of total zooplankton species). *Oithona colcarva* peak abundances also occurred in the lower stations, reaching 1,000-1,300/m^3, and appeared only sporadically at the riverine stations.

Larval stages of barnacles were the most abundant meroplankton category (Fig. III-50). Barnacle nauplii were found at all stations and ranged from 2% to 32% of the mean zooplankton densities. Nauplii density ranged from 180/m^3 at Waccamaw River to 3,054/m^3 in the Sampit River. With the exception of the Sampit River, nauplii densities were, in general, greatest in the lower bay (1,971/m^3), average at riverine stations (1,132/m^3), and lowest at the mid bay stations (897/m^3). Barnacle cyprids were less abundant than nauplii (221/m^3 vs. 1,276/m^3 overall mean density), with similar mean densities in the upper (193/m^3), lower (231/m^3), and mid bay (250/m^3). Crab zoeae were common at all stations with mean densities ranging from 21/m^3 at Esterville Plantation to 728/m^3 at The Cut. No obvious spatial patterns were apparent. Polychaete larvae were present at all stations with higher densities at the lower stations (212/m^3). The upper and mid bay stations had similar mean densities (138/m^3 and 124/m^3, respectively). Bivalve larvae were rare at the riverine and mid bay stations. Lower bay bivalve larvae densities averaged 53/m^3. Similar spatial patterns were observed during the intensive studies. Lower bay station average bivalve larvae density was 350/m^3.

Similar temporal patterns in abundance were observed during both the intensive and extensive studies. Zooplankton were most abundant during the warmer months (Fig. III-51), with densities reaching 26,000/m^3 in May. Densities were an order of magnitude lower in the winter.

The seasonal variation was due to peak abundances of *Acartia tonsa*, *Parvocalanus crassirostris*, and meroplankton at most stations (Fig. III-52). *Acartia tonsa*, while present throughout the year, dominated during the late spring to early fall. *Eurytemora affinis* and *Halicyclops* spp. dominated the seasonal abundance in the Waccamaw River, and *Euterpina acutifrons* and chaetognaths dominated at Shell Bank. *Eurytemora affinis* was most abundant from January to July with maximum abundances in March (60% of total zooplankton abundance). Meroplankton densities had distinct seasonal peaks but when present were often one of the three most

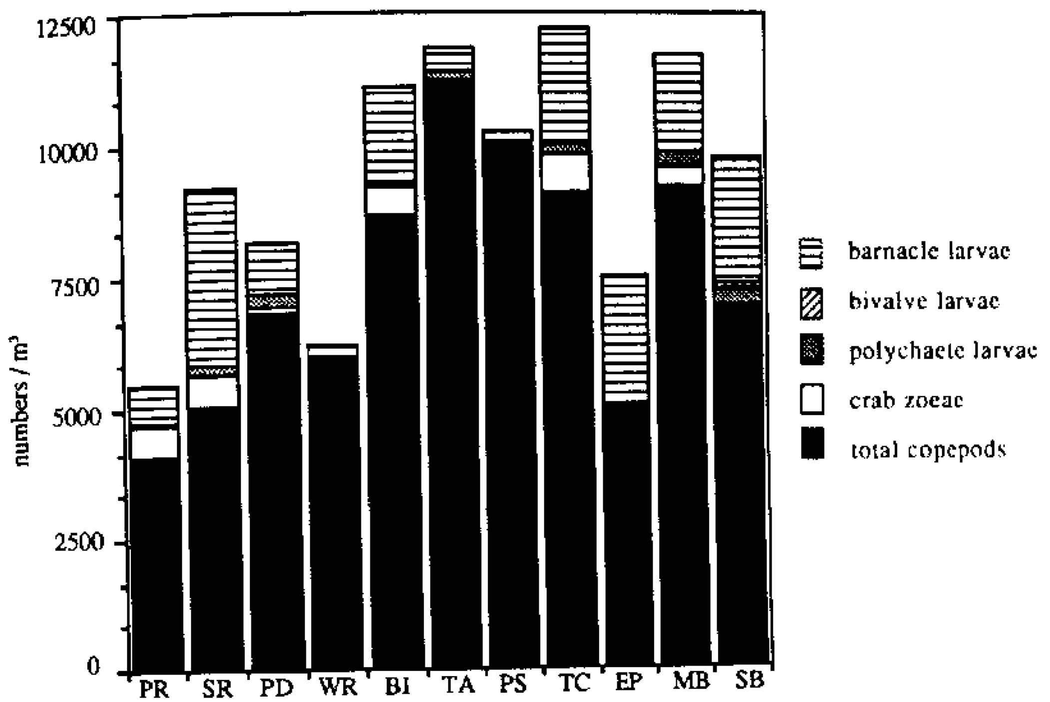


Fig. III-48. Zooplankton community at selected stations in Winyah Bay. Category total organisms (numbers /m³) is the mean abundance of all sampling dates (Allen et al. 1982, 1984).

abundant categories. The seasonal peaks were often spatially restricted. As an example, barnacle larvae were low during the winter months (January to March) and only occurred at the seaward (lower bay) stations. Peak abundance (19,000/m³) occurred in the fall at most extensive stations. Densities were highest from December to April in No Man's Friend and South Jones creeks (North Inlet Estuary - Winyah Bay interface), and between April and August in North Inlet (Lonsdale and Coull 1977; Allen et al. 1982).

Nektonic Communities

North Inlet

North Inlet Estuary has a diverse fish fauna with over 100 species identified (Appendix III-3). Fish populations have been sampled in a number of habitats in North Inlet Estuary from 1969 to 1984 (Cain and Dean 1976; Shenker and Dean 1979; Bozeman and Dean 1980; Ogburn et al. 1988). Figure III-53 shows study locations and duration. Total species collected ranged from 16 (Shenker and Dean 1979) in a short-term study to 96 in a multiyear survey (Ogburn et al. 1988). Fewer than ten species usually dominated the catch, with greater than 90% of total numbers or biomass. Differences in abundance of common species were a function of gear selectivity, period of study, and habitat (Ogburn et al. 1988). Overall dominant species included: *Anchoa mitchilli* (bay anchovy), *Menidia menidia* (Atlantic silverside), *Brevoortia tyrannus* (Atlantic menhaden), *Fundulus majalis* (striped killifish), *Leiostomus xanthurus* (spot), *Fundulus heteroclitus* (striped killifish), *Alosa aestivalis* (blueback herring), *Anchoa hepsetus* (striped anchovy), *Dorosoma petenense* (threadfin shad), *Mugil cephalus* (striped mullet), and *Mugil curema* (white mullet) (Table

Table II-12. Fish abundance (numbers or % catch) in North Inlet. 1 - Ogburn et al. 1988, seine and trawl survey, subtidal habitat; 2 - Cain and Dean 1976, medium mesh blocknet, intertidal; 3 - Shenker and Dean 1979 , fine mesh blocknet, intertidal; 4 - Moore and Reis 1983, medium mesh framenet, intertidal.

Species	Study	Common Name	Numbers	% Catch
Anchoa mitchilli	1	bay anchovy	23,639	36.0
Leiostomus xanthurus		spot	12,382	18.8
Menidia menidia		Atlantic silverside	11,632	17.7
Mugil curema		white mullet	2,483	3.8
Anchoa hepsetus		striped anchovy	1765	2.7
Fundulus majalis		striped killifish	1322	2.0
Mugil cephalus		striped mullet	692	1.1
Brevoortia tyrannus		Atlantic menhaden	400	0.6
Synodus foetens		inshore lizardfish	324	0.5
Etropus crossotus		fringed flounder	300	0.5
Total fish			65,778	
Fundulus heteroclitus	2	striped killifish	4,933	29.7
Leiostomus xanthurus		spot	3,239	19.5
Menidia menidia		Atlantic silverside	3206	19.3
Mugil curema		white mullet	914	5.5
Anchoa mitchilli		bay anchovy	797	4.8
Bairdiella chrysura		silver perch	681	4.1
Mugil cephalus		striped mullet	615	3.1
Eucinostomus argenteus		spotfin mojarra	581	3.5
Anchoa hepsetus		striped anchovy	349	2.1
Fundulus majalis		striped killifish	349	2.1
Total fish			16,611	
Menidia menidia	3	Atlantic silverside	2215	60
Anchoa mitchilli		bay anchovy	1,011	27.4
Alosa aestivalis		blueback herring	199	5.4
Dorosoma petenense		threadfin shad	80	2.2
Fundulus majalis		striped killifish	55	1.5
Gobionellus shufeldti		freshwater goby	54	1.5
Brevoortia tyrannus		Atlantic menhaden	20	0.5
Fundulus heteroclitus		mummichog	19	0.5
Givionellus boleosoma		Atlantic menhaden	10	0.3
Gobiosoma bosci		naked goby	9	0.3
Total Adult Fish			3,679	
Anchoa mitchilli	4	bay anchovy	1418	56
Brevoortia tyrannus		Atlantic menhaden	8,643	4.1
Leiostomus xanthurus		spot	117	4.4
Menidia menidia		Atlantic silverside	68	2.7
Bairdiella chrysura		silver perch	22	0.8
Lagodon rhomboides		pinfish	14	0.6
Anchoa hepsetus		striped anchovy	2	0.1
Micropogonias undulatus		Atlantic croaker	26	0.8
Total Fish			2531	

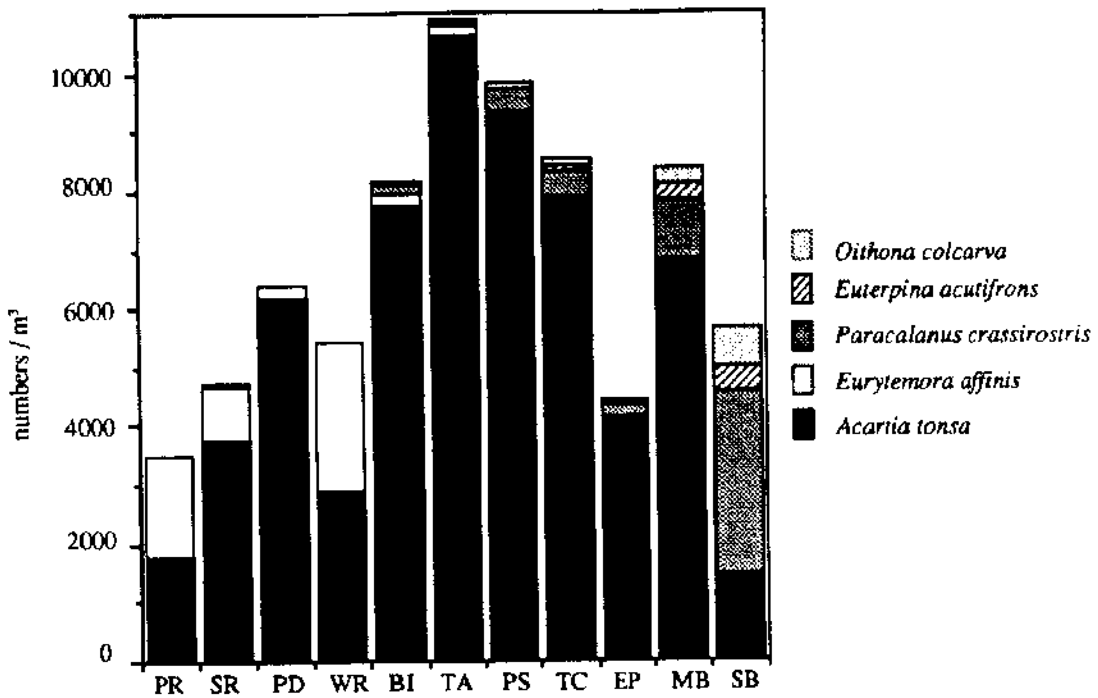


Fig. III-49. Abundance of copepods species at selected stations in Winyah Bay (Allen et al. 1982, 1984).

III-12). Total numbers of individuals collected during a study varied, usually as a function of sampling duration.

Ogburn et al. (1988) found more than 95% of species sampled were represented by larval and juvenile life stages, with 29% of the species reproducing in the estuary. Shenker and Dean (1979) found that 78% of the total individuals (91% of biomass) collected in Bozuz Creek were immature. Six fish species (spot, mullet, *Myrophis punctatus* [speckled worm eel], *Lagodon rhomboides* [pinfish], *Paralichthys* spp. [flounders], and *Micropogonias undulatus* [Atlantic croaker]) comprised 99.3% of the larval fish captured. Differences between studies were a function of sampling duration.

Spatial differences in catch composition were distinct. Ogburn et al. (1988) found the highest numbers of *Symphurus plagiusa* (blackcheek tonguefish), *Trinectes maculatus* (hogchoaker), spot, Atlantic croaker, and mullets in Clambank Creek. Both cryptic (e.g.,*Gobiosoma* spp. [gobies], *Hypleurochilus geminatus*, and *Hypsoblennius hentzi* [blennie]), *Ophidion marginatum* [eels], *Opsanus tau* [toadfish]), and demersal (e.g., flounders, spot, Atlantic croaker) fishes were more common in Clambank Creek while Atlantic silversides and striped anchovies were most common at North Inlet. Eight species accounted for greater than 90% of the catch in Clambank Creek canal (Cain and Dean 1976) which was similar to species composition found by Ogburn et al. (1988). Both studies found that spot, Atlantic silverside, white mullet, and bay anchovy were important contributors to the overall catch. Mummichog, striped mullet, silver perch, and spotfin mojorra in Cain and Dean's study

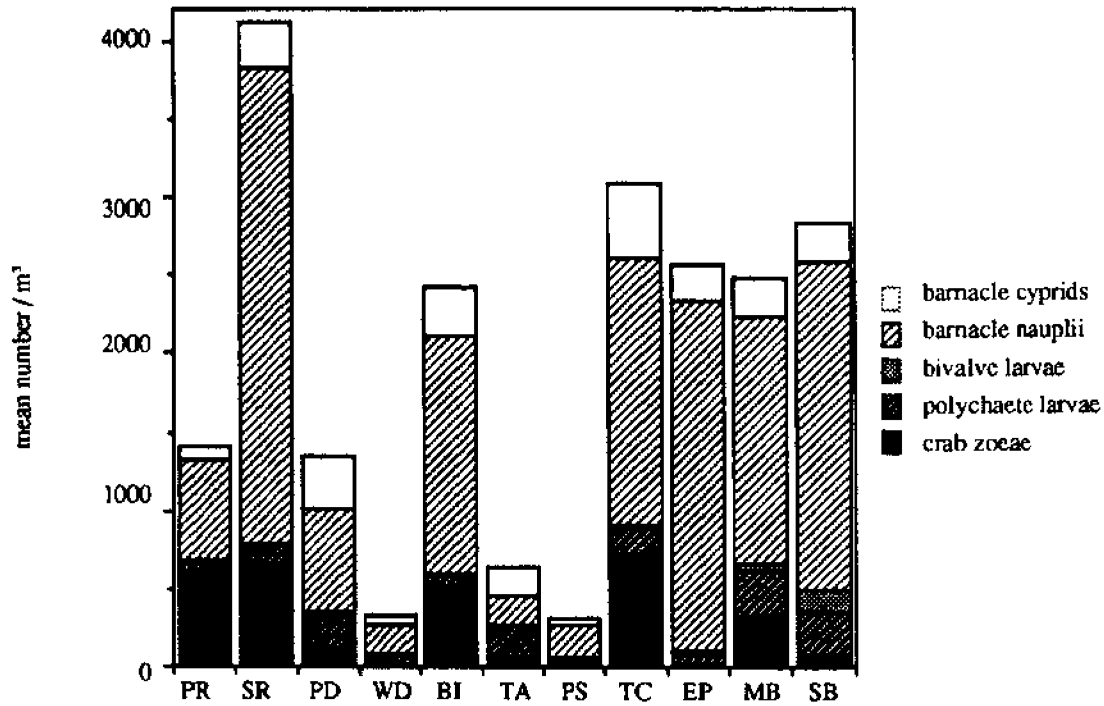


Fig. III-50. Mean station meroplankton density (number/m^3) for selected groups of organisms in Winyah Bay (Allen et al. 1982, 1984).

(1976) reflected the intertidal-marsh habitat. Similar species dominance were found in Bozuz Creek and Clambank Creek. Eight of the top ten species collected by Cain and Dean (1976) were observed in the two studies conducted in Bozuz Creek (Shenker and Dean 1979; Bozeman and Dean 1980).

Species richness or diversity indices correlated with the temperature cycle and both species richness and diversity were higher during the summer months and lower during the winter months (Freeman 1970; Cain and Dean 1976; Ogburn et al. 1988). The influx of warm-water species (e.g., spot, white mullet, silver perch, and anchovies) and emigration with decreasing temperature were distinctive features of the annual cycle (Cain and Dean 1976; Ogburn et al. 1988). Seasonal patterns in numbers of individuals caught were not distinct (Cain and Dean 1976; Ogburn et al. 1988) (Fig. III-54). Lack of correlation between numbers of individuals and temperature resulted from the clumped distribution of schooling fishes, such as spot, mummichogs, and Atlantic silverside, and seasonal variability in catch efficiency.

Blue crabs were a significant component of the overall nekton sampled at Skimmer Shoals and Town Creek, rankings sixth in overall abundance. Crab abundance was highly variable with the lowest numbers generally occurring during the winter and highest during the summer. Higher numbers of individuals were collected at the Skimmer Shoals site, which was attributed to the preference of blue crabs for muddy substrate. The remaining shrimps and crabs accounted for less than 1% of the overall catch (Table III-13).

Table III-13. Shrimps and crabs sampled from Town Creek in North Inlet Estuary (1 - Moore and Reis 1983 using frame net, passive trawl; 2 - Ogburn et al. 1988 using seine and trawl).

Species	Common Name	Number	Weight (g)
Callinectes sapidus[1]	blue crab	230	3914
Penaeus setiferus	white shrimp	130	443
Portunus gibbesi	portunus crab	123	342
Penaeus duorarum	pink shrimp	77	191
Palaemonetes pugio	grass shrimp	49	11
Palaemonetes vulgaris	grass shrimp	28	5
Portunus spinimanus	portunus crab	18	218

Species	Common Name	Number	% of Catch
Callinectes spp.[2]	blue crab	2,482	3.8
Portunus gibbesii	portunus crab	463	0.7
Ovalipes ocellatus	lady crab	409	0.6
Penaeus aztecus	brown shrimp	295	0.4
Penaeus duorarum	pink shrimp	205	0.3
Penaeus setiferus	white shrimp	114	0.2

Both brown and white shrimp arrived as postlarvae during the spring (brown) and early summer (white) and migrated to the ocean from September to December. Late spawned shrimp overwintered in the estuary but the majority migrated to deeper coastal areas. Pink shrimp were the least common penaeids in North Inlet Estuary, but occurred year-round as juveniles and adults. Pink shrimp were most abundant in the spring while brown and white shrimp were most abundant during the summer months (Ogburn et al. 1988).

Winyah Bay

Fish fauna in Winyah Bay Estuary were diverse with up to 75 species collected. Relatively few species (< 10) generally dominated more than 95% of the catch (Shealy et al. 1974; Hinde et al. 1981;Wenner et al. 1981; Allen et al. 1982). Only one study has assessed the spatial distribution of fishes in Winyah Bay (Wenner et al. 1981). Fish species were collected at nine stations in the bay (Fig. III-55). Seven species comprised over 90% of the catch in this study

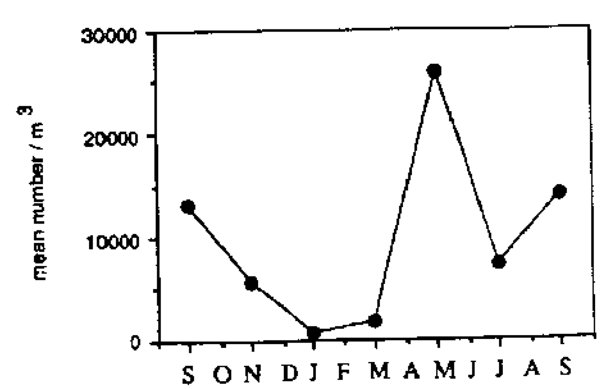


Fig. III-51. Mean monthly total zooplankters for Winyah Bay. Mean was average of all stations (Allen et al. 1982, 1984).

Table III-14. Numbers and biomass (kg) of dominant fish species for Winyah Bay Estuary, SC (1 - Shealy et al. 1974; 2 - Wenner et al. 1981; 3 - Hinde et al. 1981; 4 - Allen et al. 1982; NA - not available).

Species	Common Name	Number	Wt (kg)	Study
Anchoa mitchilli	anchovy	5,337	NA	1
Leiostomus xanthurus	spot	4,244	NA	
Micropogonias undulatus	Atlantic croaker	1,444	NA	
Bairdiella chrysura	silver perch	377	NA	
Brevoortia tyrannus	Atlantic menhaden	309	NA	
Cynoscion regalis	weakfish	206	NA	
Symphurus plagiusa	blackcheek tonguefish	168	NA	
Trinectes maculatus	hogchoaker	124	NA	
Stellifer lanceolatus	star drum	11,356	37.40	2
Micropogonias undulatus	Atlantic croaker	9,706	0.99	
Trinectes maculatus	hogchoaker	7,532	40.25	
Ictalurus catus	white catfish	3,133	69.16	
Cynoscion regalis	weakfish	1,905	8.83	
Brevoortia tyrannus	Atlantic menhaden	1,334	19.47	
Leiostomus xanthurus	spot	722	12.58	
Urophycis regia		517	5.73	
Symphurus plagiusa	blackcheek tonguefish	421	4.48	
Anchoa mitchilli	anchovy	400	0.87	
Stellifer lanceolatus	star drum	1,696	11.0	3
Symphurus plagiusa	blackcheek tonguefish	345	7.88	
Opsaus tau	oyster toadfish	171	51.13	
Menticerrhus americanus	southern kingfish	84	1.95	
Leiostomus xanthurus	spot	74	13.04	
Micropogonias undulatus	Atlantic croaker	67	3.12	
Trinectes maculatus	hogchoaker	58	0.98	
Dasyatis sabina	Atlantic stingray	41	30.15	
Paralichthys lethostigma	southern flounder	35	3.69	
Bairdiella chrysura	silver perch	34	1.25	
Cynoscion regalis	weakfish	96	NA	4
Leiostomus xanthurus	spot	72	NA	
Anchoa mitchilli	anchovy	18	NA	
Stellifer lanceolatus	star drum	15	NA	
Ictalurus catus	white catfish	15	NA	
Bairdiella chrysura	silver perch	3	NA	

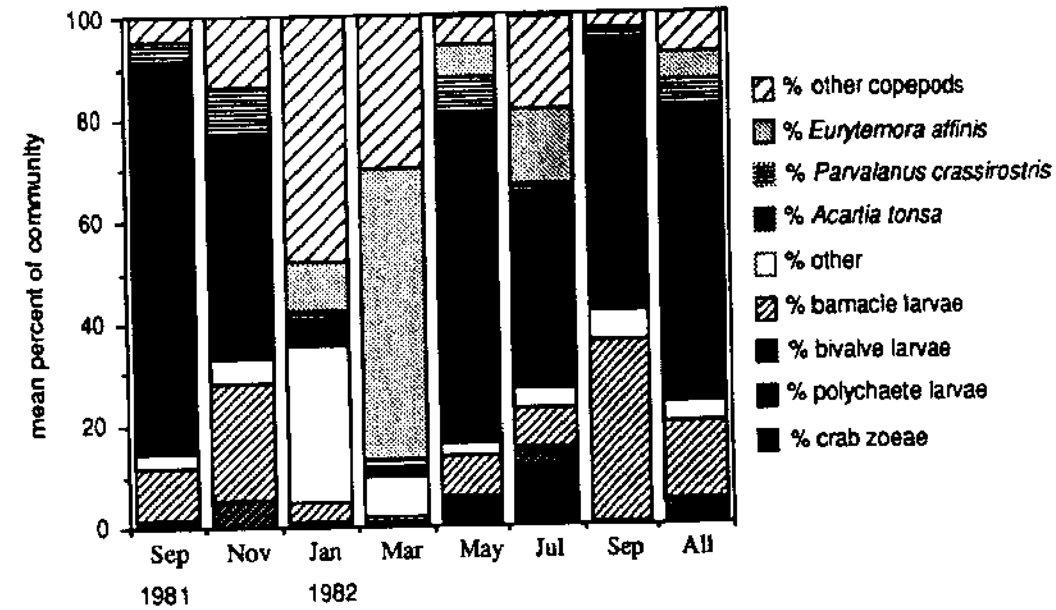


Fig. III-52. Seasonal community composition for selected categories of zooplankton for Winyah Bay. Average percent composition represents an average of all stations (Allen et al. 1982, 1984).

(Table III-14). The star drum (*Stellifer lanceolatus*) was the most abundant species (29% of catch) and the white catfish (*Ictalurus catus*) contributed the most to total biomass (16% of catch).

In general, stations with the highest and most variable salinities had the highest number of individuals and species, while stations in the Black, Pee Dee, and Waccamaw rivers (with the lowest and most stable salinities) had the lowest numbers of species and individuals. The number of species was greatest in the lower bay channel, Waccamaw River, and mid bay in the western channel. The Sampit River supported a richer fauna than other rivers draining into Winyah Bay possibly due to its higher salinities. The lower bay stations included many stenohaline and euryhaline species such as Atlantic croaker, hogchoaker, and the weakfish. Although these species occurred throughout the bay, they were most numerous at the lower bay stations. Lowest numbers of species occurred in the upper bay channel for both years sampled. Species found in the upper reaches of Winyah Bay included predominantly freshwater (e.g., white catfish [*Ictalurus punctatus*]), transient, catadromous and anadromous species.

Species richness and abundance were lower during the winter and highest during the fall. Numbers of fish species positively correlated with bottom temperature and salinity and negatively correlated with oxygen and depth. Numbers of individual fish were positively correlated with bottom temperature and salinity and negatively correlated with oxygen.

Most of the numerically dominant species were seasonal inhabitants with restricted distribution. Biomass and population densities were highest at stations in the lower bay channel and mid bay near Pumpkinseed Island during the fall and mid bay western channel during the summer. The star drum and catfish (*Ictalurus*

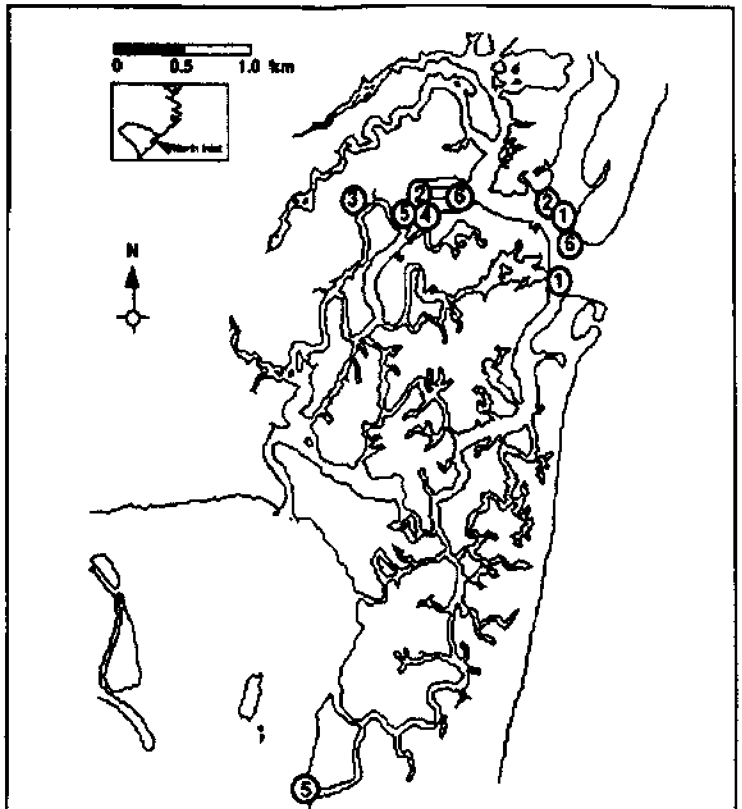


Fig. III-53. Fish sampling sites in North Inlet Estuary. (1 - Moore and Reis 1983; 2 - Ogburn et al. 1988; 3 - Cain and Dean 1976; 4 - Shenker and Dean 1979; 5 - Bozeman and Dean 1980; 6 - Beckman and Dean 1984).

maculatus) were most numerous from September to January. Atlantic croaker, star drum, and weakfish were most abundant in the summer. The fall peak in diversity was followed by a sharp decrease in the winter due to the emigration of several stenohaline and euryhaline transient species (e.g., *Chaetodipterus faber, Prionotur tribulus, Dasyatis sabina*, etc.). The total catches of fishes, density, and biomass were lower during the winter period. Winter catches were dominated by Atlantic menhaden (*Brevoortia tyrannus*) and Atlantic croaker or white catfish (1978). In the spring, numbers of individuals and species increased, but stenohaline marine species were not very abundant and were patchy in their distribution. Catches were dominated by Atlantic croaker and hogchoaker. With the influx of transient euryhaline species (such as Atlantic croaker and weakfish) during the spring to late summer, the diversity and abundance increased, peaking during the fall months.

Hinde et al. (1981) conducted a limited study of fishes (October 1980) for three locations in Winyah Bay (Fig. III-55). Although the species composition was diverse, approximately ten species accounted for 95% of the catch in both number and weight. Catch from trawl tows ranged from five (South Island) to 20 species of fish with the highest species numbers occurring at the most oceanic station. Thirty-six trawl tows resulted in 41 species of fish in 22 families. The five most abundant families (Sciaenidae, Cynoglossidae, Batrachoididae, Bothidae, and Soleidae) accounted for 95% of the total fish numbers, with nine species of the Sciaenidae contributing 71.2% of this total fish catch. The dominant ten species (Table III-14) account for 93% of the catch. Star drum was the most numerically abundant species (61%) and fourth most abundant by weight. Oyster toadfish was the most abundant by weight (38% of total catch) and fourth most abundant by numbers.

Allen et al. (1982) used several gear types (otter trawl, epibenthic sled, and gill nets) to sample fish fauna at South Jones Creek and No Man's Friend Creek (Fig. III-55). Eighty-five species of fish were identified, most of which were juveniles (Appendix III-1). The eight most abundant species comprised 92% of the total catch by numbers and 81% by weight (Table III-14). With the exception

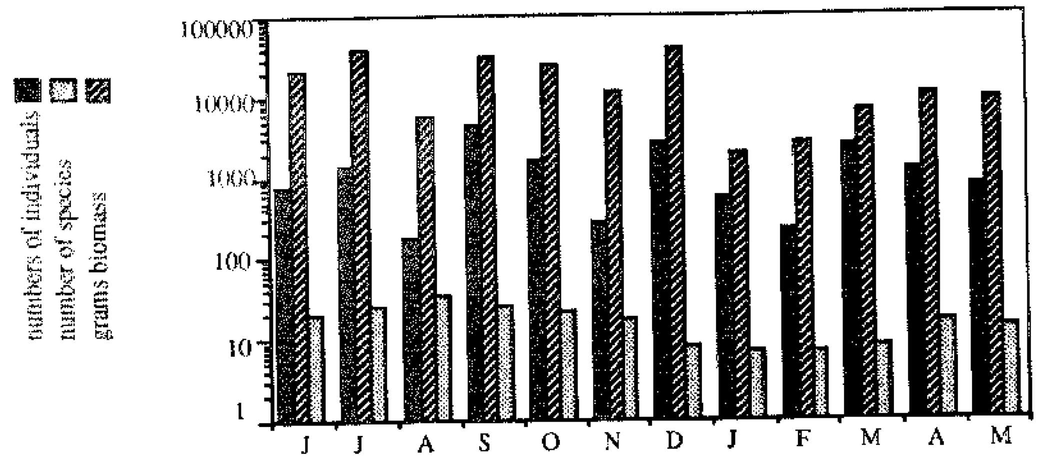


Fig. III-54. Numbers (individuals), biomass (g), and numbers of species of juvenile fish from Clambank Creek Canal (Caine and Dean 1976).

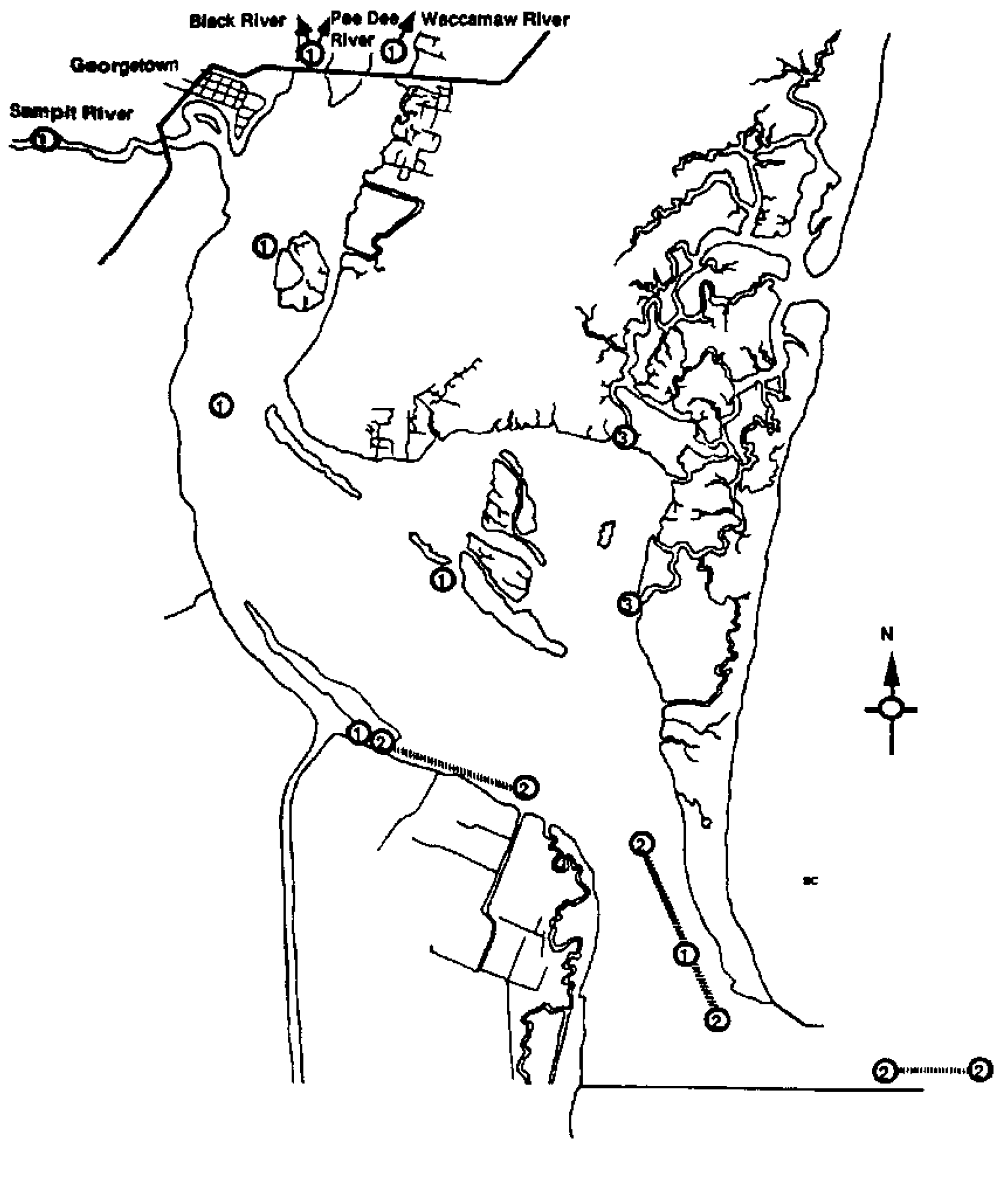
of the star drum and black sea bass most of the high salinity species found during the Wenner et al. (1981) study in Winyah Bay were similar to those found in South Jones and No Man's Friend creeks (Allen et al. 1982). Young Atlantic and shortnose sturgeons (*Acipenser* spp.) regularly caught in Winyah Bay were not caught during the Allen et al. (1982) study. Greatest numbers and biomass were obtained in the late summer and declined to an annual low in January, a pattern similar to that observed by Wenner et al. (1981). Total weights and numbers of fishes were greatest at South Jones Creek. Greater habitat variability and closer proximity to the ocean contributed to the greater abundance in South Jones Creek.

Although decapod crustaceans were not as abundant (by weight or numbers) as fishes, significant populations exist in Winyah Bay. Penaeid shrimp (*Penaeus setiferus*, *P. duorarum*, *P. aztecus*, and *Trachypenaeus constrictus*) were numerically dominant, comprising 50% to 53% of the decapod catch; *Penaeus setiferus* alone comprised ~ 42% (Hinde et al. 1981; Wenner et al. 1981; respectively). Portunidae was the most diverse family (eight species) and ranked second by numbers and first by weight. Portunidae comprised 85% of the decapod biomass with blue crabs contributing approximately 74% of the total decapod catch biomass (Hinde et al. 1981; Wenner et al. 1981).

Blue crabs were found throughout the Winyah Bay system during the entire year with catches greatest from September to December (Wenner et al. 1981). Highest numbers occurred along the western channel of the mid bay and in the Sampit River (Hinde et al. 1981; Wenner et al. 1981). Size frequency analysis showed a broad range (25-186 mm). Individuals with carapace width greater than 90 mm predominated; however, individuals with less than 40 mm were prevalent in the summer and fall (Hinde et al. 1981; Wenner et al. 1981).

Penaeid shrimps were limited seasonally but not spatially in Winyah Bay (Wenner et al. 1981). Shrimps were collected at all Winyah Bay stations (Fig. III-55). Dominance among the white, brown, and pink shrimps varied annually. White shrimp, normally considered the

Fig. III-55. Fish sampling stations in Winyah Bay Estuary (1 - Wenner et al. Jan. 1977 - Dec. 1978, 2 - Hinde et al. Oct. 1980, 3 - Allen et al. Aug. 1980 - Sept. 1981).



most abundant, were dominant during studies conducted in 1980 and 1981-1982, accounting for up to 42% of the decapod catch (Wenner et al. 1981; Allen et al. 1982). However, in 1977-1978 white shrimp had the lowest biomass and abundance. During 1977-1978, pink shrimp dominated both the biomass (8% of total decapod catch), and numbers (31% of total decapod catch) ranking second by weight and numbers (Hinde et al. 1981). In 1980 pink shrimp ranked fifth in numerical abundance and represented less than 1% of the catch by weight. Brown shrimp ranged from the ninth most numerically abundant and less than 1% of the overall weight (Hinde et al. 1981) to third most abundant by numbers and biomass (10% of overall weight, Wenner et al. 1981).

Both size frequency and abundance were seasonally distinct. Pink and white shrimps were most numerous in September and October; brown shrimp were most abundant during July and August (Wenner et al. 1981; Allen et al. 1982). A large decline in all three shrimp species occurred during the winter months. Pink shrimp sizes changed little seasonally and average 60-90 mm. Brown shrimp increased from 70 mm in the spring to 100 mm in the summer. White shrimp had overlapping sizes with two distinguishable bimodal lengths of 80-160 mm in the fall and 120-140 mm during the summer (Wenner et al. 1981).

LONG-TERM TRENDS

Few studies described in the previous sections were appropriate for useful trends analysis. Most studies were not designed to collect data over a sufficient period of time to provide the data record necessary for rigorous analysis. Although a few short-term studies have been conducted in similar locations in North Inlet or Winyah Bay, differences in analytical techniques or sampling gear prevent temporal comparisons. Data sets available for trends analysis include land and water use, basic water quality parameters, pollutant concentrations, fisheries resources, and meiobenthic populations. These trends are summarized in the following sections.

USE TRENDS

Land and Water Use

The first settlement on this continent occurred in the Waccamaw Neck in 1526 on Hobcaw Barony, Winyah Bay. This settlement (San Miguel de Gualdape) was maintained until 1527. Grants from British kings divided the lower portion of the Pee Dee-Yadkin basin into numerous plantations with the earliest land grants dating from 1705. Indigo was a stable cash crop in Georgetown County. Rice shortly followed, as the primary crop produced and in the 1840's almost half of the rice produced in the US was grown on plantations in Georgetown County. After the Civil War, rice culture declined due to the loss of slave labor and the development of mechanized farms in the southwest. By the 1900's wood industries dominated the area. Currently many of the timber plantations are being converted into residential communities for permanent and seasonal residents (Waccamaw Regional Planning and Development Council 1985).

Land and water use data were available for the entire Pee Dee-Yadkin Basin (including both North and South Carolina counties), Georgetown County, the Waccamaw subbasin region (Winyah Bay Estuary, North Inlet Estuary, the lower Waccamaw River, and Georgetown), and the Waccamaw Neck (area east of the Waccamaw River from Murrells Inlet south to Winyah Bay) (SCDHEC 1976; Brooks et al. 1977; Moore, Gardner, and Associates Inc 1977; Yadkin-Pee Dee River Basin 1979; Conservation Foundation 1980; Waccamaw Regional Planning and Development Council 1982; Snyder 1983; USACOE 1984). Forests were the major land use (> 60%) in the entire Pee Dee-Yadkin Basin in 1970 but have declined by over 38 km^2 per year. These projected decreases will result in a 3% loss of forest land by the year 2010. Agriculture was the second largest land use in the entire basin with over 16,187 km^2 in 1970, but also has declined by 20 km^2 per year. Farms in the South Carolina portion of the Pee Dee-Yadkin Basin numbered 16,805 in 1969 and occupied 12,435.7 km^2 (Brooks et al. 1977). Water areas were 1% and other areas (non-forested wetlands, commercial, roads, etc.) 5% with only a slight increase (< 0.1%). Urban land use increased from 4% of the land area by 48 km^2 per year (Yadkin-Pee Dee River Basin 1979; Conservation Foundation 1980). The pie charts (Fig. III-56) are for the entire basin. Urban land use will increase over 48 km^2 from 1970 to 2110.

Land use data were also available for the Waccamaw subregion (Waccamaw Regional Planning and Development Council 1978) (Fig. III-57). During the period 1975-1985 the major land use change was a conversion of 34.4 km² of forested land to residential communities. In 1975 forests accounted for 45.6% of the land area. In Georgetown County during the ten-year period 1976 to 1986 forest area decreased from 78.6% to 73.2% (total land area 2,128 km²) (Waccamaw Regional Planning and Development Council 1977; South Carolina Statistical Abstracts 1987-1988). Agriculture (21.1% of the area) decreased during the study period by 10.2 km². In the Waccamaw subregion, farms numbered 5,993 and occupied 2,546 km². By 1982 the area and number of farms had decreased by 27% and 46%, respectively. (Waccamaw Regional Planning and Development Council 1976; USDOC 1987). In Georgetown County farm area decreased from 274 km² to 162 km² during the same period. This trend was expected to continue through 1995 with a conversion of forested and agricultural land to primarily residential-urban development. By 1995 residential areas are expected to increase by 24 km² and forest to decline by 64.9 km². These shifts, however, are less than 1% of the total land area in the Waccamaw subregion. Commercial and industrial areas will increase from 28 km² to 38 km² by 1985, again representing only 1% of the total area.

In 1976 slightly more than 2% of Georgetown County was developed. Of the undeveloped land, 53% (2,008.4 km²) was forested, 6% agriculture, 27% in forested wetlands, and 12% in non-forested wetlands. By 1985 projected land use changes would result in a decrease in forests (1.4%), forested wetlands (0.6%), non-forested wetlands (0.6%), and agriculture (0.1%). Residential, industrial, and commercial land use was projected to increase by 0.6% (Waccamaw Regional Planning and Development Council 1976).

In 1970 over 1,954,500 people resided in the entire Yadkin-Pee Dee river basin (Yadkin-Pee Dee River Basin 1979). Approximately 519,000 people resided in South Carolina's portion of the Pee Dee-Yadkin river basin, with increases of approximately 20% projected over the next ten years (Snyder 1983). Sixty-eight percent of the population was classified as rural with the remaining 166,000 people living in urban areas (Brooks et al. 1977). Over 137,8735 people resided in the Waccamaw subregion in 1970 and by 1986 that population increased to 215,800 (SC Statistical Abstract 1986). By 1990 the population in the entire basin was expected to increase by

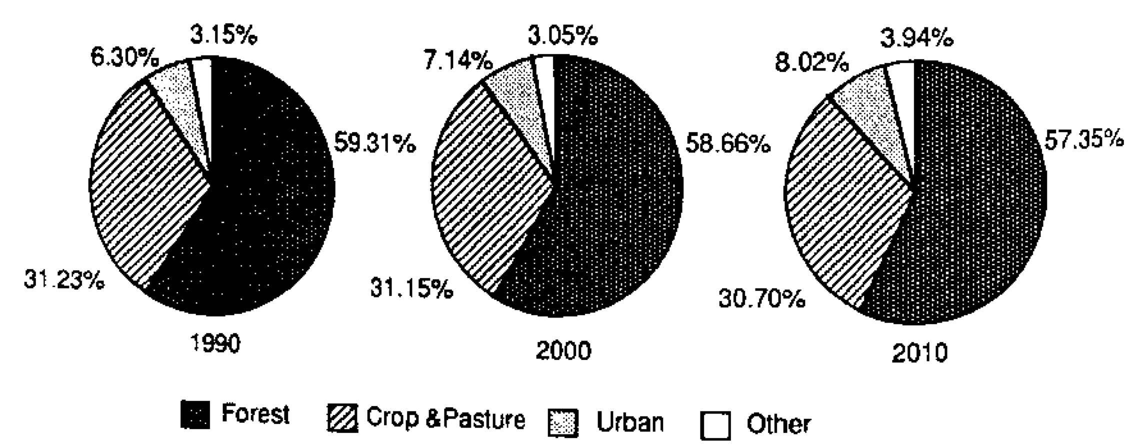


Fig. III-56. Land use projections for the entire Pee Dee-Yadkin Basin (Yadkin-Pee Dee River Basin 1979).

sub-area (Georgetown, Horry, and Williamsburg counties). With the exception of recreational growth on the Grand Strand and industrial growth in and around Georgetown, Sumter, and Florence, large industrial growth in the Pee Dee Basin has not occurred (Brooks et al. 1977).

The population of Georgetown County increased from 33,500 persons in 1970 to 42,461 permanent residents by 1980, with projected increases to 47,000 by 1986 (SC Division of Research and Statistical Services 1988). In the Waccamaw Neck region (encompassing North Inlet Estuary and the eastern portion of Winyah Bay Estuary) the population has more than doubled from 3,153 in 1970 to 6,523 in 1980 and is expected to increase by about 150% by the year 2000 (Waccamaw Regional Planning and Development Council 1985). The coastal areas of Georgetown and Horry counties will undergo the most rapid growth (90% and 142%, respectively) over the 30-year period 1970-2000 (Yadkin-Pee Dee River Basin 1979; Conservation Foundation 1980).

The major growth in population is expected to occur along the lower Waccamaw Neck and is

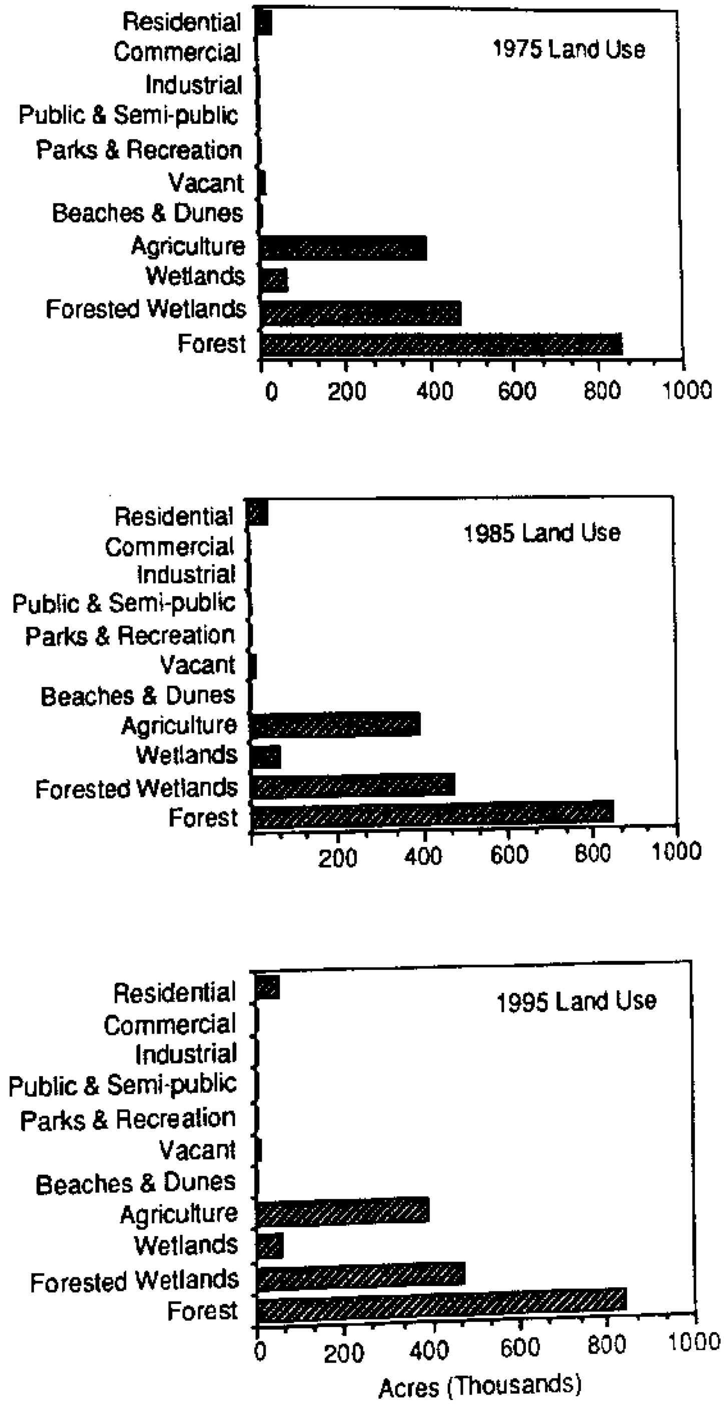


Fig. III-57. Projected land use changes in the Waccamaw subregion (Waccamaw Regional Planning and Development Council 1977).

expected to increase drinking water demand and sewage wastewater treatment. This growth will have significant impacts on all of the water systems within the basin. The population in the 44 counties of the Yadkin-Pee Dee Basin in North Carolina and South Carolina is expected to increase by 53% over the next 30 years (Fig. III-58). These increases are due to a national trend of population migration into the Sunbelt states, and more business and industry locating in this area providing ample economic opportunities (Yadkin-Pee Dee River Basin 1979; Conservation Foundation 1980).

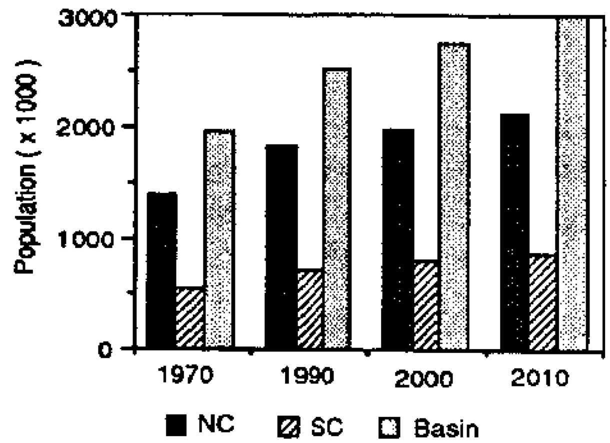


Fig. III-58. Population projections for the entire Pee Dee Basin (Yadkin-Pee Dee River Basin 1979; Conservation Foundation 1980).

As a result, there will be greater water demands placed on the estuarine system for power, industry, irrigation, and consumption. The electric power industry was potentially one of the largest water users in the basin. The consumptive water use by thermal electric plants is expected to increase 30% by the year 2010 (Fig. III-59). Public water supplies increased slightly less than six million gallons per day (MGD) each year or 88 MGD from 1970-1985. Municipal and industrial demand increased from 251 MGD in 1970 to 319 MGD in 1985, resulting in a 4.5 MGD increase per year (Yadkin-Pee Dee River Basin 1979).

Irrigation use within the entire basin was 36.3 MGD in 1977 and projected to increase by 1 MGD

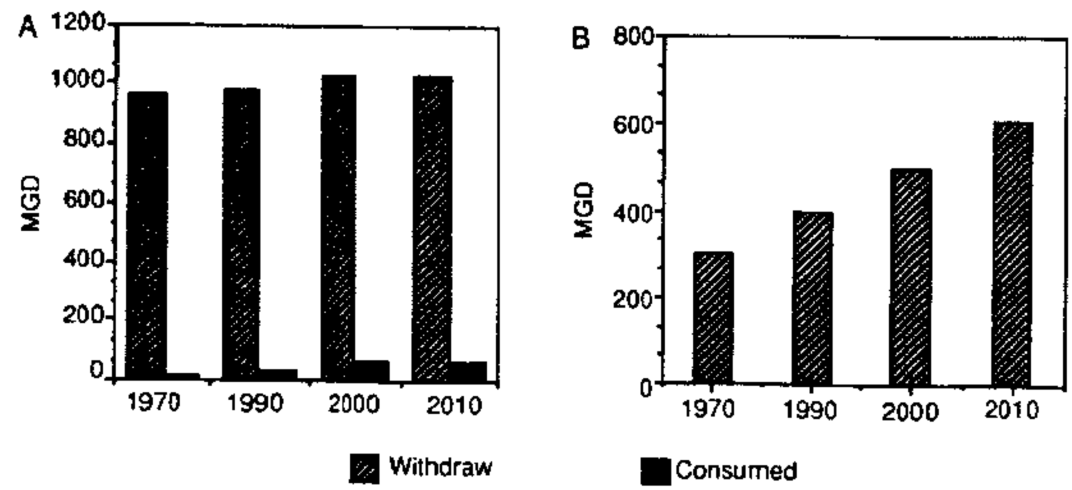


Fig. III-59. Water use by (A) thermal electric power plants and (B) municipal and industrial water demand in the Yadkin-Pee Dee Basin (Yadkin-Pee Dee River Basin 1979; Conservation Foundation 1980).

each year. Irrigation will increase rapidly and is expected to increase by the year 2010 to 83.5 MGD (Fig. III-60). In 1980, 80% of irrigation water came from streams and ponds, with the remainder from groundwater wells. In the Coastal Plain of South Carolina, the supply from wells is expected to increase to 35% by the year 2010 (Yadkin-Pee Dee River Basin 1979; Conservation Foundation 1980).

Commercial use of Winyah Bay varied but did not show a decreasing or increasing trend during the study period. Shipment tonnage at the Port of Georgetown changed from 1960 to 1981, averaging 1,174,972 for 1961-1971, 1,500,000 for 1971-1976, and 1,200,000 for 1977-1980 (Brooks et al. 1977; USACOE 1984).

The lower Waccamaw River subbasin was being subjected to increasing amounts of industrial and private domestic effluents from point-source discharges (Table III-15). In 1969, there were eight industrial, municipal, and domestic dischargers into the lower Waccamaw River subbasin (including Pee Dee River below its confluence with Little Pee Dee and city of Georgetown) with a total discharge of slightly more than 95 million gallons per day (MGD) (Table III-15). The major discharger in the basin was International Paper Co. which was permitted to discharge 95.3 MGD and 316,396 lbs/day of oxygen demanding substances (measured as BOD_5). The total municipal discharge was less than 1 MGD with a total BOD_5 of < 57 lbs/day (SC Water Resources Commission, unpublished data).

By 1976, five additional dischargers were sited in the lower Waccamaw River subbasin; together, the 13 had a permitted discharge of 41.18 MGD and a BOD_5 lbs/day wasteload of 22,422. This wasteload was primarily from industrial dischargers (21,889 lbs/day). The major reduction resulted from a decrease in the International Paper Co. discharge. Municipal discharge increased by greater than 450 lbs/day (SCDHEC 1976). By 1989 three new municipal and one industrial discharger were added to and one industrial discharge removed from the Winyah Bay watershed. At the same time, International Paper (IP) and SC Public Service Authority (SC PSA) discharges were decreased, reducing the total discharge to 29.27 MGD. The three municipal dischargers added 915.7 lbs/day BOD_5 to the Waccamaw River, but a decrease in BOD_5 from IP and SC Public Service Authority resulted in a net decline of 8,589 lbs/day. It should be noted that the Swartz municipal sewage treatment plant has a design capacity for 19 MGD and Wedgefield 0.4 MGD. Another municipal sewage treatment plant will be added to the Waccamaw River at Pawleys Island with a design capacity of 2.8 MGD (SCDHEC 1987). Therefore, the major trend in wastewater discharge into the Winyah Bay system was an increase in municipal sewage. There were no municipal or industrial wastewater discharges into North Inlet Estuary.

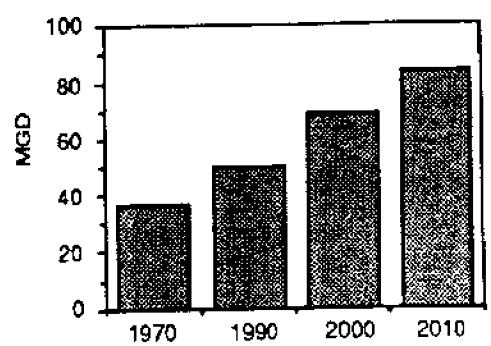


Fig. III-60. Irrigation water use 1977-2010 in the Yadkin-Pee Dee Basin (Yadkin-Pee Dee River Basin 1979; Conservation Foundation 1980).

Recreation, Boating, and Tourism

Recreation includes swimming, boating, fishing, and sightseeing in the Grand Strand portion of the Yadkin-Pee Dee Basin. In South Carolina over 36% of the total tourist trade occurred in the Grand Strand. Recreational use has increased from <9.5 million travelers and visitors in 1972 to over 13 million visitors in 1985 (Waccamaw Regional Planning and Development Council 1978; SC Div. of Research and Statistical Services 1987). In the northern coastal district (Winyah Bay, Murrells Inlet, and Little River Inlet) the major boating activity was fishing, with shellfishing, shrimping, and crabbing lower activity preferences (Low et al. 1986). Boat registrations in Georgetown County increased from 1,124 persons in 1965 to 5,785 in 1985 (USACOE 1984; SC Division of Research and Statistical Services 1988). There has been no increase in the number of public boat landings in Winyah Bay Estuary.

Within the South Carolina portion of the Yadkin-Pee Dee Basin, two major state park facilities exist. Myrtle Beach State Park, located in Horry County, has the heaviest vistor use of any state park; attendance has increased from 924,002 visitors in 1969 to 1,232,660 in 1987. The third most popular state park was Huntington Beach State Park in Georgetown County. Huntington Beach State Park visitor use has decreased from 433,438 in 1969 to 382,156 in 1987 (SC Division of Research and Statistical Services 1988).

Table III-15. Industrial (I), municipal (M), and private municipal (PM) facilities which discharge into the lower Waccamaw subbasin (SCDHEC 1976, SCDHEC unpublished data).

Facility Name	Type	MGD 1975	MGD 1989	BOD_5 1975	BOD_5 1989	Receiving Stream
City of Georgetown	M	2		26		Whites Cr. to Sampit R.
Garden City STP	M	0.2	0.3	30	30	Cedar Swamp to Waccamaw R.
Litchfield Plantation	PM	0.02	0.2	30	30	Chapel Cr. to Waccamaw R.
Litchfield Beach	M	0.5	0.5	15	15	Chapel Cr. to Waccamaw R.
State Ports Authority	M	<0.001	<0.001	30	30	Sampit R.
Sea Gull Inn	PM	0.047	0.047	24	24	Waccamaw R.
Whites Creek Subdiv.	PM	0.083	0.12	30	10	Whites Cr. to Sampit R.
Brookgreen Gardens	PM	0.005	0.005	60	60	Brookgreen Cr. to Waccamaw R.
Harmony Hills	PM	0.036	0.1	25	15	Turkey Cr. to Sampit R.
Swartz Plant G	M		7.5		30	Waccamaw R.
Hagley	M		0.05		30	Waccamaw R.
Wedgefield	M		0.4		30	Black R.
Georgetown Steel	I	0.46	2.04		18.5	Sampit R.
International Paper	I	35	18	75	77	Sampit R.
Midland-Ross Corp.	I	0.461				Sampit R.
SC Public Service	I	2.307	0.006	5	30	Turkey Cr. to Sampit R.
VVV Corporation	I		0.004		30	Sampit R.
TOTAL		41.120	29.273			

TRENDS IN PHYSICAL CONDITIONS

Only one long-term data set was available to evaluate water quality in Winyah Bay. This data set was collected by the South Carolina Department of Health and Environmental Control as part of a state-wide water quality monitoring program and was available through the USEPA STORET database (SCDHEC 1989; USEPA Research Triangle Park, NC). Unfortunately, sampling of water quality parameters in the Winyah Bay Basin was not standardized by tidal stage, river discharge, time of day, day of month, or month of the year. Sampling prior to 1975 did not cover a full 12-month period. Only one 10-year record was available for adequate temporal analysis (although rigorous, detailed time series analysis cannot be done).

Analyses of water quality parameters in North Inlet Estuary (1978 to present) documented large changes in water quality conditions relative to tidal stage, time of day, day to day within a month, and episodic events such as storms, winds and high freshwater discharge (LTER unpublished data; Chrzanowski et al. 1982; Gardner 1984; Whiting et al. 1987; Wolaver et al. 1988). Prior to 1981 studies were limited to seasonal or discrete time periods. In 1981, daily measurements for water quality were initiated at three locations in North Inlet Estuary as part of a larger study (LTER). The water quality assessment for North Inlet Estuary was based on the LTER data for years 1981-1986. Samples were collected at 10:00 EST for the purpose of simulating tidal variation over a 15-day period. Daily measurements were averaged into monthly means for analysis.

Fresh Water (Flow and Perturbations)

No significant trends were observed in freshwater inflow to Winyah Bay or North Inlet estuaries (Fig. III-61). No major disturbances or perturbations occurred in the watershed to modify flow. Freshwater discharge was related to precipitation variation, with lower discharges occurring during 1978, 1980, and 1984.

Salinity

Winyah Bay

The salinity regime of Winyah Bay varied with tidal cycle, tidal amplitude, and freshwater inflow from the Pee Dee and Waccamaw rivers. Due to large freshwater inputs, stratification in the bay was high (Mathews and Shealy 1982). The surface salinity decreased from the entrance of the bay toward the US Highway 17 bridge where the Pee Dee and the Waccamaw rivers enter the bay. Allen et al. (1982) measured salinities ranging from 27.2 ‰ to 35.2 ‰ and found large spatial variability in salinity for the bay with a maximum range of 33.3 ‰. Generally, salinities were highest in November and lowest in January (after a period of significant precipitation).

The freshwater line in Winyah Bay extended from 22.5 km to 48 km upstream from the mouth of the bay, with the average location at 37 km (Johnson 1970). The freshwater-saltwater interface was dependent on the tidal cycle and its actual movement was affected by the inertia of the water mass resulting in maximum intrusion at high-slack tide and minimum at ebb-slack tide. The interface reached 3.2 km on the Black River and 8 km on the Pee Dee and the Waccamaw rivers at high-slack tide, with average freshwater inflow of 510 m^3/s. If freshwater flow was reduced, the interface reached 25.7 km on the Pee Dee and the Waccamaw rivers and 21 km on the Black River, while high flow (991 m^3/s or greater) held the interface near the mouth of the rivers (Johnson 1970).

Vertical salinity stratification was dependent on tidal stage, wind disturbance, and the amount of freshwater runoff (Van Dolah et al. 1984). During most of the year, surface and bottom measurements indicate some salinity stratification at all the deep water stations, with differences between surface and bottom samples of 10‰. The denser, more saline waters were near the bottom and the fresher waters were near the surface

(Allen et al. 1984). In the study by Hinde et al. (1981), bottom water analysis showed that salinities ranged from mesohaline in the Western Channel and South Island, where they fluctuated from mesohaline at low tide to euhaline at high tide, to euhaline in the nearshore waters of the mouth of the bay.

North Inlet

North Inlet was characterized by high monthly average salinities of 30 - 34 ‰ (LTER unpublished data). The majority of water exchange with the Atlantic Ocean was through a barrier island inlet, with additional but limited exchange through Winyah Bay. It was a well-mixed estuary with little stratification (Kjerfve 1984).

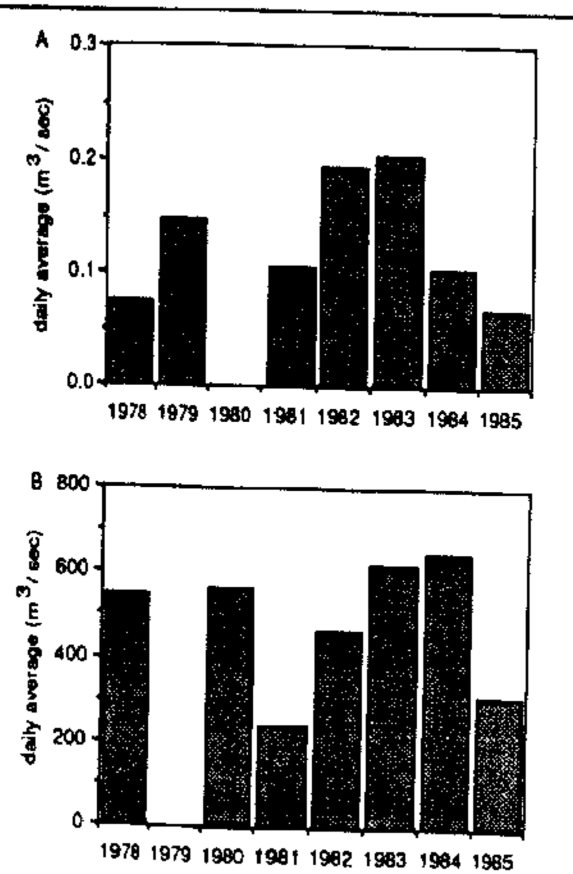


Fig. III-61. Freshwater discharge into (A) North Inlet Estuary (as represented by a 5.3 km² watershed which drains into North Inlet Estuary) and (B) Winyah Bay Estuary (daily average flow from the Waccamaw, Pee Dee, Black, Lynches, and Little Pee Dee rivers).

There was negligible freshwater runoff into the estuary; the runoff that exists emanated from the maritime forest to the northwest, which serves as a catchment area for the annual rainfall of 1.2 m (Kjerfve 1984). The mean freshwater input was between 1.0 to 5.0 m^3/s. The area of marsh adjacent to the forest had salinities as low as 4 ‰ for several days as a result of intense frontal rains or hurricanes (Kjerfve 1984). Intrusions of low salinity water from Winyah Bay influenced salinity regimes in North Inlet Estuary. This influence varies interannually and on time scales of days to several weeks (LTER unpublished data). Because of the large tidal pumping through North Inlet, these low salinity pulses were rapidly distributed throughout the North Inlet Estuary. Little spatial variation in average salinities occurred. Salinity had significant seasonal patterns related to freshwater discharge in Winyah Bay and North Inlet estuaries. North Inlet seasonal and interannual salinity variation was related to intrusions from Winyah Bay Estuary. No significant long-term trends were found for salinity using either the monthly data or annual means.

Temperature

No significant trends were observed for temperature in North Inlet or Winyah Bay estuaries using linear regression analysis on monthly or annual data.

Dissolved Oxygen and BOD_5

The SCDHEC STORET database contained monthly measurements for a number of water quality parameters in Winyah Bay and the lower Waccamaw River. Two water quality assessments of this area have been conducted. Twenty-two stations were used to assess water quality in 1972-1973 and eight stations were used to assess changes for 1977-1986 (SCDHEC 1976; Knowles and Fable

1986). In general water quality has improved since 1972. Nineteen percent of water quality samples (SCDHEC monitoring stations) during 1972-1973 showed contraventions of South Carolina Water Quality Standards for dissolved oxygen. Most of these violations were associated with point-source discharges. There were also dissolved oxygen contraventions which indicated the presence of nonpoint sources. However, by 1984 and 1985, more than 99% of the saltwater area in the lower Waccamaw subbasin met South Carolina Water Quality Standards. The major problems were dissolved oxygen contraventions due to municipal discharges into Whites Creek (City of Georgetown) and the industrial discharge from International Paper into the Sampit River. Between 1977 and 1986 dissolved oxygen was less than 5 mg/l for 14 samples and of those 14 only 4 were less than 4 mg/l, representing less than ~14% or ~4% of the 120 samples.

Only one primary water quality monitoring station was located in Winyah Bay (MD080). SCDHEC performed a trends analysis on data from this station for the years 1975-1985 using a nonparametric test. Spearman correlation coefficients for the ranks of the annual means related to years were used to determine whether a given water quality parameter increased or decreased consistently. Dissolved oxygen showed no significant trend in water quality while BOD_5 declined significantly (Knowles and Fable 1986).

Linear regression analysis was performed on all monthly data from station MD080 to determine if there was a significant seasonal or long-term trend in the water quality parameters. No long-term trends were found in monthly dissolved oxygen. Dissolved oxygen had significant seasonal variation ($p < 0.05$) which may have contributed to the lack of long-term variation in monthly data. To remove the seasonality in dissolved oxygen, monthly data were averaged annually and linear regression analysis then performed on the annual mean data to determine long-term trends. Dissolved oxygen significantly increased over the ten-year period. Dissolved oxygen concentrations were significantly related to freshwater discharge. Monthly BOD_5 significantly declined during this ten-year period (Fig. III-62) while BOD_5 showed no significant long-term trends based on annual data.

Nutrients

Winyah Bay

Based on nonparametric statistics, nitrate and total phosphorus showed no significant trend in water quality, but total Kjeldahl nitrogen and ammonium significantly increased during the ten-year period 1975-1985 (Knowles and Fable 1986) (Fig. III-63). Nitrate was significantly related to changes in salinity ($p < 0.05$), suggesting a freshwater source. Using linear regression analysis, no long-term trends in total phosphorus, total Kjeldahl nitrogen and nitrate were detected.

Table III-16 shows the significant long-term trends in water quality parameters which were obtained using linear regression analysis. In general, concentrations of total nitrogen and total phosphorus decreased in North Inlet Estuary. Inorganic nitrogen fractions showed differing temporal patterns at each of the three stations. Inorganic nitrogen (nitrate-nitrite and ammonium) significantly increased at Town Creek. Nitrate-nitrite significantly increased during the study period at Oyster Landing while ammonium showed no significant change. No significant trends were observed in nitrate-nitrite or ammonium at Clambank. Oyster Landing was influenced by ammonium-rich freshwater runoff from an undisturbed forest watershed with interannual ammonic variation which reflected variation in freshwater discharge. This station was shallower than Clambank and Town creeks and was more susceptable to marsh runoff than either creek. The increasing trend at Town Creek was influenced by Atlantic Ocean and increased trends in inorganic nitrogen reflected factors influencing offshore waters. Clambank was episodically influenced by intrusions from Winyah Bay to a greater degree than Town

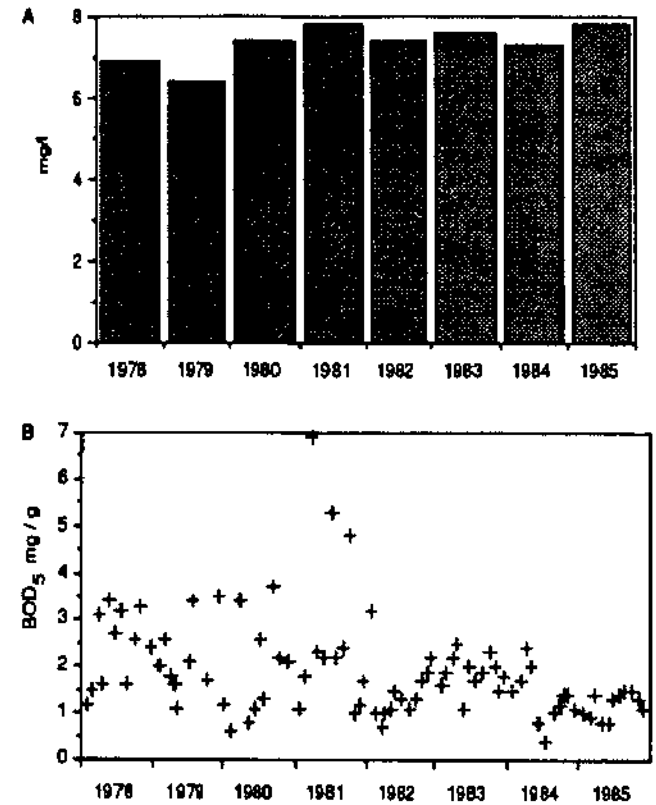


Fig. III-62. Dissolved oxygen long-term trends of annual mean concentrations and monthly data for BOD_5 from station MD080 (SCDHEC STORET database).

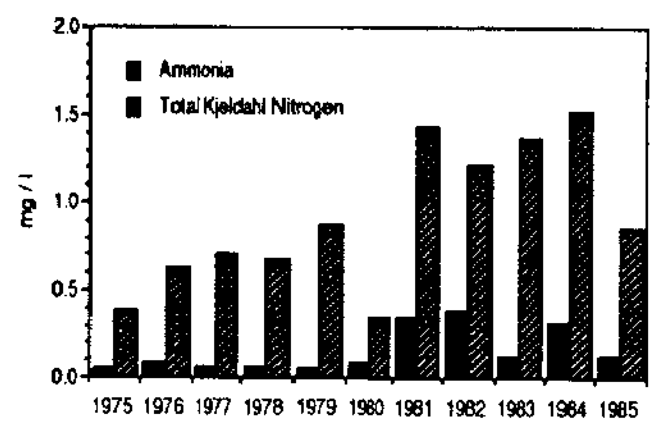


Fig. III-63. Annual mean total Kjeldahl nitrogen and ammonium concentrations for 1975-1985 for Winyah Bay (MD080, SCDHEC STORET database).

Creek and Oyster Landing and the episodic variation masked any longer term patterns.

Significant seasonal trends (based on monthly means) were found in a number of parameters (Table III-17). For some parameters, such as total nitrogen or phosporus, the seasonal pattern was consistent from year to year (Fig. III-64); however, other parameters, such as ammonium, were influenced by factors such as interannual variation in terrestrial runoff. Ammonium and nitrate-nitrite had significant interannual variation in seasonal patterns. Interannual seasonal variation in ammonium was strongly linked to salinity, further substantiating the influence by freshwater-supplied ammonium. Higher concentrations of ammonia occurred in terrestrial runoff and waters in Winyah Bay.

North Inlet

Nitrate-nitrite was strongly influenced by intrusions from Winyah Bay and accounted for the interannual variation from 1981 to 1985. This pattern was particularly obvious at Clambank Creek. However, the high concentrations that occurred during 1986 cannot be linked to freshwater inflow or intrusions from Winyah Bay. The salinities and temperatures during 1986 were among the highest recorded for North Inlet; salinity on a seasonal basis and temperature over an extended time period. Results suggested that the increase in nitrate-nitrite in North Inlet during this year was due to enhanced microbial degradation of organic matter resulting in elevated nutrient release and concurrent oxidation.

Table III-16. Significant trends in water quality parameters for North Inlet (NC - no change, I -increasing, D - decreasing) based on linear regression analysis of monthly means (LTER unpublished data) (Town Creek - TC, Oyster Landing - OL, Clambank - CB).

Parameter	TC	OL	CB
Salinity	D	NC	NC
Total Nitrogen	D	D	D
Dissolved Organic N	D	D	D
Nitrate-Nitrate	I	I	NC
Ammonia	I	NC	NC
Total Phosphorus	D	D	D
Dissolved Organic P	D	D	D
Orthophosphate	D	D	D

Table III-17. Water quality parameters in North Inlet Estuary which have significant seasonal patterns ($p < 0.05$) (LTER unpublished data) (Town Creek - TC, Oyster Landing - OL, Clambank - CB).

Parameter	TC	OL	CB
Salinity			
Total Nitrogen	*	*	*
Dissolved Organic N		*	
Nitrate-Nitrite			
Ammonium		*	*
Total Phosphorus	*	*	*
Dissolved Organic P	*		
Orthophosphate		*	*

Other factors influenced phosphorus dynamics on short-term episodic (e.g., rain events at low tide) or tidal frequencies. There was substantial temporal variation on scales less than monthly for the various phosphorus fractions. Biweekly variation (25-35% of total variation in total phosphorus) occurred, with episodic phenomena contributing significantly to this shorter term variation. For example, rain occurring at low tide accounted for an additional 60% of the variation in total phosphorus adjacent to the maritime forest. Upland runoff, drainage from marsh surfaces, exchange with the marsh surface, and dilution with flooding waters from the ocean contributed to tidal variations in orthophosphate and total phosphorus concentrations. Tidal variation explained between 6% and 23% of the orthophosphate and 8% to 29% of the total phosphorus variation in North Inlet Estuary. Highest total phosphorus concentrations occurred at low tide and lowest concentration at high tide. The higher concentrations at low tide were not due to exchange with the marsh surface. Wolaver et al. (1988) studied the exchange of phosphorus between the marsh surface and adjacent tidal creek (Bly Creek). Higher concentrations were detected in flooding waters and decreased concentrations in ebbing waters. Although there were elevated concentrations during seepage and low tide drainage of the marsh, this flux was less than 25% of the phosphorus retained by the marsh during innundation. No benthic exchange studies have been conducted in North Inlet to determine whether tidal creek bottoms or unvegetated marsh area were sources for total P or orthophosphate. Higher concentrations of orthophosphate in the sediments and an inverse relationship between orthophosphate concentrations and discharge of water leaving the marsh surface suggested that diffusion from the sediments occurred and that diffusion from unvegetated areas and creek bottoms was potentially a source for the orthophosphate at low tide (Gardner 1975; Wolaver et al. 1988). During periods of upland runoff the forest was a source for the higher concentrations at low tide. Higher concentrations occurred adjacent to the forest particularly at low tide (Blood unpublished data).

pH

No significant trends were observed in pH for Winyah Bay Estuary. Insufficient data exist for North Inlet Estuary to address this water quality parameter.

Sediments

Winyah Bay

Due to the limited flushing capacity of Winyah Bay (Conservation Foundation 1980), most sediments were deposited in the bay. The bay bottom environment was in a constant state of change due to factors such as stream flows, currents, storm events, dredging, and tidal fluctuations. Large quantities of sand brought into the bay with flood tides become trapped in the estuary as a result of the bay's typical estuarine circulation pattern (Hinde et al. 1981). Under most circumstances, a portion of the sediment load would exit the bay to the ocean floor with the tides. However, in Winyah Bay, the flood tide, in conjunction with the density of the currents, push the sediments along the bottom upstream. These upstream flows were strong enough to trap the sediments in the bay and move the load into smaller tributaries such as the Sampit River (Conservation Foundation 1980). At the saltwater- freshwater interface near Georgetown Harbor, siltation was very rapid during periods of average freshwater flow, due to flocculation and biological processes that cause particle aggregation into denser masses (Conservation Foundation 1980; Hinde et al. 1981). Dredging causes differential deposition into the dredged channels so that the volume of sediment dredged should include almost all upland sediments that have entered the bay plus any marine sands that have been brought in through the entrance channel (Moore, Gardner and Assoc., Inc. 1983). Since 1952, the Georgetown Harbor Project has maintained the entrance channel at 9.18 m with average annual maintenance dredging of 94,910 m^3 (USACOE 1976).

Turbidity (as an indicator of suspended sediment load) had a significant seasonal pattern, significantly related to salinity. Long-term turbidity patterns were related to salinity variation indicating loading associated with freshwater discharge. However, no significant long-term trends were observed using linear regression analysis on monthly and annual data for MD080.

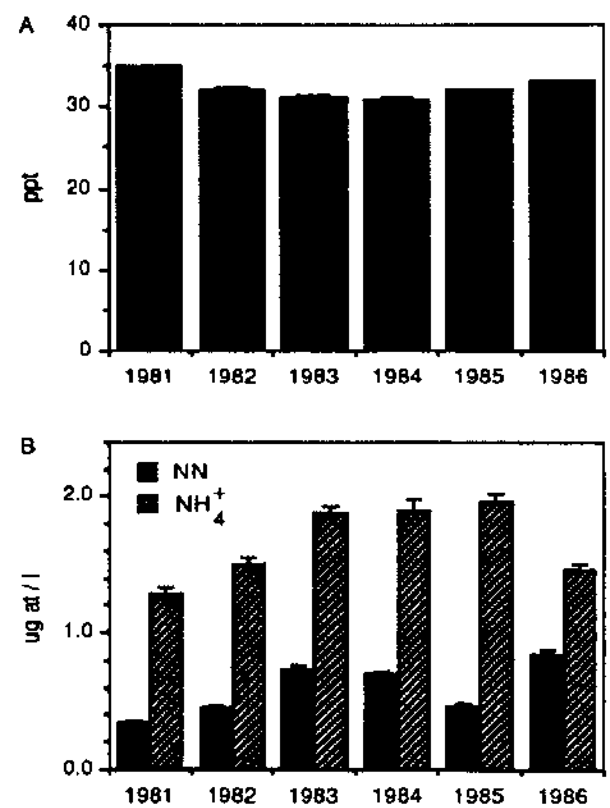


Fig. III-64. Annual salinity, nitrate-nitrite and ammonia for North Inlet Estuary. Means (± SE) represent an average of daily values from three stations.

TRENDS IN POLLUTANT LOADINGS AND AMBIENT POLLUTION CONCENTRATIONS

Toxics data for Winyah Bay have been collected on coliforms (SCDHEC STORET 1970-1985; Newell 1985; 1987;), heavy metals (Johnson 1970; SCDHEC STORET 1970-1985; USACOE 1976, 1981; Jones et al. 1979), grease (SCDHEC STORET 1970-1985; USACOE 1976, 1981; Jones et al. 1979), and selected organic compounds (Johnson 1970; SCDHEC STORET 1970-1985; USACOE 1976, 1981; Jones et al. 1979) (Fig. III-65). However, no comprehensive studies (i.e., spatial data over an annual cycle) have been conducted in Winyah Bay. Several short- term studies, usually single sample dates, have been conducted in association with continued dredging of Georgetown Harbor and the shipping channel through Winyah Bay (Jones, Edmunds and Assoc., Inc. 1979; USACOE 1976, 1981; Van Dolah et al. 1984). SCDHEC has monitored both metals and organics dissolved in the water and contained in the sediment at selected sites in the upper bay. Only coliforms (total and fecal) have been monitored in the lower bay by SCDHEC (Fig. III-65).

Inorganics

Winyah Bay

Heavy metals have been analyzed in water, sediments, and fish at several locations in Winyah Bay (Fig. III-65). Evaluation of dissolved heavy metals in Winyah Bay was difficult since several of the metals (cadmium, copper, nickel, and chromium) have over 75% of their reported concentrations below analytical detection limits. Only lead, zinc, and mercury had greater than 50% of the analyses above the detection limit (Table III-18). Concentrations of heavy metals dissolved in the water were generally very low. Only lead and zinc were detected at levels above the criteria used for relative assessment of major pollutants by SCDHEC (zinc -170 ppb, lead -140 ppb) (SCDHEC 1986). Using the criteria established by EPA for one-hour average for lead and one-time concentration calculated to protect aquatic life, lead values exceeded the criteria in 23% of the samples (average of all stations) and zinc in 13%. Van Dolah et al. (1984) found similar levels of dissolved heavy metals in the lower bay and offshore. Dissolved copper, mercury, lead, and nickel were below detection limits. Zinc concentrations (140 - 265 ppb) were similar to upper bay concentrations at SCDHEC stations. Cadmium (< 0.1 - 7.1 ppb) and chromium (1.4 - 5.3 ppb) concentrations were lower than those at SCDHEC stations. Arsenic concentrations were variable ranging from < 0.1 ppb to 92.8 ppb.

Heavy metals dissolved in the water were generally at the detection limit except for chromium, lead, and mercury (Figs. III-66, III-67). No significant long-term trends were found for any of the dissolved metals at any of the stations based on linear regression analyses of annual data. Dissolved heavy metal concentrations were averaged for the peroids 1975-1980 and 1981-1985. Although cadmium, copper, zinc, nickel, and lead decreased, the decreases were were not significant. Mercury decreased at MD080 and MD073 from the mid-1970's to mid-1980's. The two other stations (MD075 and MD077) showed no significant reduction (Figs. III-68, III-69).

Sediment heavy metal concentrations in Winyah Bay varied spatially as a function of sediment type and point-source discharges. Sediments from 20 stations were analyzed for lead, zinc, copper, and chromium (USACOE 1976). In general,

Fig. III-65. Sampling stations for toxics (heavy metals, organics) (1 - Jones, Edmunds, and Associates, Inc. 1979; 2 - Van Dolah et al. 1984; 3 - USACOE 1976; 4 - SCDHEC STORET database; 5 - Johnson 1970).

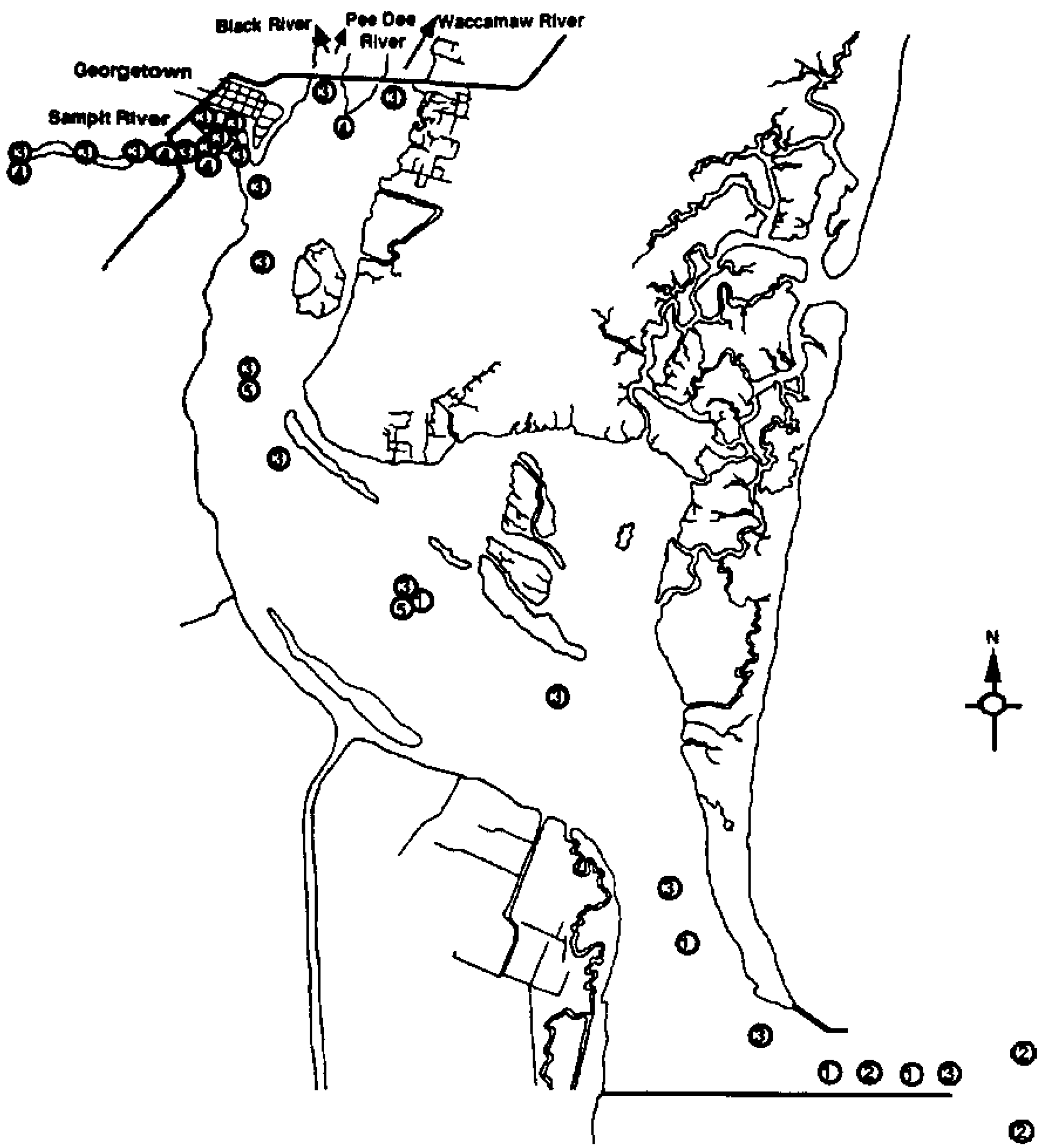


Table III-18. Heavy metals dissolved in water. Samples collected one to four times per year by SCDHEC. Means were average (ppb) of all annual average data above the detection limit (DL) with the number of observations in (). Mean of all data values were calculated by setting the concen trations at or below the detection limit to the appropriate detection limit for that particular year. Data cover 1972- 1985. Stations MD073, MD075 and MD077 were located in the Sampit River.

Metal	MD080		MD073		MD075		MD077	
	Mean Above DL	# All Data	Mean Above DL	# All Data	Mean Above DL	# All Data	Mean Above DL	# All Data
Cd	12 (1)	21 (12)	-	21 (12)	11 (1)	21 (12)	-	21 (12)
Cu	-	74 (12)	-	74 (13)	-	74 (13)	-	74 (13)
Pb	105 (9)	96 (12)	100 (10)	92 (13)	110 (11)	105 (12)	102 (11)	98 (12)
Ni	107 (3)	94 (12)	116 (3)	92 (12)	104 (4)	93 (12)	125 (3)	94 (12)
Zn	130 (4)	102 (12)	121 (5)	106 (12)	152 (7)	124 (12)	139 (6)	118 (12)
Hg	0.5 (8)	0.4 (12)	0.4 (10)	0.4 (14)	0.4 (9)	0.4 (13)	0.5 (9)	0.4 (13)
Cr	138 (6)	106 (12)	151 (3)	84 (12)	550 (1)	96 (12)	325 (3)	123 (12)

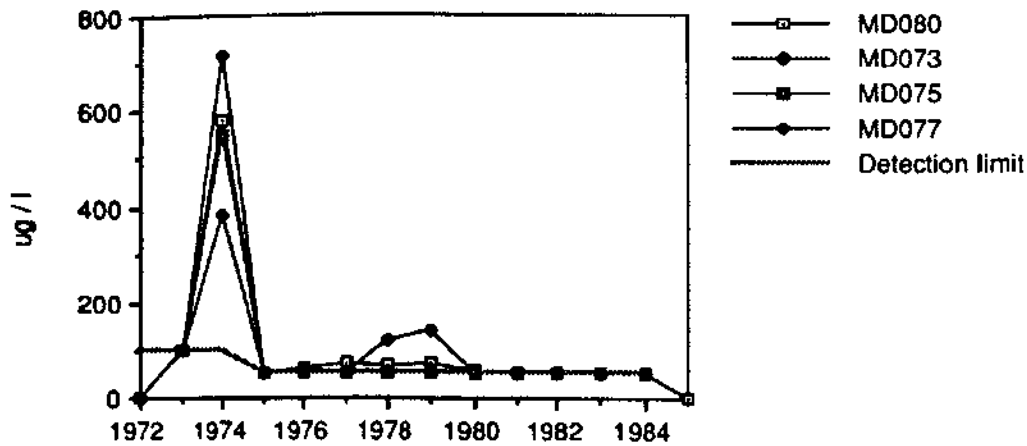


Fig. III-66. Dissolved chromium in Winyah Bay (MD080) and the Sampit River (MD073, MD075, MD077) (SCDHEC STORET database).

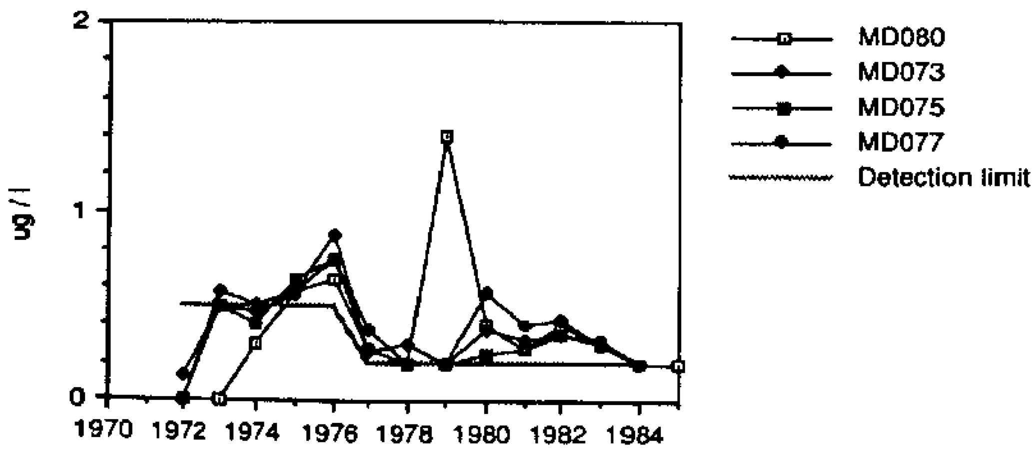


Fig.III-67. Dissolved mercury in Winyah Bay (MD080) and the Sampit River (MD073, MD075, MD077) (SCDHEC STORET database).

highest concentrations were detected in the Sampit River adjacent to Georgetown Steel. The upper bay stations had higher heavy metal concentrations than lower bay stations. Zinc and lead were five to six times greater in the upper bay than the lower bay sediments (Figs. III-70, III-71). Copper was highest in the upper bay, averaging 24 times greater than the lower bay (Fig. III-72). Chromium was 13 to 18 times greater in the upper bay and Sampit River, than in the remaining estuary (Fig. III-72). Concentrations in the Pee Dee and Waccamaw rivers were, in general, comparable to the levels detected in the lower and mid bay stations.

No obvious spatial patterns in arsenic, copper, cadmium, chromium, cobalt, mercury, or nickel

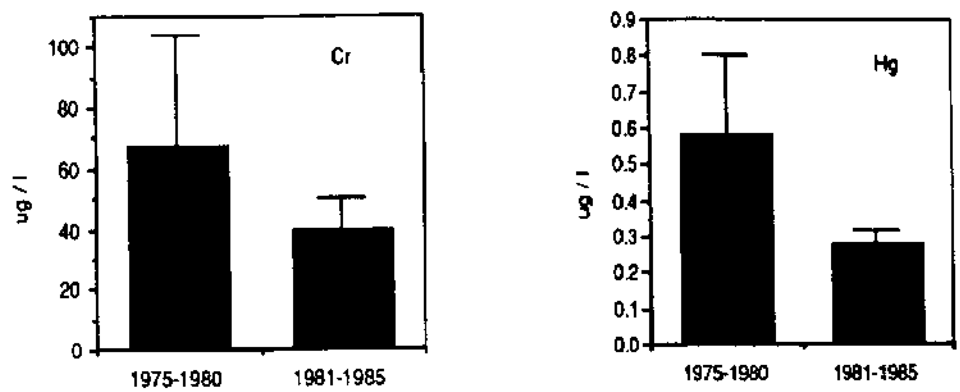


Fig. III-68. Dissolved chromium (Cr) and mercury (Hg) from station MD080 (SCDHEC STORET database).

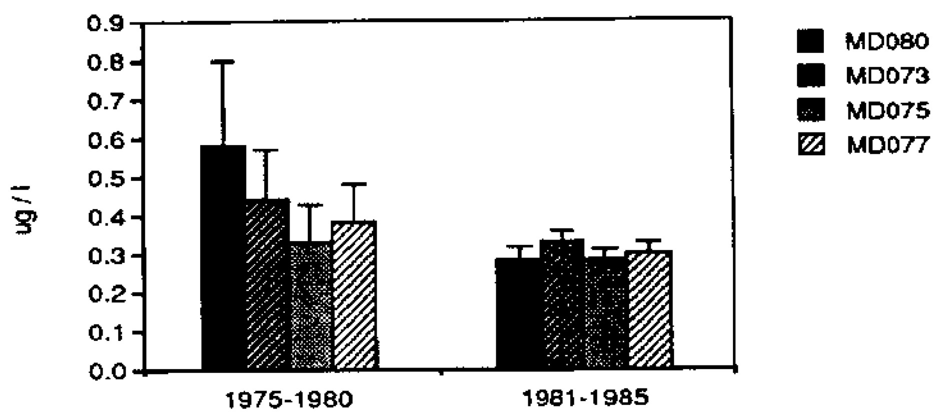


Fig. III-69. Spatial variation in long-term trend in dissolved mercury comparing the periods 1975- 1980 and 1981-1985.

concentrations were apparent in a survey of sediments in the upper portion of Winyah Bay and the Sampit River (USACOE 1984). Lead and zinc were slightly elevated in the Sampit River (Fig. III-73). Concentrations of chromium, copper, lead, zinc, and mercury at MD080 were similar to levels detected in the upper portion of Winyah Bay. Only nickel was significantly higher at MD080 than in the upper bay or Sampit River. In general, lower concentrations were found in the lower harbor and offshore from Winyah Bay than in the upper harbor and Sampit River (USACOE 1979; Van Dolah et al. 1984) (Fig. III-74).

Sediment heavy metal data for trends analysis were available for MD080. Only copper significantly declined from 1975 to 1985 (based on linear regression analysis of annual data) (Fig. III-75). Sediment copper concentrations ranged from 1 mg/kg to 10.9 mg/kg (mean ± SE, 7.1 ± 1.3). Sediment

Fig. III-70. Zinc concentrations in sediments (µg/g).

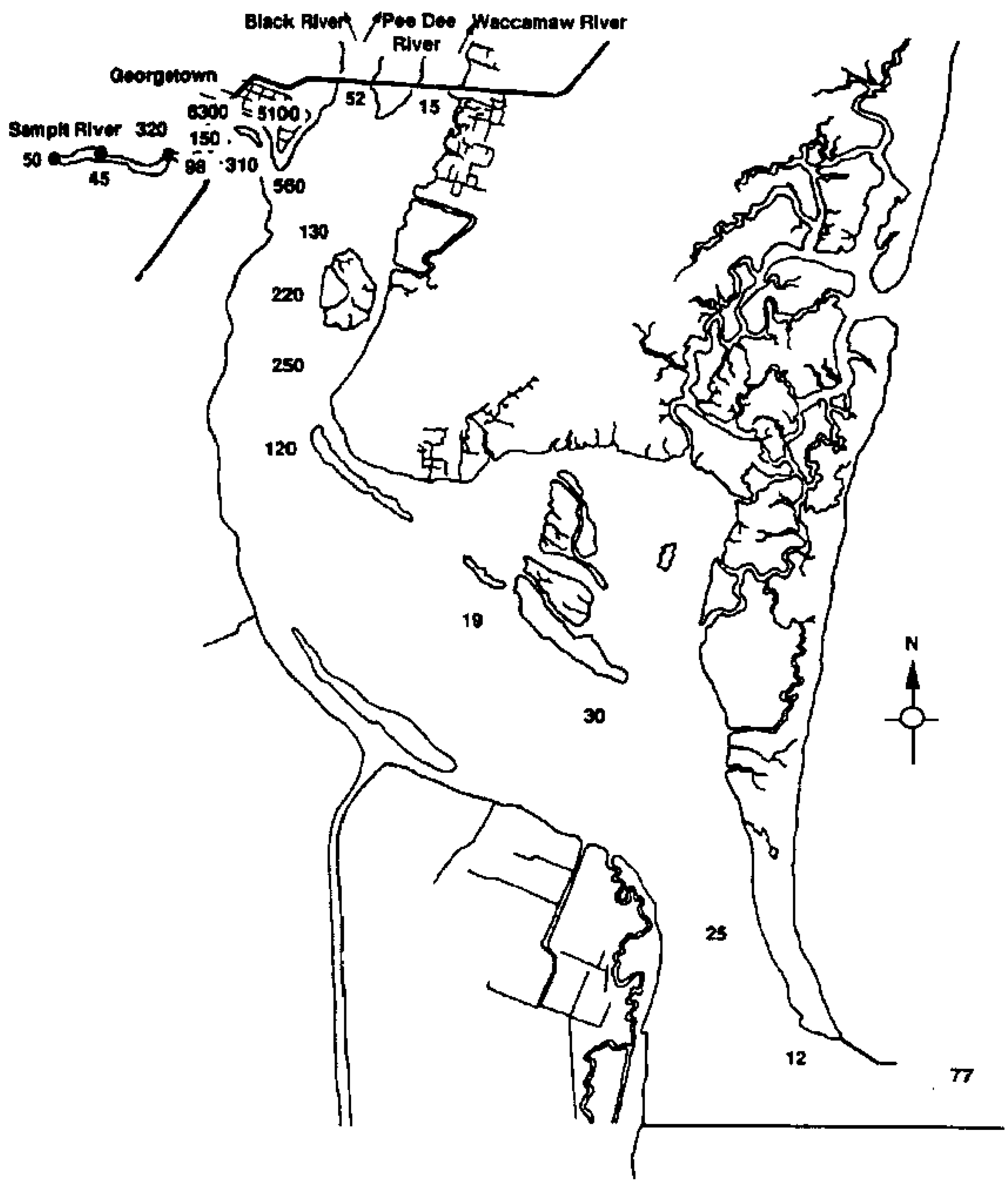
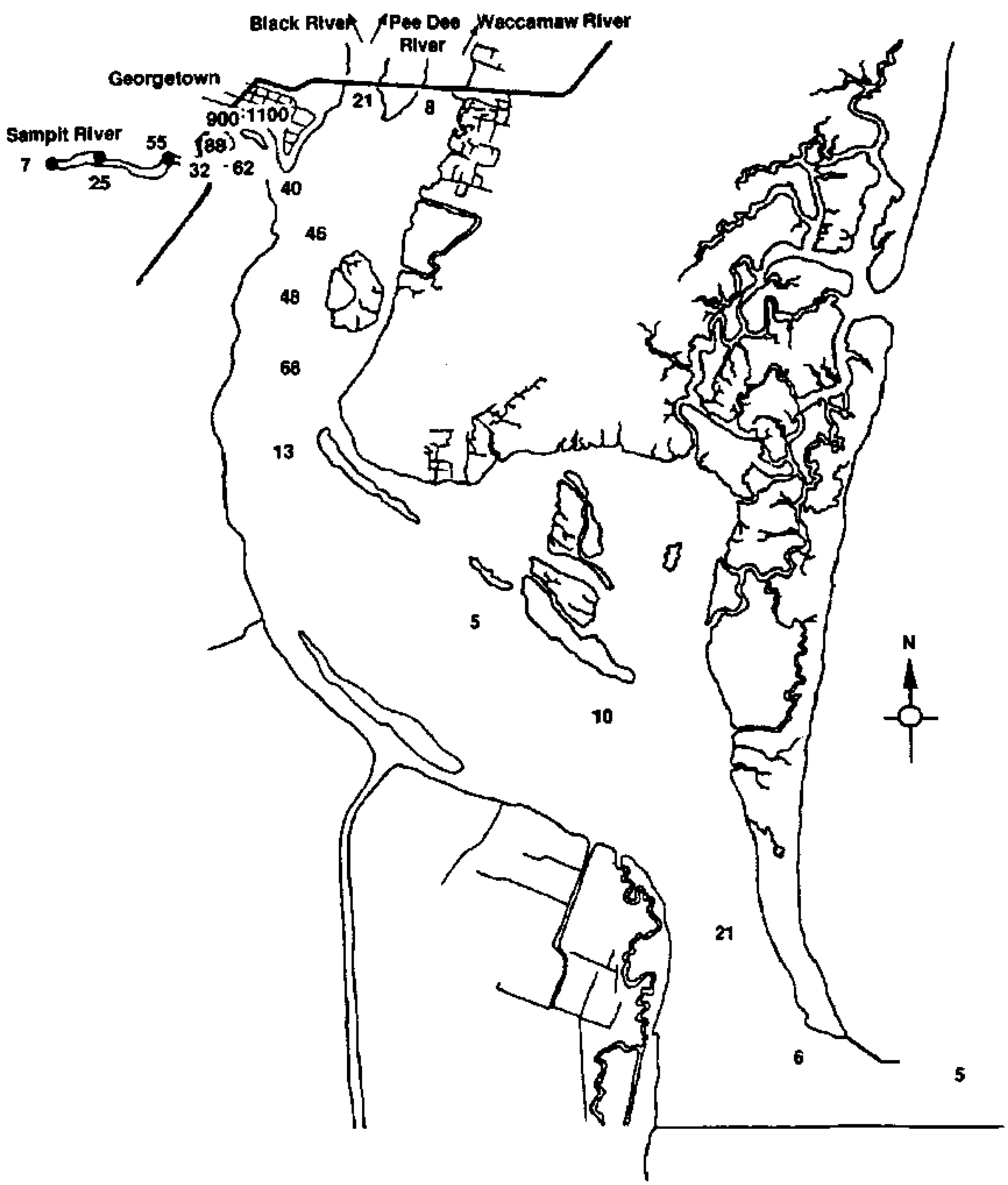


Fig. III-71. Lead concentrations in sediments (μg/g).



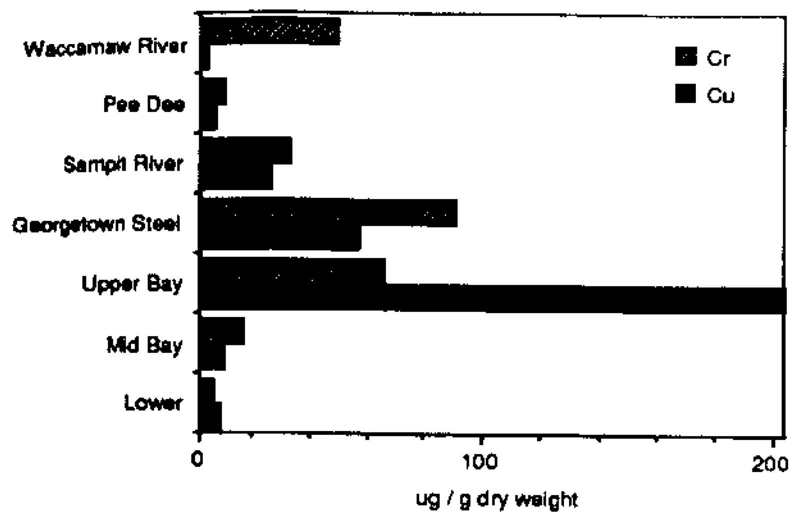


Fig. III-72. Concentrations of copper and chromium in sediments (μg/g dry wt) from Winyah Bay, Sampit River, Pee Dee River, and Waccamaw River (USACOE 1976).

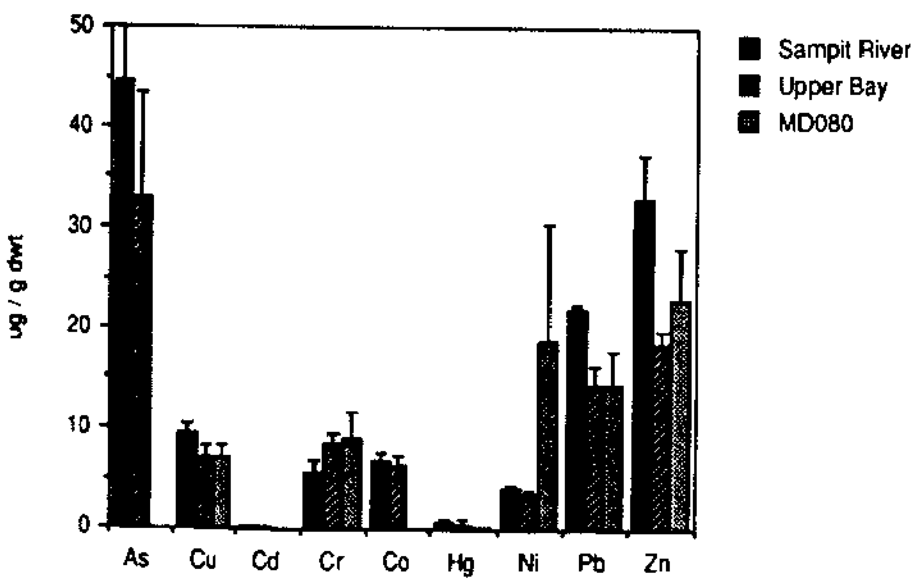


Fig. III-73. Heavy metal concentrations in sediment. Concentrations were μg/g dry weight. Average and standard error. Sampit River data were average of four samples and upper bay average of six samples. MD080 data were an average of data from 1977-1985.

chromium concentrations averaged 9.1 ± 2.6 mg/kg with a range of 5-26.2 mg/kg. Lead ranged from 5 to 26 mg/kg with a mean of 14.2 ± 3.4 mg/kg. Nickel had the highest detected concentration of 100 mg/kg and averaged 18.9 ± 11.6 mg/kg with a range of 5-100 mg/kg. Zinc average concentrations were the highest at 23 ± 5.1 mg/kg and ranged from 8-40 mg/kg. Mercury concentrations were very low (0.24 ± 10.02, 0.2-0.3 mg/kg).

Station MD080 was a poor station to sample for trends in heavy metals because it was "upstream" from the Sampit River. The highest major heavy metal concentrations occurred in the Sampit River adjacent to Georgetown Steel Mill. No long-term data were available for the Sampit River or Winyah Bay below the river to assess the impact of this significant point-source discharge. Therefore, caution should be exercised in extrapolation of the MD080 data analysis to the entire bay.

No information was available for metals in sediment or water for North Inlet. Heavy metal concentrations in fish and shellfish were poorly known for Winyah Bay and such information was nonexistent for North Inlet. Limited data were available for Winyah Bay (Table III-19); however, they were insufficient to assess long-term heavy metal trends in fish.

Organics

Agricultural applications of 28 commonly-used pesticides were estimated for 78 estuarine drainage areas in the US (Pait et al. 1989). Agricultural use was calculated from crop type, area of crop, and the application rate of pesticide for each specific crop. The Winyah Bay estuarine area ranked fifth in overall estuarine drainage area with 25% of the land area (9,560 mi^2) in agriculture. Soybeans were the predominant crop. Winyah Bay has one of the highest reported pesticide uses in the United States. It ranked second nationally in overall annual pesticide use (3,240,000 lbs/yr) and ninth in annual pesticide use per area (1,344 lbs/mi^2/yr).

The heaviest application of Carbaryl occurred in Winyah Bay, with over 290,000 lbs applied mainly to soybeans. Additionally, over 355,000 lbs of methyl parathion were applied to cotton and soybeans. Ethoprop, a nematicide, was also heavily used; over 182,000 lbs were applied to soybeans, tobacco, and corn. The dominant herbicides used to control annual grasses and broad-leafed weeds were Alachlor and Atrazine. Winyah Bay ranked fourth and third, respectively, for use of these herbicides.

To assess the potential toxicity of these compounds, an environmental hazard rating was established based on toxicity, persistence of the compound and potential to accumulate. Winyah Bay ranked fifth in toxicity-normalized pesticide use, meaning that it was not only a high use area but also uses pesticides which have a high toxicity.

Even with this heavy use, relatively few pesticides have been detected in Winyah Bay water, sediments, shellfish, or fish tissue. The only organic compounds which have routinely been detected were Dieldrin, DDT, DDD, DDE, and PCBs. Numerous other compounds have been the subject of analysis, but no dectectable levels have been found: Aldrin; Alpha BHC; Arochlor 1242, 1254, 1260; Atrazine; Beta BHC; Endosufan II; Endrin; Gamma BHC; Heptachlor Epoxide; Malathion; Mehoxychlor; Methyl Parathion; Trithion; Toxaphene; Mitrex; Lindane; and Chlordane. Concentrations of DDD (0.4-4.2 ppb), DDE (0-3.4 ppb),

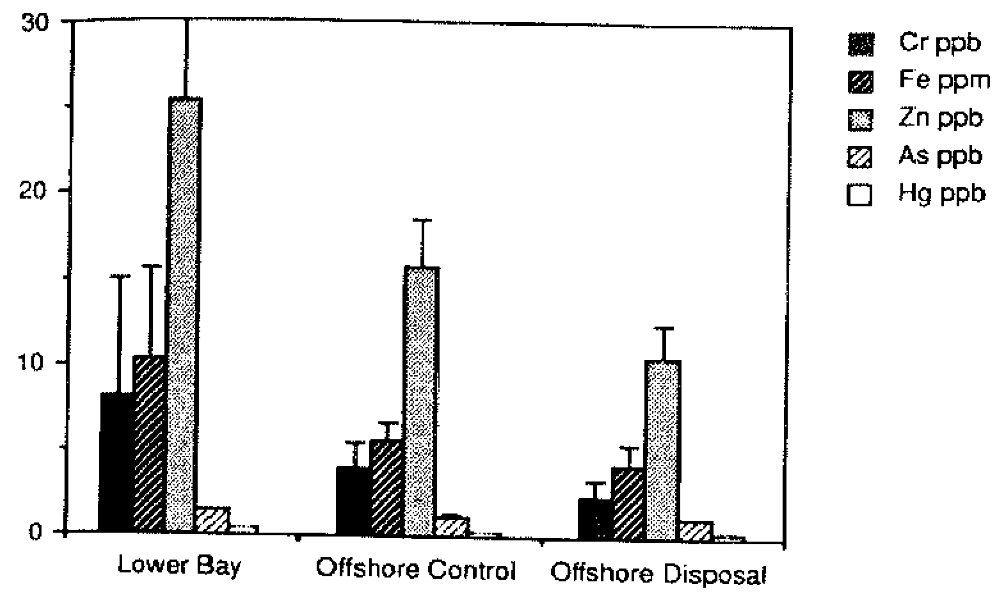


Fig. III-74. Heavy metal concentrations in sediment in lower bay and offshore (Van Dolah et al. 1984).

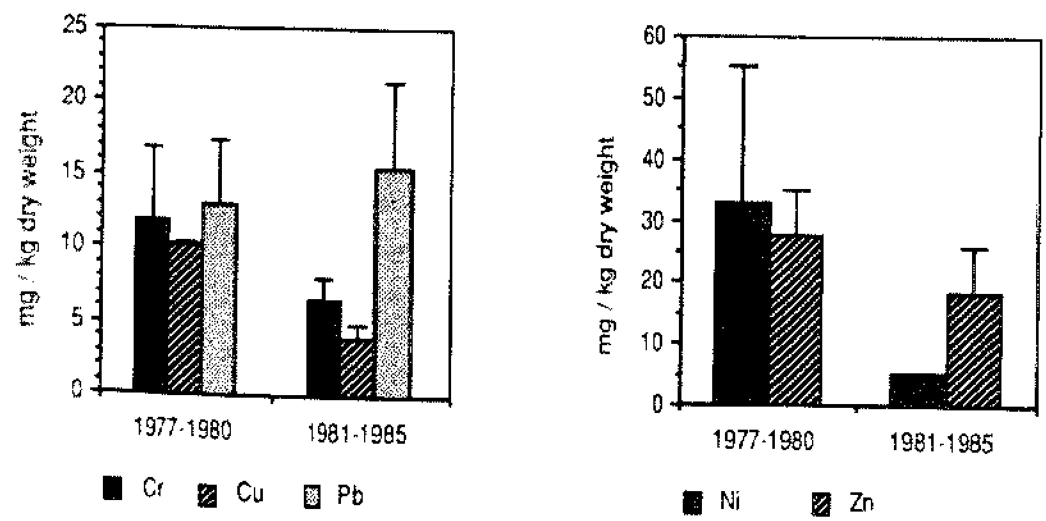


Fig. III-75. Heavy metal mean concentrations (± SE) in sediment from MD080 for the time period indicated (SCDHEC STORET database).

Table III-19. Heavy metal concentrations (ppb) in fish tissue from station MD080 (SCDHEC STORET data). Mean was average of all data for the period 1977-1985.

	Cadmium	Chromium	Copper	Lead	Zinc	Mercury
Mean	361	2,227	9,883	2,841	101,466	254
Number	5	6	6	8	9	5
Minimum	300	1,000	1,250	1,000	4,250	250
Maximum	400	6,950	18,000	12,050	220,000	270

Table III-20. Pesticide and PCB levels in fish tissue collected in 1974-1976. Concentrations are µg/kg wet weight (SCDHEC STORET).

Species	Dieldrin	DDT	DDD	DDE
Elops saurus[1]	18.7	2.9	7.6	
Esox niger[2]	16.7	16.4	11.9	
Leiostomus xanthurus[2]	18.0	33.0		31.0
Micropogon undulatus[2]	4.2	6.5	6.4	
Mugil cephalus[2]	18.6	13.7		

[1] Samples collected in 1974 [2]Samples collected in 1975

and Dieldrin (1.1-9.1 ppb) were detected in sediments from the upper portion of Winyah Bay by Johnson (1970). No detectable levels of Aldrin, Endrin, or Lindane were observed.

South Carolina Department of Health and Environmental Control monitored 297 fish from 74 trend monitoring stations throughout South Carolina from 1974 to 1976. One station from the upper portion of Winyah Bay was sampled (Fig. III-65). Only Dieldrin, DDT, DDD, and DDE were found in the fish tissue (Table III-20). During the sampling period, 88% of fish in the state of South Carolina contained DDT or its isomers and metabolites, with an average of 9.4 ppb in 1974 and 4.8 in 1975. The average DDD was 6.6 ppb in 1974 and 4.7 ppb in 1975. DDE was found in 94% of all fish analyzed, with a mean of 81.6 ppb.

Van Dolah et al. (1984) found no detectable concentrations of PCBs; alpha BHC; Lindane; Heptachlor; beta BHC; Aldrin; Heptachlor Epoxide; DDT; DDE; DDD; Chlordane; Dieldrin; or Endrin dissolved in water, bound with sediments, or in tissue from the knobbed whelk (*Busycon carica*) in the lower Winyah Bay. Jones, Edmunds, and Assoc., Inc. (1979) also found no detectable levels.

The SCDHEC STORET database contains annual measurements for organics in sediments, shellfish, and fishes. Dissolved organics were collected quarterly. To evaluate pollutant concentration trends

Table III-21. Pesticides trend data based on SCDHEC monitoring data for MD080 1977-1985. In 1983 no fish or shellfish were sampled and in 1984 the sampling station was changed from the upper bay to the lower bay off South Island.

Pesticide (μg/kg)	Range
DDD shellfish	4.5
DDE shellfish	1.9-24.5
DDT fish	10-25
DDT shellfish	2.8
Dieldrin shellfish	5.0
PCBs fish	53.5-536.7
Chlordane fish	4.5
α-BHC fish	2.0

in water and sediments, data from MD073, MD074, and MD077 (all three located in the Sampit River) and MD080 (located in upper Winyah Bay) were used. Biological data were available for two stations MD213 and MD637. No trends were obvious in the organic pollutants dissolved in water or present in sediments because rarely did pollutants exceed the detection limit. Table III-22 contains all organic pollutants which have been detected in fish, shellfish, or sediments. As mentioned in the previous toxics section, many other organic pollutants were monitored but all measurements fell below detection limits. These data were insufficient to predict trends in organic pollutants. Data from the only long-term station also were insufficient to assess the impacts on Winyah Bay Estuary. The station was located in the upper portion of the bay and not in a zone where sediments accumulate. It was surprising, given the potential loading of organic pollutants predicted by Pait et al. (1989), that more organics were not detected.

Coliform Bacteria

Winyah Bay

Winyah Bay's water quality was classified SC by SCDHEC. Under this classification coliforms may average 1,000 colonies/100 ml annually. Classification SB requires fecal coliform levels of less than 200 colonies/100 ml, and in SA water less than 70 colonies/100 ml. Based on the long-term fecal coliform average (28.5 ± 18.1, range 0-2,000, mode 30) (1970-1985) at MD080, Winyah Bay should be classified as SA. Sources for fecal coliforms in Winyah Bay included municipal point sources and numerous nonpoint source contaminations from

Table III-22. Pesticides (μg/kg) trend data based on SCDHEC monitoring data. During 1983 no fish or shellfish were sampled and in 1984 the MD080 station was changed to MD213 (lower bay off South Island). Blank cells indicate organics below the detection limit.

Pesticides (μg/kg)	1977	1978	1979	1980	1981	1982	1983	1984	1985
PCB mud	11.8								
DDD shellfish				4.5					
DDE shellfish		24.5	3.5	2.1				1.85	
DDT fish		25	10						
DDT shellfish				2.8					
Dieldrin shellfish		5							
PCBs fish		107			53.5	536.7			
Chlordane fish				4.5					
α-BHC fish								2	

Table III-23. Municipal dischargers into Winyah Bay and associated rivers and tributaries (SCDHEC 1976). Represents target wasteload allocation in 1976.

Municipal Discharger	Volume (MGD)	BOD_5 lbs/day	Fecal Coliform colonies / 100 ml
City of Georgetown	2.0	30	200
White's Creek Subdivision	0.125	30	200
Harmony Hills	0.036	25	
Litchfield Plantation	0.02	30	200
Litchfield Beach	0.02	15	200
Brookgreen Gardens	0.005	60	200
Sea Gull Inn	0.044	24	
Garden City	0.2	30	200

septic systems. Municipal dischargers which were permitted to discharge into Winyah Bay or its tributaries include: the city of Georgetown, White's Creek Subdivision, and Harmony Hills. Litchfield Plantation, Litchfield Beach Sewage Treatment Plants (STP), Brookgreen Gardens, Sea Gull Inn, and Gardent City STP discharge into the Waccamaw River which drains into Winyah Bay (SCDHEC 1976) (Table III-23).

Seasonal trends in fecal coliform were hard to discern because of the high variability in the monthly geometric averages (Fig. III-76). Fecal coliform levels were, in general, higher in May (60.3/100 ml) and November (61.9 colonies/100 ml), with lower levels occurring during the early spring (11.1 colonies/100 ml). Highly variable concentrations occurred during July (SE - 177 colonies/100 ml) and November (SE - 125 colonies/100 ml). These highly variable data resulted from episodic events likely associated with storm discharges.

Linear regression analysis was used on all monthly data from station MD080 to determine if there was a significant seasonal or long-term tend in fecal coliform. Fecal coliform significantly declined during this 15-year period. From 1970 to 1985, fecal coliform at MD080 only exceeded the SB designation (1,000/colonies/100 ml) twice (November 1974, July 1975) and the SA designation (200 colonies/100 ml) four times (Fig. III-77). The apparent lack of significant contamination can be attributed to two factors. First, MD080 was above the Sampit River where the major fecal coliform input originated and significantly down-

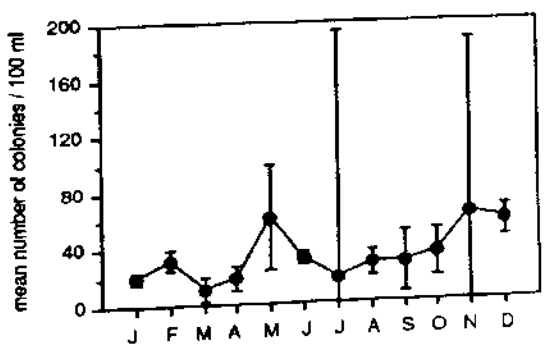


Fig. III-76. Mean monthly fecal coliforms and standard error for 1975-1985 (SCDHEC STORET database).

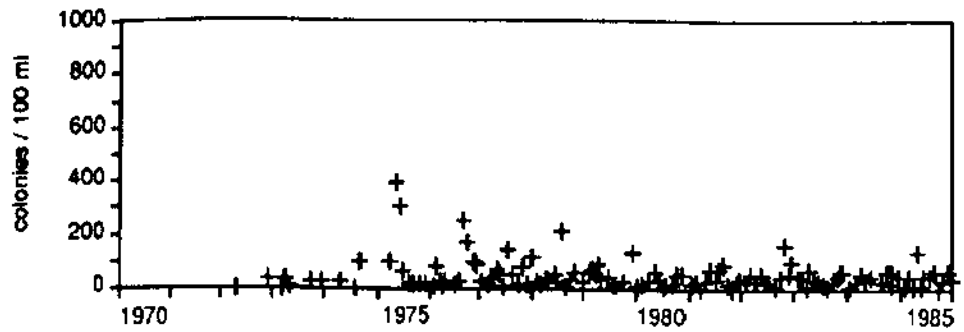


Fig. III-77. Fecal coliform concentrations (colonies/100 ml) at station MD080 (SCDHEC STORET database). Two samples (November 1974 and July 1975) exceeded 1,000 colonies/100 ml (not displayed in the figure).

stream from municipal inputs into the rivers draining into Winyah Bay. Second, the lower portion of the Pee Dee Basin was relatively undeveloped compared to other estuaries (e.g., Charleston Harbor); therefore, the lower loading during the study period contributed to the lack of high coliform measurements.

North Inlet

Fecal coliforms have been sampled at 11 stations in North Inlet Estuary since 1970 (Fig. III-78). Portions of North Inlet Estuary have been restricted or conditionally-restricted for shellfish harvesting based on fecal coliform levels. Figs. III-79 to III-81 contain fecal coliform data for North Inlet Estuary. For stations in the approved area (classification SAA) only one sample during the 15-year record exceeded 200 colonies/100 ml. The geometric average fecal coliform level for stations 10, 3, and 4 were 39, 35.9, and 40 colonies per 100 ml, respectively (SCDHEC STORET database). In the restricted area (stations 6 and 7), fecal coliforms were higher (50.5 and 54.6 colonies/100 ml) with five samples at station 6 and two samples at station 7 exceeding 200 colonies/100 ml. Geometric averages at the remaining conditionally restricted stations ranged from 26 colonies to 91 colonies/100 ml. Violations of the 200 colonies per 100 ml standard averaged four samples per site.

No trends were obvious or significant over the 15-year period. The lack of significant trends reflected the lack of human development in the North Inlet Estuary. Coliforms were primarily due to animal contamination or intrusion from Winyah Bay waters. Even inputs from the North Inlet Estuary terrestrial component were from animal sources in wetland areas draining the forests.

No long-term studies have been conducted on benthic populations in Winyah Bay Estuary at similar locations or with similar sampling equipment. It was not possible to draw inferences from the few isolated studies which have been conducted because of differences in substrate and sampling location.

However, meiofauna have been sampled at two locations (sand habitat and mud habitat) consistently from January 1973 to December 1983 (Coull 1985) in North Inlet Estuary. Nematodes were the most abundant taxon at both sites with higher abundance (856/10 cm^2) at the mud site than the sand site (641/10 cm^2). Copepods were the second most abundant at the mud site (223/10 cm^2) while gastrotrichs (275/10 cm^2) were the second most abundant at the sand site.

Overall meiofauna abundance was similar over the 11-year period (sand - 1,240/10 cm^2, mud - 1,247/10 cm^2). However, the variability was almost double at the sand site. Repeatable annual cycles were evident for the major taxa but no long-term trends were observed. Total meiofaunal abundances were greater from 1974 to 1977 but no physical or biological causative factors were able to explain the increases in abundance (Fig. III-82). Proposed hypotheses included shifts in sediment composition at the sand site and potential longer term natural cyclic phenomena at the mud site.

No data were available to assess long-term trends in planktonic communities of North Inlet Estuary and Winyah Bay Estuary.

Limited data were available to evaluate long-term trends of nekton in North Inlet Estuary. Ogburn et al. (1988) assessed four years of seine and trawl samples at two sites, collected biweekly, from 1981 to 1984. Numbers of nekton species had similar seasonal patterns each year. In 1981, a greater number of species were collected than during the remaining three years. Species richness was greatest during the summer and lowest during the winter.

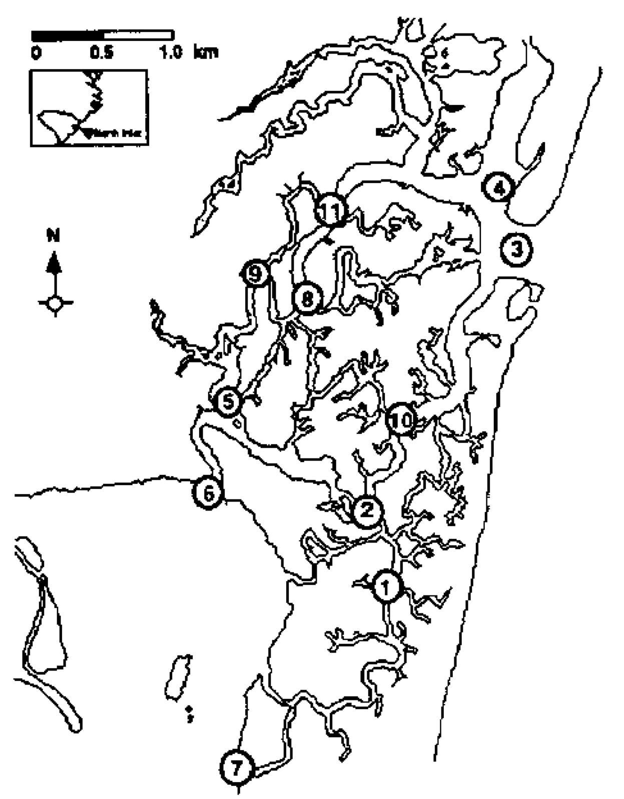


Fig. III-78. Sampling locations in North Inlet Estuary for fecal coliform (# colonies/100 ml).

Fig. III-79. Fecal coliform levels in an area of North Inlet Estuary classified as approved for shellfish harvesting.

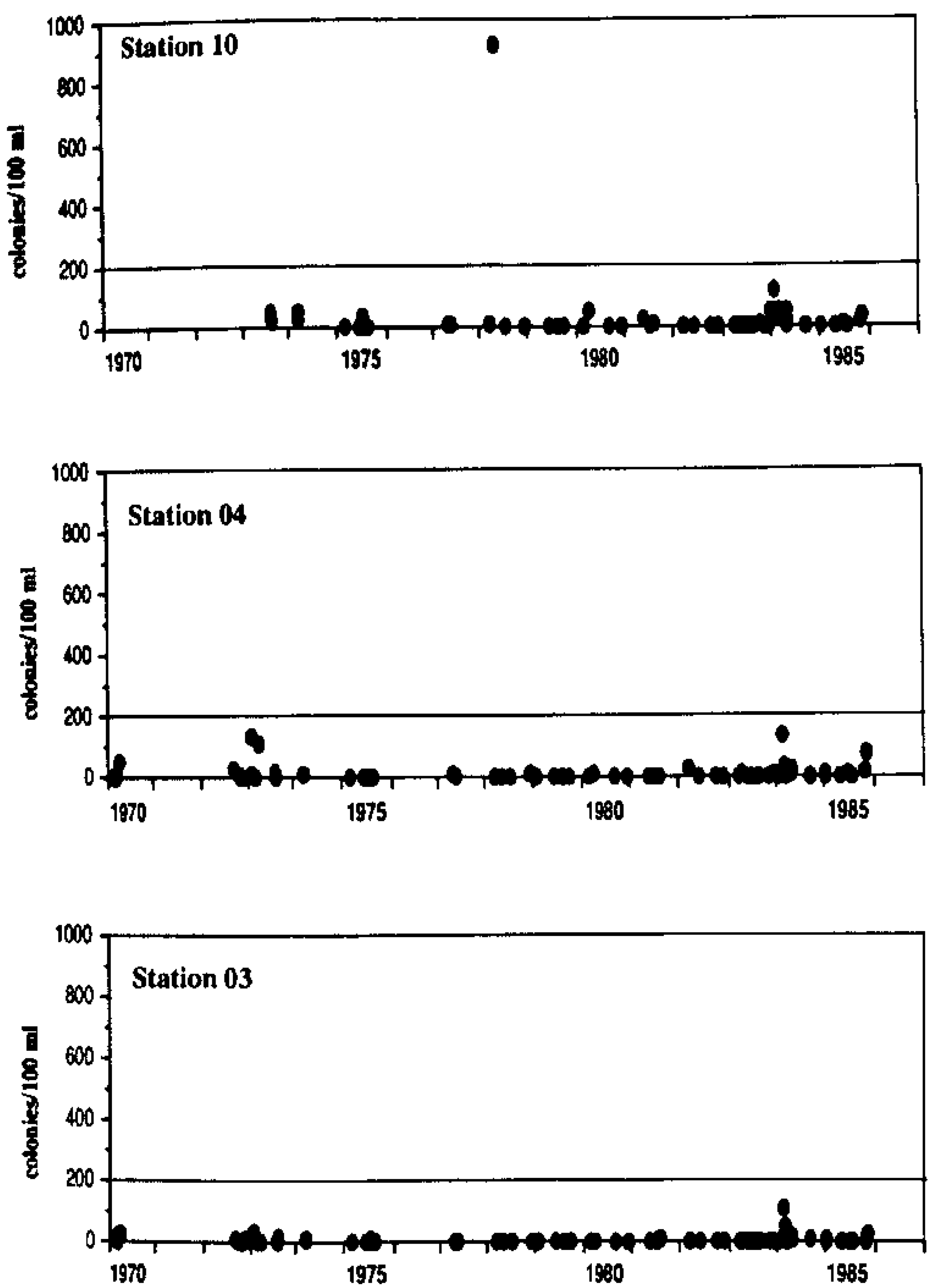


Fig. III-80. Fecal coliform levels in areas of North Inlet Estuary classified as restricted and conditionally approved for shellfish harvesting.

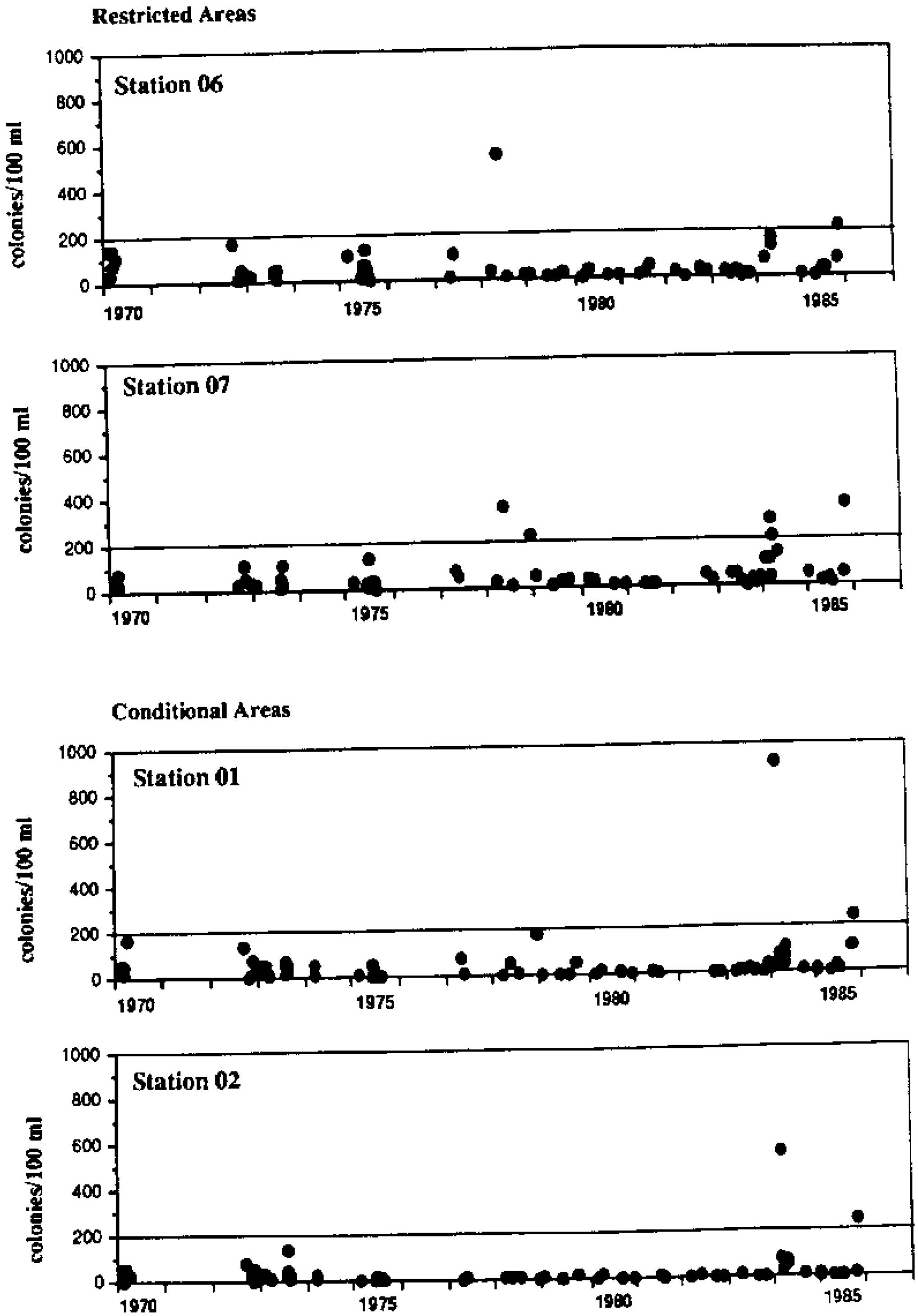
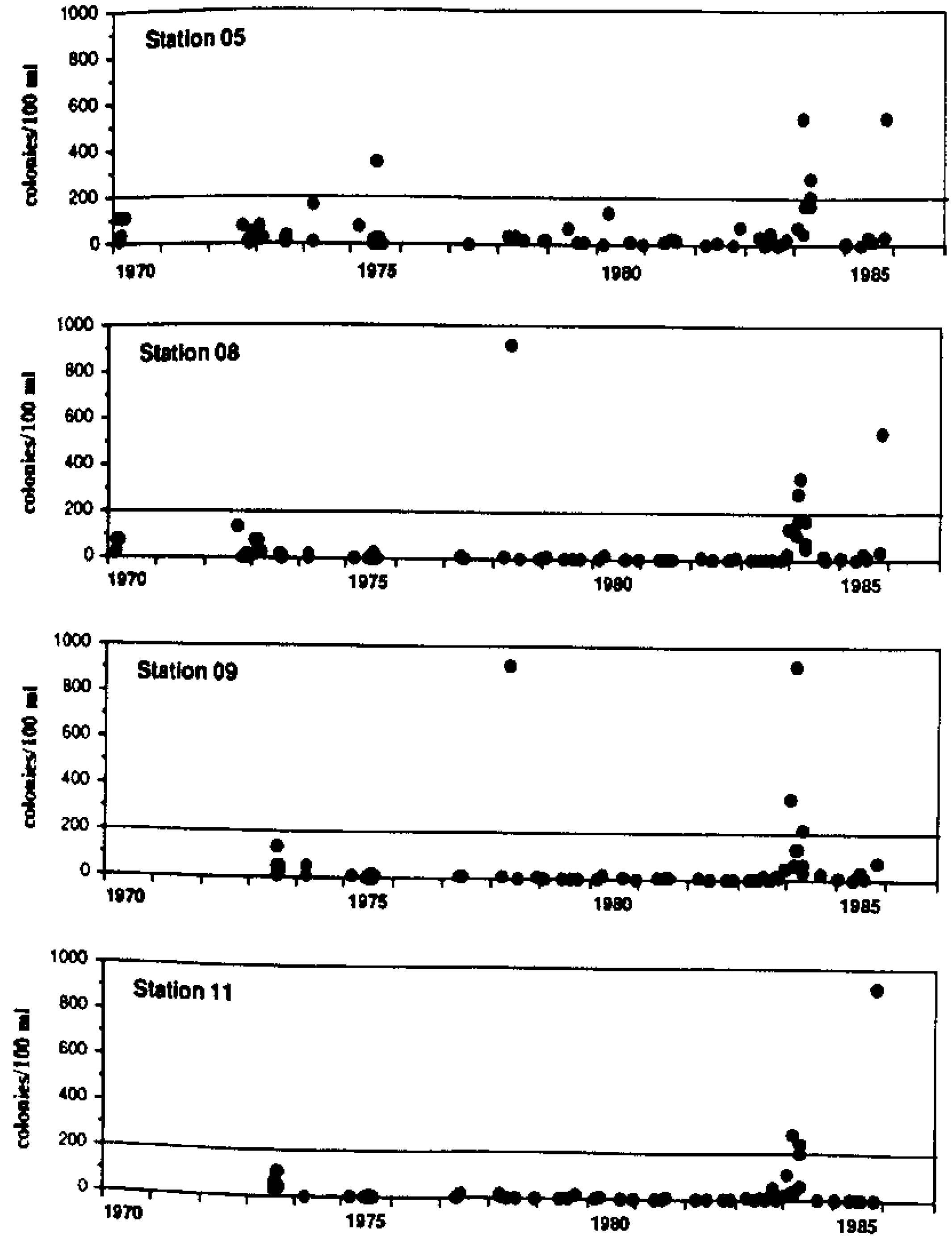


Fig. III-81. Fecal coliform levels in an area of North Inlet Estuary classified as conditionally approved for shellfish harvesting.



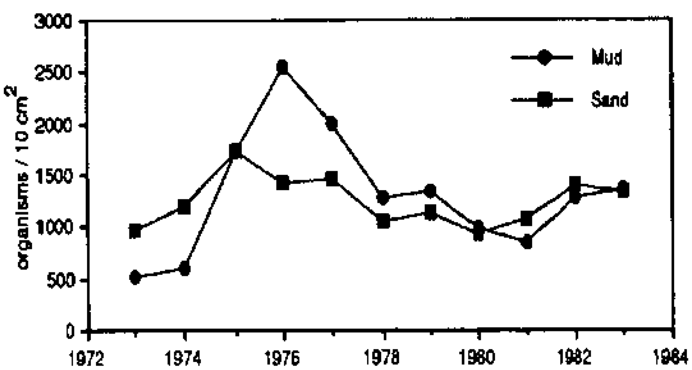


Fig. III-82. Total meiofauna abundance for two sites (mud and sand) in North Inlet Estuary (Coull 1985).

Species richness was not different between years. There was significant year-to-year variation in the number of individuals collected. Annual variation in numbers of individuals varied with sampling location and sampling equipment. As an example, the greatest numbers of individuals were collected in 1983 and 1984 at a mid estuary creek site using trawls while using seines in 1981 were greatest at both a mid-estuary site and in Town Creek.

Winyah Bay has a limited commercial fishery, including shad, river herring, sturgeon, shrimp, and blue crab (Table III-24; Conservation Foundation 1980). The bay was closed to shellfishing (oysters and clams) due to elevated fecal coliform counts (SCDHEC). Recreational fishing activities were low to moderate, with emphasis on red drum, flounder, sea trout, tarpon, sheepshead, and striped bass. The blue crab and shrimp industries in Winyah Bay were minor, accounting for less than 5% (blue crabs) and 10% (shrimps) of the state harvest (Bishop and Shealy 1977; Theiling 1977; Low et al. 1987). Annual reported shrimp landings from Winyah Bay range from approximately 2,700 kg to 91,000 kg and average 36,000 kg (Bearden et al. 1985). The permitted area for shrimp trawling in Winyah Bay was 1,120 hectares, making it one of the most productive of the six permitted areas in South Carolina on a per hectare basis.

South Carolina supports a substantial sturgeon fishery. South Carolina accounted for 55% of the total US landings in 1976 and Winyah Bay reported 93% of total catch in the state. The average sturgeon catch (1958-1982) was 20,700 kg carcass per year. The estimated value for the total sturgeon fishery (carcass and caviar) in 1982 was $177,286 (Smith et al. 1984). A number of offshore species were caught in the Atlantic Ocean within 5 km of Winyah Bay. These commercial and recreational species include: flounders, king fish, blue-

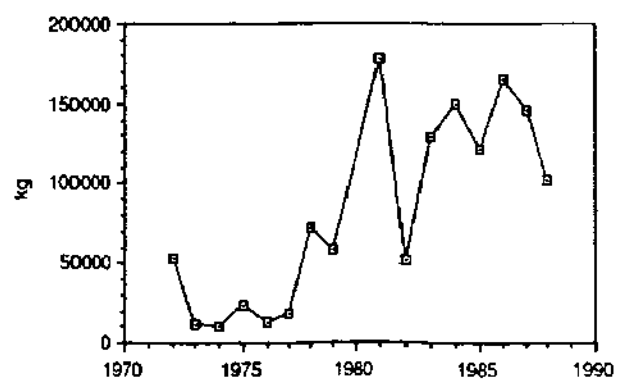


Fig. III-83. Long-term trends in commercial landings of shad in Georgetown, SC, based on fish caught in Winyah Bay and 0-4.8 km offshore from Winyah Bay (SCWMRD unpublished data).

Table III-24. Fishery resources in Winyah Bay (Conservation Foundation 1980).

Anadromous Fishes

- Shad (*Alosa* spp.)
- River herring (*Alosa aestivalis*)
- Sturgeon (*Acipenser oxyrphynchus*)
- Striped bass (*Morone saxatilis*)

Freshwater Fishes

- Largemouth bass (*Micropterus salmoides*)
- Bluegill (*Lepomis macrochirus*)
- Redbreast sunfish (*Lepomis auritus*)
- Warmouth (*Lepomis gulosus*)

Inshore Fishes

- Sea trouts (*Cynoscion nebulosus, C. regalis*)
- Black drum (*Pogonias cromis*)
- Whiting (*Menticirrhus americanus, M. littoralis, M. saxatillis*)
- Channel bass (*Sciaenops ocellata*)
- Spot (*Leoistomus xanthurus*)
- Sheephead (*Archosargus probatocephalus*)
- Croaker (*Micropogon undulatus*)
- Pigfish (*Orthopristis chrysoptera*)
- Flounder (*Paralichthys lethostigma, P. dentatus*)
- Silver perch (*Bairdiella chrysura*)
- Tarpon (*Megalops atlantica*)
- Pompano (*Trachinotus carolinus*)
- Cobia (*Rachycentron canadum*)
- Bluefish (*Pomatomus saltatrix*)
- Spadefish (*Chaetodipterus faber*)

Commercial Estuarine Invertebrates

- Blue crab (*Callinectes sapidus*)
- White shrimp (*Penaeus setiferus*)
- Pink shrimp (*Penaeus duorarum*)
- Brown shrimp (*Penaeus aztecus*)
- Oysters (*Crassostrea virginica*)
- Hard clams (*Mercenaria mercenaria*)

Offshore Pelagic Fishes

- Spanish mackerel (*Scomberomorus maculatus*)
- King mackerel (*Scomberomorus cavalla*)
- Dolphin (*Coryphaena hippurus*)
- Sharks (*Carcharhinus* spp. *Galeocerdo cuvieri, Sphyrna* sp.)
- Bluefish (*Pomatomus saltatrix*)
- Jacks (*Caranx* spp., *Seriola* spp.)
- Wahoo (*Acanthocybium solanderi*)
- Tunas (*Euthynnus* spp., *Thunnus* spp.)
- Barracuda (*Sphyraena barracuda*)
- Cobia (*Rachycentron canadum*)
- Sailfish (*Istiophorus platypterus*)
- Marlins (*Makaira nigrican, Tetrapturus albidus*)

Offshore Demersal Fishes

- Black sea bass (*Centropristis striata*)
- Snappers (*Lutjanus* spp., *Rhomboplites aurorubens*)
- Porgies (*Calamus* spp., *Pagrus sedecim, Stenotomus* spp.)
- Grunts (*Haemulon aurolineatum, H. plumieri*)
- Groupers (*Epinephelus* spp., *Mycteroperca* spp.)

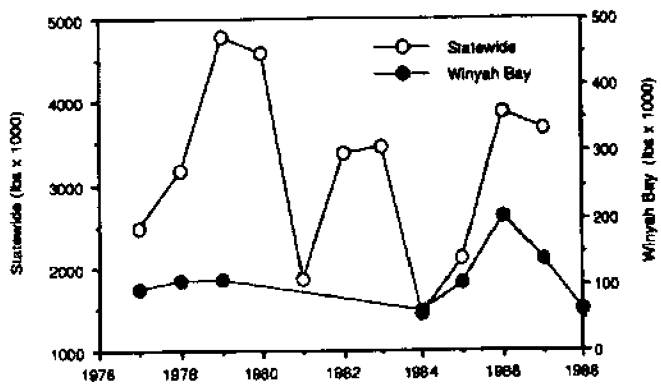


Fig. III-84. Comparison of estimated landings of penaeid shrimp caught in Winyah Bay and out to 4.8 km offshore versus statewide landings estimates (SCWMRD unpublished data). Commercial landings estimates represent catches from Capers Inlet to Kiawah Island 0-9.2 km offshore.

fish, croaker, mullet, pompano, spotted sea trout, spot, spanish mackerel, and shrimp. Average annual total catch (1972-1988) landed at Georgetown was 423,423 kg at an average annual commercial value of $800,634 (SCWMRD unpublished data).

There were only two biological data sets available for Winyah Bay which provide sufficient data to assess long-term trends in fishery resources. One data set included commercial landings of blue crabs, shrimp, and shad caught in Winyah Bay and offshore to 4.8 km (and landed in Georgetown) (SCWMRD unpublished data). The second biological data set was sturgeon fishery landings for South Carolina (Smith et al. 1984). Georgetown landings represent 93% of the state's sturgeon catch. These data have been collected since the early 1900's and reliable data were available from 1958.

Shad (*Alosa* spp.) was an important commercial species in Winyah Bay (Fig. III-83). Commercial landings significantly increased over the study period. Reduced landings were observed from 1973 to 1977. By 1981 landings were averaging 130,000 kg.

Landings of penaeid shrimp (brown and white) showed little variation over the study period (Fig. III-84). Reliable data were only available for the late 1970's and mid 1980's, but by comparing these two periods no trend was obvious. Landings in Georgetown during 1979 did not follow the statewide trend; no increased catch was observed. During

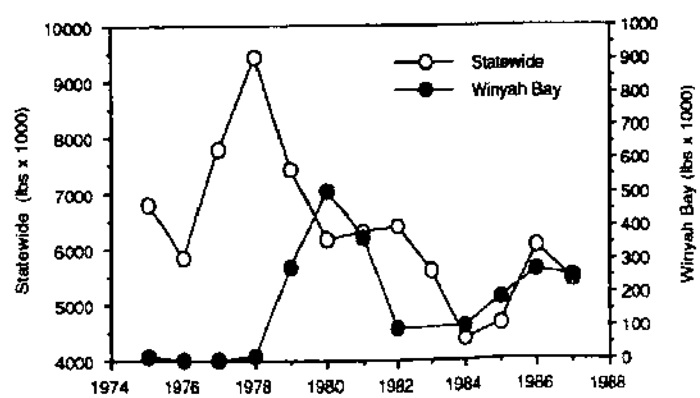


Fig. III-85. Long-term trends in commercial landings of *Callinectes sapidus* (blue crab) Georgetown, SC, based on crabs caught in Winyah Bay and 0-4.8 km offshore from Winyah Bay (SCWMRD unpublished data).

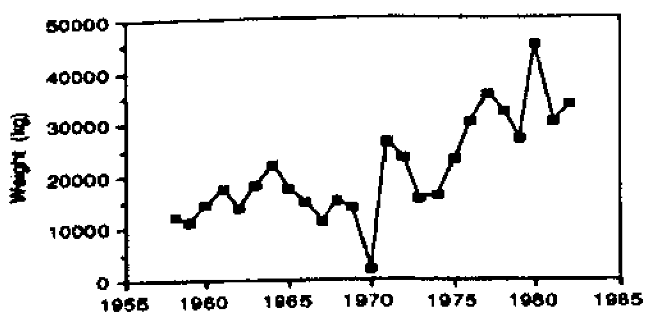


Fig. III-86. Estimated ex-vessel *Atlantic* sturgeon reported landings for South Carolina. Winyah Bay accounts for 93% of these landings (Smith et al. 1984).

the mid 1980's landings for Winyah Bay were similar to statewide trends.

Blue crab landings from Winyah Bay were less than 5% of the state catch (Fig. III-85). Over the study period there was an increase in blue crab landings. The blue crab fishery was almost nonexistent from 1974 until 1978. Landings increased to greater than 500,000 in 1980 but had declined again by 1982. Landings have been steadily increasing since then.

The longest biological data set available for Winyah Bay was the Atlantic sturgeon fishery (Smith et al. 1984). The sturgeon fishery began in Winyah Bay in 1897 when landings peaked at 218,200 kg. In the early 1900's a large decline in landings resulted in the closure of the sturgeon fishery from 1917 to 1919. However, fishing continued during this period and by 1918 landings had been reduced to 58,000 kg. Landings declined to between 10,000 kg to 30,000 kg by the 1930's. Since 1958 there has been an apparent increase in sturgeon landings in Winyah Bay (Fig. III-86).

Caution should be exercised when inferring the nature of fishery resources from landings data. The apparent increase in fishery resource was the result of increased fishing effort over the same period (Fig. III-87). Smith et al. (1984) calculated the catch-per-unit-effort based on number of licensed nets and reported landings. They found that the increased catch since 1976 was a direct reflection of the increased fishing effort and gear competition.

Incidence of Disease

No data exist to evaluate the incidence of disease on estuarine fishes, crustaceans and molluscs.

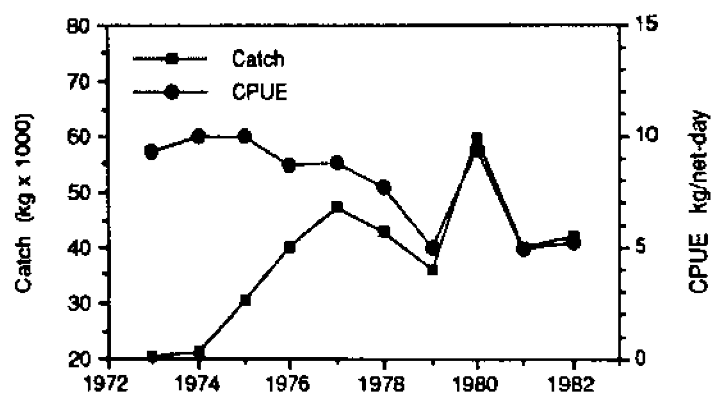


Fig. III-87. Catch-per-unit-effort (CPUE) data for Atlantic sturgeon calculated from total number of licensed nets and reported landings (Smith et al. 1984).

Table III-25. Status of shellfish areas in the Winyah Bay and North Inlet estuaries as January 1, 1986 (Newell 1985).

Waterbody	Acres	Status
North Inlet	1,414	Approved
North Inlet adjacent to Mud Bay	881	Restricted
North Inlet intermediate area	292	Conditional
Oyster Bay	612	Restricted
Sampit River	2,118	Prohibited
Winyah Bay and Mud Bay	12,310	Restricted

Human Health Implications

Closures of Shellfish Areas and Restrictions on Recreation

Waters were closed to shellfishing in September 1974 due to indications of "gross pollution" (SCDHEC 1976; Brooks et al. 1977). The area closed to shellfishing included the Pee Dee and Waccamaw rivers 1.5 km above the US Highway 17 bridges, the Sampit River approximately 3 km up river, Winyah Bay, the Intracoastal Waterway, and parts of several small creeks in North Inlet adjacent to Winyah Bay (Fig. III-88).

In 1976 an appraisal of Winyah Bay Estuary and North Inlet Estuary (both included in the Area 5 designation - SCDHEC) was conducted, which resulted in subdividing the area into prohibited, restricted, and approved for portions of North Inlet Estuary (Fig. III-88) (Newell 1985). No commercial harvesting of shellfish was allowed in Area 5.

A similar assessment was conducted in 1986 which determined that conditions in the lower harbor were not "grossly polluted." Area 5 was

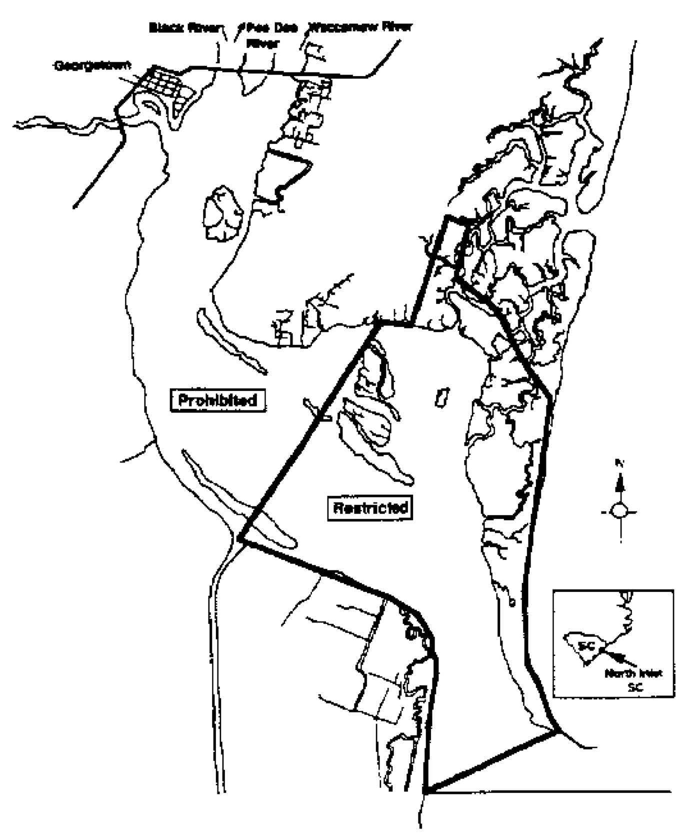


Fig. III-88. Shellfish closure classifications for Winyah Bay Estuary.

reclassified. Within North Inlet Estuary (Fig. III-89) three areas were delineated: the Mud Bay area adjacent to Winyah Bay as restricted; an interface zone delineated as conditionally restricted; and most of North Inlet Estuary as approved (Newell 1985). Recreational harvesting of clams or oysters was restricted seasonally and allowed only in approved areas or in restricted areas for depuration or relaying. Harvesting was allowed during season in conditional areas except when rainfall of > 6.62 cm occurred within a 72-hour period or when prevailing S-SW winds and high river flow caused intrusions of fresh water into the interface zone. Table III-25 contains the status of shellfish areas in Winyah Bay Estuary and North Inlet Estuary as of January 1986.

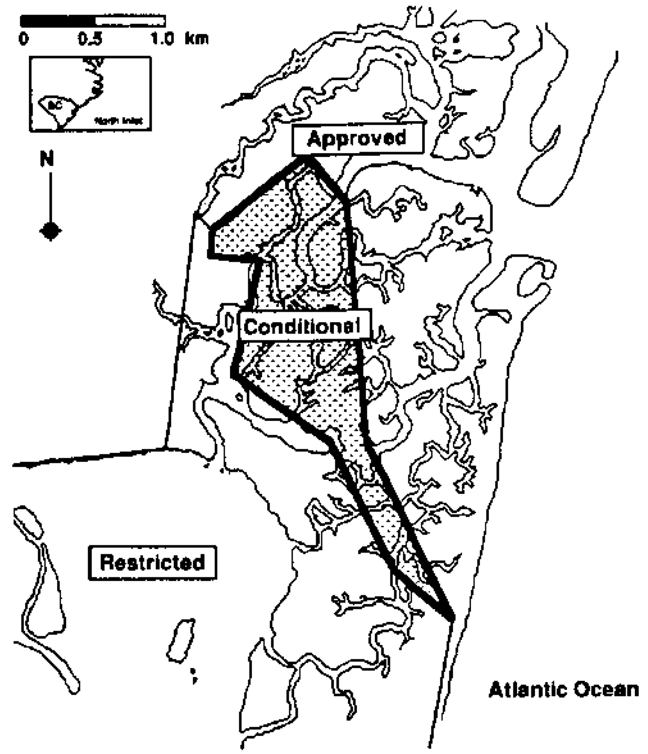


Fig. III-89. Shellfish closure classifications for North Inlet Estuary.

LITERATURE CITED

Allen, D. M., S. E. Stancyk, and W. K. Michener (eds.). 1982. Ecology of Winyah Bay, SC, and Potential Impacts of Energy Development Baruch Institute Special Publication No. 82-1. BelleW. Baruch Institute for Marine Biology and Coastal Research, University of South Carolina, Columbia, SC. 275 p.

Allen, D. M., W. K. Michener, and S. E. Stancyk (eds.). 1984. Pollution Ecology of Winyah Bay, SC: Characterization of the Estuary and Potential Impacts of Petroleum. Baruch Institute Special Publication No. 84-1, Belle W. Baruch Institute for Marine Biology and Coastal Research, University of South Carolina, Columbia, SC. 271 p.

Bearden, C. R., R. Low, R. Rhodes, C. Van Dolah, D. Wenner, E. Wenner, and D. Whitaker. 1985. A review and analysis of commercial shrimp trawling. In: The Sounds and Bays of South Carolina. SC Marine Resource Center Technology Report No. 62. Charleston, SC 51 p.

Beckman, D. and J.M. Dean. 1984. The age and growth of young-of-the-year spot, Leiostomus xanthurus Lacepede, in South Carolina. *Estuaries* 7(4B): 487-496.

Bell, S.S. 1978. Biogenic structure and its effect on the spatial heterogeneity of fauna in a salt marsh. *Journal of Experimental Marine Biology* 35: 99-107.

Bell, S.S. 1979. Short and long term variation in a high marsh meiofauna community. *Estuarine and Coastal Marine Science* 9: 331-350.

Bozeman, E.L. and J.M. Dean. 1980. The abundance of estuarine larval and juvenile fish in a South Carolina intertidal creek. *Estuaries* 3 (2): 99-97.

Brooks, C. L., S. R. Pettigrew, M. C. Moore, M. R. Cannon, and B. C. Springer. 1977. Pee Dee River Basin Framework Study. South Carolina Water Resources Commission Report No. 118 , Columbia, SC. 427 p.

Cain, R. L. and J. M. Dean. 1976. Annual occurrence, abundance and diversity of fish in a South Carolina intertidal creek. *Marine Biology* 36: 200-211.

Childers, D. L. and H. N. McKellar, Jr. 1986. A simulation of saltmarsh water column dynamics. *Ecological Modelling* 35: 211-238.

Chrzanowski, T. H., L.H. Stevenson, and J. D. Spurrier. 1982. Transport of particulate organic carbon through the North Inlet ecosystem. *Marine Ecology Progress Series* 7: 231-245.

Colquhoun, D.J. 1973. Georgetown Harbor, South Carolina environmental studies: Physical framework. Department of Geology, University of South Carolina, Columbia, SC.

Conservation Foundation. 1980. Winyah Bay Reconnaissance Study Summary Report . Washington, D.C. 75 p.

Coull, B. C. 1985. Long-term variability of estuarine meiobenthos: An 11-year study. *Marine Ecology Progress Series* 24: 205-218.

Coull, B. C., S.S. Bell, A.M. Savory, and B.W. Dudley. 1979. Zonation of meiobenthic copepods in a southeastern United States salt marsh. *Estuarine Coastal Marine Science* 9: 181-188.

Coull, B.C. and J. W. Fleeger. 1977. A new species of *Pseudostenhelia*, and morphological variations in *Nannopus palustris* (Copepoda, Harpacticoida). *Transactions of the American Microscopical Society.* 96: 332-340.

Coull, B.C. and W.B. Vernberg. 1975. Reproductive periodicity of meiobenthic copepods: seasonal or continuous. *Marine Biology* 32: 289-293.

Coutinho, R. 1987. Ecology of macroalgae in North Inlet Estuary, SC. Ph.D. Dissertation. University of South Carolina, Columbia, SC. 228 p.

Dame, R. F., T. Chrzanowski, K. Bildstein, B. Kjerfve, H. McKellar, D. Nelson, J. Spurrier, S. Stancyk, H. Stevenson, J. Vernberg, and R. Zingmark. 1986. The outwelling hypothesis and North Inlet, South Carolina. *Marine Ecology Progress Series* 33: 217-229.

Davis and Floyd, Inc. and Arthur D. Little, Inc. 1983. Georgetown Port and Industry Development Study. Phase II-Appendix B Dredging Evaluation. South Carolina State Ports Authority. Charleston-Greenwood, SC. 61 p.

Ebeling, D. E. 1982. Biomass, zonation, and seasonal succession of benthic, intertidal macroalgae on oyster beds in the North Inlet Estuary, South Carolina. M.S. Thesis. University of South Carolina, Columbia, SC. 46 p.

Eiser, W. C. and B. Kjerfve. 1986. Marsh topography and hypsometric characteristics of the South Carolina salt marsh basin. *Estuarine, Coastal, and Shelf Science* 23(5): 595-605.

Erkenbrecher, C. W. and L. H. Stevenson. 1977. Factors related to the distribution of microbial biomass in salt marsh creeks. *Marine Biology* 40: 121-125.

Erkenbrecher, C. W. and L. H. Stevenson. 1980. The dynamics of the bacterial population associated with a salt marsh. *Journal of Experimental Marine Biology and Ecology* 48: 123-138.

Eskin, R. A. 1985. Population dynamics and ecology of the meiobenthic nematodes of North Inlet, South Carolina, Ph.D. Dissertation. University of South Carolina.

Fleeger, J.W. 1979. Population dynamics of three estuaine meiobenthic harpacticoids (*Copepoda*) in South Carolina. *Marine Biology* 52: 147-156.

Fleeger, J.W. 1980. Community structure of an estuarine meiobenthic copepod assemblage. *Estuarine, Coastal and Shelf Science* 10: 107-118.

Fleeger, J.W. and M.A. Palmer. 1982. Seconday production of the estuarine meiobenthic copepod *Microarthridion littorale*. *Marine Ecology Progress Series* 7: 157-162.

Findlay, S.E. G. 1981. Small scale spatial distribution of meiofauna on a mud and sandflat. *Estuarine Coastal and Shelf Science* 12: 471-484.

Gardner, L. R. 1973. The effect of hydrologic factors on the pore water chemistry of intertidal marsh sediments. *Southeastern Geology* 15(1): 17-28.

Gardner, L. R. 1975. Runoff from an intertidal marsh during tidal exposure: Recession curves and chemical characteristics. *Limnology Oceanography* 20(1): 81-89.

Gardner, L. R. and M. Bohn. 1980. Geomorphic and hydraulic evolution of tidal creeks on a subsiding beach ridge plain, North Inlet, SC. *Marine Geology* 34: m91-m97.

Gardner, L. R. and C. Gorman. 1984. Summertime net transport of dissolved oxygen, salt and heat in a salt marsh basin, North Inlet, SC. *Estuarine, Coastal and Shelf Science* 19: 331-339.

Gentry, R. C. 1971. Hurricanes, one of the major features of air-sea interaction in the Caribbean Sea. p. 80-87. In: Symposium on Investigation and Resources of the Caribbean and Adjacent Regions. UNESCO, Paris.

Grant, J. 1981. Sediment transport and disturbance on an intertidal sandflat: Infaunal distribution and recolonization. *Marine Ecology Progress Series* 6: 249-255.

Grant, J. 1983. The relative magnitude of biological and physical sediment reworking in an intertidal community. i. 41: 673-689.

Guttman, N. B. and M. S. Plantico. 1987. Drought history and chances of recurrence. p. 4-7. In: Southeastern Drought Symposium Proceedings. SC State Climatology Office, Columbia, SC. Pub. G-30.

Hall, M. 1979. The species composition and abundance cycle of the phytoplankton in North Inlet Estuary, South Carolina, with special reference to tidal effects. M.S. Thesis. University of South Carolina, Columbia, SC. 61 p.

Hatcher, R. D., Jr. 1972. Developmental model for the southern Appalachians. *Geological Society of America Bulletin* 83: 2734-2760 p.

Hinde, R. M., C. A. Wenner, J. Smith, and D. R. Calder. 1981. Benthic and Nektonic Studies of Winyah Bay for the Proposed Channel Deepening Project and Dredging of the Western Turning Basin. US Corps of Engineers, Charleston, SC. Contract Report DACW60=80-C0029. 141 p.

Holland, A.F. and T.T. Polgar. 1976. Seasonal changes in the structure of an intertidal community. *Marine Biology* 37: 341-348.

Ivester, M.S. 1980. The distibution of meiobenthic copepods along a sediment gradient: factor and niche analyses. *Bulletin of Marine Science* 30(3): 634-645.

Johnson, F. A., 1970. A reconnaissance of the Winyah Bay estuarine zone, South Carolina. SC. Water Resources Commission Report No. 4. Columbia, SC. 36 p.

Jones, Edmunds and Assoc., Inc. 1979. Results of bioassay evaluation of sediments from Georgetown harbor channel. Final Report. Prepared for United States Army Corps Of Engineers, Gainesville, FL. 6 p.

Kjerfve, B. 1978. Bathymetry as an indicator of net circulation in well-mixed estuaries. *Limnology and Oceanography* 23: 816-821.

Kjerfve, B. 1982. Estuarine characteristic, circulation, and mixing. p. 47-78. In: J. W. Day, Jr., C. A. S. Hall, A. Yanez-Arancibia, and L. M. Bahr, Jr. (eds), *Estuarine Ecology*. John Wiley and Sons, NY.

Kjerfve, B. 1984. Hydrographic considerations in estuarine outwelling studies: An example and definitions. p. 37-47. In: O.J. Eong and G. Wooi-Khoon (eds.), Productivity of the Mangrove Ecosystem: Management Implications. UNESCO, Paris.

Kjerfve, B. and H. N. McKellar. 1980. Time series measurements of estuarine material fluxes. p. 341-357. In: V. S. Kennedy (ed.), Estuarine Perspectives. Academic Press, NY.

Kjerfve, B. and J. A. Proehl. 1979 . Velocity variability in a cross-section of a well-mixed estuary. *Journal of Marine Resources* 37: 409-418.

Kjerfve, B., A. Proehl, F. B. Schwing, H. E. Seim, and M. Marozas. 1982. Temporal and spatial considerations in measuring estuarine water fluxes p. 37-51. In: V.S. Kennedy (ed.), Estuarine Comparisons. Academic Press, Inc. NY.

Kjerfve, B. , L.H. Stevenson, J.A. Proehl, T. H. Chrzanowski, and W. M. Kitchens. 1981. Estimation of material fluxes in an estuarine cross section: A critical analysis of spatial measurement density and errors. *Limnology and Oceanographyy* 26(2): 325-335.

Knowles, S. C. and D. J. Fabel. 1986. Water Quality Assessment FY1984-1985 Report. South Carolina Department of Health and Environmental Control, Columbia, SC. 155 p.

Lonsdale, D. J. and B. C. Coull. 1977. Composition and seasonality of zooplankton of North Inlet, South Carolina. *Chesapeake Science* 18(3): 272-283.

Low, R.A., W. Waltz, R. Martore, and C.J. Moore. 1986. South Carolina marine recreational fishery surveys, 1985 and 1986. South Carolinal Marine Resources and Research Institute of Technology. Technical report 65. Charleston, SC. 65 p.

Low, R., R. Rhodes, E. Hens, D. Theiling, E. Wenner, and D. Whitaker. 1987. A profile of the blue crab and its fishery in South Carolina. Marine Resources Research Institute Technical Report 66. Charleston, SC. 37 p.

Mathews, T. D. and M. H. Shealy, Jr. 1978. Hydrography of South Carolina Estuaries with emphasis on the North and South Edisto and Cooper Rivers. SC Marine Resources Center Tech.nical Report 30. Charleston, SC. 148 p.

Mathews, T. D. and M. H. Shealy, Jr. 1982. A Description of the Salinity Regimes of Major South Carolina Estuaries. SC Marine Resources Center, Report 54. Charleston, SC. 142 p.

Mathews, T. D., D. W Stapor, Jr., C. R. Richter, J. V. Miglarese, M. D. McKenzie, L. A. Barclay, E. B. Joseph, and M. D. McKenzie (eds.). 1980. Ecological Characterization of the Sea Island Coastal Region of South Carolina and Georgia. Vol. I: Physical Features of the Characterization Area. US Fish and Wildlife Service, Office of Biological Service, Washington D.C. FWS/OBS- 79/40. 212 p.

Michener, W. K., D. M Allen, E. R. Blood, T. A. Hiltz, B. Kjerfve, and F. H. Sklar 1990. Climatic variability and salt marsh ecosystem response: Relationship to scale. In: D. Greenland and L.W. Swift, Jr. (eds.). Climate Variability and Ecosystem Response. Proc., Long-Term Ecological Research Workshop. USDA Forest Service General Technical Rep. SE-65, Asheville, NC.

Miller, J. L. and L. R. Gardner. 1981. Sheet flow in a salt marsh basin, North Inlet, SC. *Estuaries* 4: 234-237.

Montagna, P. A. 1984. In situ measurement of meiobenthic grazing rates on sediment bacteria and edaphic diatoms. *Marine Ecology Progress Series* 18: 119-130.

Montagna, P. A., B. C. Coull, T. L. Herring, and B. W. Dudley. 1983. The relationship between abundances of meiofauna and their suspected microbial food (diatoms and bacteria). *Estuarine, Coastal, and Shelf Science* 17: 381-394.

Moore, R. H. and R. R. Reis. 1983. Analysis of spatial and temporal variations in biomass and community structure of motile organisms in Town Creek, SC. *Journal of Marine Science* 26: 111-125.

National Oceanic and Atmospheric Administration. 1985. Local Climatological Data for Georgetown, SC. (30 year summary, 1951-1981), National Climatic Data Center, Asheville, NC.

Newell, C. 1985. Sanitary Survey Area 5. South Carolina Department of Health and Environmental Control, Columbia, SC.

Newell, C. 1987. Sanitary Survey Area 5 1983-1985. South Carolina Department of Health and Environmental Control, Columbia, SC.

Ogburn, M. V., D. M. Allen, and W. K. Michener. 1988. Fishes, Shrimps, and Crabs of the North Inlet Estuary, SC: A Four-Year Seine and Trawl Study. Belle W. Baruch Institute Technical Report 88-1. BelleW. Baruch Institute for Marine Biology and Coastal Research, University of South Carolina, Columbia, SC. 299 p.

Pait, A. S., D. R. G. Farrow, J. A. Lowe, and P. A Pacheco. 1989. Agricultural Pesticide Use in Estuarine Drainage Areas: A Preliminary Summary for Selected Pesticides. Office of Oceanography and Marine Assessment, National Ocean Service, NOAA. Rockville, MD. 134 p.

Palmer, M.A. 1980. Variation in life-history patterns between intertidal and subtidal populations of the meiobenthic copepod *Microarthridion littoral.*. *Marine Biology* 60: 159-165.

Palmer, M. A., B. Kjerfve, and F. B. Schwing. 1980. Tidal analysis and prediction in a South Carolina estuary. *Contributions in Marine Science* 23: 17-23.

Palmer, M. A. and G. Gust. 1985. Dispersal of meiofauna in a turbulent tidal creek. *Journal of Marine Research* 43: 179-210.

Palmer, M. A. 1986. Hydrodynamics and structure: interactive effects on meiofauna dispersal. *Journal of Experimental Biological Ecology* 104: 53-68.

Palmer, M. A. and R. M. Molloy. 1986. Water flow and the vertical distribution of meiofauna: A flume experiment. *Estuaries* 9(3): 225-228.

Palmer, M.A. 1988. Epibenthic predators and marine meiofauna: separating predation, disturbance, and hydrodynamic effects. *Ecology* 69(4): 1251-1259.

Pilkey, O. H., F. Keer, and S. Keer. 1979. Surficial sediments of the Atlantic southeastern United States continental shelf. *South Atlantic Outer Continental Shelf Geological Studies* 138-181.

Pritchard, D. W. 1955. Estuarine circulation patterns. *Proceedings American Society of Civil Engineers* 81(717): 1-11

Purvis, J. C. and A. McNab, Jr. 1985. Hurricane Vulnerability for Georgetown County. South Carolina Water Resources Commission, Columbia, SC. 17 p.

Purvis, J. C., W. Tyler, and S. Sidlow. 1986. Hurricanes Affecting South Carolina. South Carolina State Climatology Office, Columbia, SC. 19 p.

Schwing, F. B. and B. Kjerfve. 1980. Longitudinal characterization of a tidal marsh creek separating two hydrographically distinct estuaries. *Estuaries* 3(4): 236-241.

Schwing, F. B., B. Kjerfve, and J. E. Sneed. 1983. Nearshore coastal currents on the South Carolina continental shelf. *Journal of Geophysical Research* 88: 4719-4729.

Sellner, B. W. 1973. Primary production and the release of dissolved organic matter from natural communities of estuarine phytoplankton. M.S. Thesis. University of South Carolina, Columbia, SC. 40 p.

Sellner, D. G., R. G. Zingmark, and T. G. Miller. 1976. Interpretations of the 14C method of measuring the total annual production phytoplankton in a South Carolina estuary. *Botanica Marina* 21: 119-125.

Sharma, P. L. R. Gardner, W. S. Moore, and M. S. Bollinger. 1987. Sedimentation and bioturbation in a salt marsh as revealed by ^{210}Pb, ^{137}Cs and ^{7}Be studies. *Limnology and Oceanography* 32: 313-326.

Shealy, M. H., Jr., J. V. Miglarese, and E. B. Joseph. 1974. Bottom Fishes of South Carolina Estuaries - Relative Abundance, Seasonal Distribution and Length Frequency Relationships. Technical Report No 6. SC Marine Resources Center, Charleston, SC. 189 p.

Shenker, J. M. and J. M. Dean. 1979. The utilization of an intertidal salt marsh creek by larval and juvenile fishes: Abundance, diversity, and temporal variation. *Estuaries* 2: 154-163.

Smith, T. I., D.E. Marchette, and G. Ulrich. 1984. The Atlantic sturgeon fishery in South Carolina. *North American Journal of Fisheries Management* 4: 164-176.

Snyder, H. S. 1983. State Water Assessment. Report No. 140. South Carolina Water Resources Commission, Columbia, SC. 368 p.

South Carolina Division of Research and Statistical Services. 1988. SC Statistical Abstracts 1987-1988. SC Budget and Control Board, Columbia, SC. 454 p.

Stapor, F. W. and R.S. Murali. 1978. Computer modeling of littoral sand transport (shoreline-parallel) for coastal South Carolina. Technical Report 29. South Carolina Marine Resoures Research Institute, Charlestion, SC. 9 p.

Tansey H . B. 1987. Forest Statistics for Northern Coastal Plain of South Carolina. Resource Bulletin SE-91. USDA, Southeast Experimental Station, Charleston, SC.

Theling, D. 1977. South Carolina's 1976 Shrimp Trawler Season .Technical Report 24. SC Marine Resources Research Institute, Charleston, SC. 31 p.

Tiner, R. W. 1977. An Inventory of South Carolina's Coastal Marshes. Technical Report No. 23. SC Marine Resources Center, Charleston, SC. 33 p.

Trawle, J. J. 1978. Georgetown Harbor, South Carolina; Report 1, Hydraulic, Salinity, and Shoaling Verification; Hydraulic Model Investigation. USACOE District, Charleston, SC. Miscellaneous paper H-78-6 Report 1 of a series.

US Army Corps of Engineers. 1984. Final Environmental Impact Statement for Oil Refinery Pipeline Crossing Georgetown, South Carolina. Vol 1. Charleston, SC. 33 p.

US Department of Commerce. 1987. Census of agriculture Volume 1. Geographic area series part 40. South Carolina. Washington, D.C. 304 p.

US Soil Conservation Service. 1979. Yadkin-Pee Dee River Basin, North Carolina and South Carolina; Erosion and Sediment Inventory. US Department of Agriculture, Special Report. Charleston, SC.

US Water Resource Commission. 1979. Yadkin-Pee Dee River basin, Level B Existing Plan. US Water Resources Commission. 94 p.

Van Dolah, R. F., D. M. Knott, E. L. Wenner, T. D. Mathews, and M. P. Katuna. 1984. Benthic and Sedimentological Studies of the Georgetown Ocean Dredged Material Disposal Site. Technical Report Number 59. South Carolina Marine Resources Center, Charleston, SC. 97 p.

Vennewitz, M. 1977. Biomass, productivity and associated environmental variables of the net- and nannophyto-plankton in the North Inlet Estuary, South Carolina. M.S. Thesis. University of South Carolina, Columbia, SC.

Vernberg, W. A. and B. C. Coull. 1975. Multiple factor effects of environmental parameters on the physiology, ecology, and distribution of some marine meiofauna. *Cahiers De Biologie Marine* 16: 721-732.

Waccamaw Regional Planning and Development Council. 1977. Georgetown County Land Use Plan. Waccamaw Regional Planning and Development Council, Georgetown, SC. 125 p.

Waccamaw Regional Planning and Development Council. 1978. Waccamaw Regional 208 Areawide Water Quality Plan, Appendix 5 Regional Data Development, Appendix 6 Water Quality Evaluation and ICWW Model Calibration, Appendix 7 Non-Point Source Evaluation and Storm Model Calibration. Waccamaw Regional Planning and Development Council, Georgetown, SC.

Waccamaw Regional Planning and Development Council. 1985. Land Use Plan Update for the Waccamaw Neck. Georgetown, SC. 125 p.

Wenner, E. L., W. P. Coon, III, M. H. Shealy, and P. A. Sandifer. 1981. Species Assemblages, Distribution, and Abundance of Fishes and Decapod Crustaceans from the Winyah Bay. Technical Report, Number 3, South Carolina Sea Grant, Charleston, SC. 61 p.

Whiting, G. J., E. L. Gandy, and D. C. Yoch. 1986. Tight coupling of root associated nitrogen fixation and plant photosynthesis in the salt marsh grass *Spartina alterniflora* and carbon dioxide enhancement of nitrogenase activity. *Applied and Environmental Microbiology* 52(1): 108-113.

Whiting, G. J., H. N. McKellar, Jr., B. Kjerfve, and J. D. Spurrier. 1987. Nitrogen exchange between a southeastern U. S. salt marsh and the coastal ocean. *Marine Biology* 95: 173-182.

Wolaver, T. G., R. F. Dame, J. D. Spurrier, and A. B. Miller. 1988. The Bly Creek Ecosystem Study: Sediment Exchange between a euhaline salt marsh in South Carollina and the adjacent tidal creek. *Journal of Coastal Research* 4(1): 17-26

Wolaver, T. G., S. Hutchinson, and M. Marozas. 1986. Dissolved and particulate organic carbon In:the

North Inlet Estuary, South Carolina: What controls their concentrations. *Estuaries* 9(1): 31-38.

Wolaver, T. G., W. V. Johnson, and M. Marozas. 1984. Nitrogen and phosphorus concentrations withIn:North Inlet, South Carolina; Speculation as to sources and sinks. *Estuarine, Coastal and Shelf Science* 19: 243-255.

Yadkin Pee Dee River Basin. 1979. Level B exising plan and technical appendices. United States Water Resources Council. Washington, D.C.

Zarillo, G. A, L. G. Ward, and M. O. Hayes. 1985. An Illustrated History of Tidal Inlet Changes in South Carolina. SC Sea Grant Consortium, Charleston, SC. 76 p.

Zeeman, S. I. 1981. Phytoplankton photosynthesis and its relation to light intensity in a turbid estuary and the nearshore coastal ocean. Ph.D. Dissertation. University of South Carolina, Columbia, SC. 210 p.

Zingmark, R. G. 1977. Studies on the phytoplankton and microbenthic algae in the North Inlet Estuary. p. 35-39, In: F. J. Vernberg, R. Bonnell, B. Coull, R. Dame, Jr., P. Decoursey, W. Kitchens, Jr., B. Kjerfve, H. Stevenson, W. Vernberg and R. Zingmark (eds). The Dynamics of an Estuary as a Natural Ecosystem. USEPA EPA-600/3-77-016. Gulf Breeze, FL. 86 p.

Appendix I. North Inlet Estuary Compiled Species List

Phytoplankton (Hall 1979)

() are numbers of different species identified

Achnanthes haukiana
Achnanthes fimbriata
Achnanthes sp.
Actinocyclus ehrenbergii
Actinoptypchus undulatus
Amphora granulata
Amphora spp. (6)
Anorthoneis tenuis
Asteromphalus hookeri
Asterionella glacialis
Bacteriastrum hyalinum
Bacteriastrum varians
Biddulphia aurita
Biddulphia longicruris
Biddulphia mobiliensis
Biddulphia regina
Biddulphia sinensis
Biddulphia tridens
Caloneis oregonica
Campylosira cymbelliformis
Ceratium furca
Chaetoceros didymus
Chaetoceros spp. (3)
Cocconeis disculoides
Cocconeis placentula var. lineata
Cocconeis scutellum
Cocconeis spp. (6)
Coscinodiscus asteromphalus
Coscinodiscus curvatulus
Coscinodiscus excentricus
Coscinodiscus lineatus
Coscinodiscus marginatus
Coscinodiscus nitidus
Coscinodiscus perforatus
Coscinodiscus radiatus
Coscinodiscus spp. (9)
Cyclotella striata
Cylindrotheca closterium
Cymatosira belgica
Clorenziana
Cymbella sp.
Denticula subtilis
Dictyocha fibula
Dimerogramma fulvum
Dimerogramma minor
Dimerogramma spp. (2)
Dinophysis homuculus
Diploneis bombus
Diploneis interrupta
Diploneis smithii
Diploneis spp. (4)
Diplopsalis sp.
Eunotogramma laevis
Grammatophora marina
Gymnodinium spp. (9)
Gyrodinium sp.
Gyrosigma acuminatum
Gyrosigma balticum
Gyrosigma fasciola
Gyrosigma humii
Gyrosigma peisonis
Gyrosigma sp.
Hyalodiscus subtilis
Hantzschia sp.
Licmorpha sp.
Mastogloia sp.
Melosira mummuloides
Melosira sulcata
Navicula abunda
Navicula agnita
Navicula arenaria
Navicula cancellata
Navicula clavata
Navicula clementis
Navicula crucicula
Navicula diversestriata
Navicula fromenterae
Navicula irrorata
Navicula longa
Navicula platyventris
Navicula subforcipata
Navicula tuscula
Navicula spp. (22)
Nitzschia compressa
Nitzschia constricta
Nitzschia fasiculata

Nitzschia hummii
Nitzschia pacifica
Nitzschia panduriformis
Nitzschia procera
Nitzschia seriata
Nitzschia sigma
Nitzschia spp. (22)
Naked flagellate (3)
Oxytoxum sp.
Peridinium oceanicum
Peridinium trochodium
Peridinium tuba
Peridinium spp.(4)
Plagiogramma rhombicum
Plagiogramma van Heurckii
Plagiogramma wallianchium
Plagiogramma sp.
Pleurosigma aestuarii
Pleurosigma australe
Pleurosigma marium
Pleurosigma naviculaceum
Pleurosigma normanii
Pleurosigma sp.
Prorocentrum micans
Prorocentrum minimum
Rhaphoneis amphiceros
Rhaphoneis surirella
Rhizosolenia alata
Rhizosolenia bergonii
Rhizosolenia calcaravis
Rhizosolenia dilicatula
Rhizosolenia fragilissima
Rhizosolenia imbricata
Rhizosolenia setigera
Rhizosolenia stolterforthii
Skeletonema costatum
Stephanopyxis turris
Surirella sp.
Synedra sp.
Thalassiothrix longissima
Trachyneis aspera
Triceratium alternans

Macroalgae (Ebling 1982)

Enteromorpha sp.
Enteromorpha siliculosus
Ulva lactuca
Bryopsis plumosa
Porphyra leucosticta
Gracilaria folifera
Chondria baileyana
Ceramium sp.
Grinellia americana
Dasya pedicellata
Polysiponia denudata
Monostroma oxyspermum
Giffordia mitchellae
Sytosiphon lomentaria

Fishes, Shrimps and Crabs (Ogburn et al. 1987)

Carcharhinidae - requiem sharks
- *Rhizoprionodon terraenovae* - Atlantic sharpnose shark

Rajidae - skates
- *Raja eglanteria* - clearnose skate

Dasyatidae - stingrays
- *Dasyatis* americana - southern stingray
- *Dasyatis sabina* - Atlantic stingray
- *Dasyatis sayi* - bluntnose stingray
- *Gymnura micrura* - smooth butterfly ray

Clupeidae - herrings
- *Alosa aestivalis* - blueback herring
- *Brevoortia tyrannus* - Atlantic menhaden
- *Dorosoma cepedianum* - gizzard shad
- *Dorosoma petenense* - threadfin shad
- *Sardinella aurita* - Spanish sardine

Engraulidae - anchovies
- *Anchoa hepsetus* - striped anchovy
- *Anchoa mitchilli* - bay anchovy

Synodontidae - lizardfishes
- *Synodus foetens* - inshore lizardfish

Ariidae - sea catfishes
- *Arius felis* - hardhead catfish

Batrachoididae - toadfishes
- *Opsanus tau* - oyster toadfish

Gobiesocidae - clingfishes

Fishes, Shrimps, and Crabs - continued

Gobiesox strumosus - skilletfish
- Gadidae - codfishes
  - *Urophycis floridana* - southern hake
  - *Urophycis regia* - spotted hake
- Ophidiidae - cuskfishes
  - *Ophidion marginatum* - striped cusk-eel
- Belonidae - needlefishes
  - *Strongylura marina* - Atlantic needlefish
- Cyprinodontidae - killifishes
  - *Fundulus heteroclitus* - mummichog
  - *Fundulus majalis* - striped killifish
- Atherinidae - silversides
  - *Membras martinica* - rough silverside
  - *Menidia beryllina* - inland silverside
  - *Menidia menidia* - Atlantic silverside
- Syngnathidae - pipefishes
  - *Hippocampus erectus* - lined seahorse
  - *Syngnathus floridae* - dusky pipefish
  - *Syngnathus fuscus* - northern pipefish
  - *Syngnathus louisianae* - chain pipefish
  - *Syngnathus* spp.- pipefish
- Percichthyidae - temperate basses
  - *Morone americana* - white perch
- Serranidae - sea basses
  - *Centropristis philadelphica* - rock sea bass
  - *Centropristis striata* - black sea bass
  - *Epinephelus morio* - red grouper
  - *Mycteroperca microlepis* - gag
- Pomatomidae - bluefishes
  - *Pomatomus saltatrix* - bluefish
- Rachycentridae - cobias
  - *Rachycentron canadum* - cobia
- Carangidae - jacks
  - *Caranx hippos* - crevalle jack
  - *Caranx latus* - horse-eye jack
  - *Chloroscombrus chrysurus* - Atlantic bumper
  - *Selene vomer* - lookdown
  - *Trachinotus carolinus* - Florida pompano
  - *Trachinotus falcatus* - permit
- Lutjanidae - snappers
  - *Lutjanus analis* - mutton snapper
  - *Lutjanus griseus* - gray snapper
  - *Lutjanus synagris* - lane snapper
- Gerreidae - mojarras
  - *Diapterus auratus* - Irish pompano
  - *Eucinostomus argenteus* - spotfin mojarra
  - *Eucinostomus gula* - silver jenny
- Haemulidae - grunts
  - *Orthopristis chrysoptera* - pigfish
- Sparidae - porgies
  - *Lagodon rhomboides* - pinfish
- Sciaenidae - drums
  - *Bairdiella chrysoura* - silver perch
  - *Cynoscion nebulosus* - spotted seatrout
  - *Cynoscion regalis* - weakfish
  - *Leiostomus xanthurus* - spot
  - *Menticirrhus americanus* - southern kingfish
  - *Menticirrhus saxatilis* - northern kingfish
  - *Micropogonias undulatus* - Atlantic croaker
  - *Stellifer lanceolatus* - star drum
- Ephippidae - spadefishes
  - *Chaetodipterus faber* - Atlantic spadefish
- Mugilidae - mullets
  - *Mugil cephalus* - striped mullet
  - *Mugil curema* - white mullet
- Sphyraenidae - barracudas
  - *Sphyraena borealis* - northern sennet
- Uranoscopidae - stargazers
  - *Astroscopus guttatus* - northern stargazer
  - *Astroscopus y-graecum* - southern stargazer
- Blenniidae - combtooth blennies
  - *Hypleurochilus geminatus* - crested blenny
  - *Hypsoblennius hentzi* - feather blenny
- Gobiidae - gobies
  - *Gobionellus boleosoma* - darter goby
  - *Gobiosoma bosci* - naked goby
  - *Gobiosoma ginsburgi* - seaboard goby
- Trichiuridae - cutlassfishes
  - *Trichiurus lepturus* - Atlantic cutlassfish
- Scombridae - mackerels
  - *Scomberomorus maculatus* - Spanish mackere
- Stromateidae - butterfishes
  - *Peprilus alepidotus* - harvestfish
- Scorpaenidae - scorpionfishes
  - *Scorpaena brasiliensis* - barbfish
- Triglidae - searobins
  - *Prionotus carolinus* - northern searobin
  - *Prionotus evolans* - striped searobin
  - *Prionotus scitulus* - leopard searobin
  - *Prionotus tribulus* - bighead searobin
  - *Prionotus* spp.
- Bothidae - lefteye flounders
  - *Ancylopsetta quadrocellata* - ocellatedflound
  - *Citharichthys macrops* - spotted whiff
  - *Citharichthys spilopterus* - bay whiff
  - *Etropus crossotus* - fringed flounder
  - *Paralichthys albigutta* - gulf flounder
  - *Paralichthys dentatus* - summer flounder
  - *Paralichthys lethostigma* - southern flounder
  - *Scophthalmus aquosus* - windowpane

Soleidae - soles

Trinectes maculatus - hogchoaker

Cynoglossidae - tonguefishes

Symphurus plagiusa - blackcheek tonguefish

Balistidae - leatherjackets

Aluterus schoepfi - orange filefish

Monacanthus hispidus - planehead filefish

Tetraodontidae - puffers

Lagocephalus laevigatus - smooth puffer

Sphoeroides maculatus - northern puffer

Sphoeroides spengleri - bandtail puffer

Diodontidae - porcupinefishes

Chilomycterus schoepfi - striped burrfish

Loliginidae - inshore squids

Lolliguncula brevis - shortfin squid

Squillidae - mantis shrimps

Squilla empusa - mantis shrimp

Penaeidae - penaeid shrimps

Penaeus aztecus - brown shrimp

Penaeus duorarum - pink shrimp

Penaeus setiferus - white shrimp

Trachypenaeus constrictus - roughneck shrimp

Portunidae - swimming crabs

Ovalipes ocellatus - lady crab

Callinectes spp. - blue, lesser blue, shelligs crab

Portunus gibbesii

Portunus spinimanus

Macrobenthic Species - Mud Substate Site

Polychaetes

Pectinaridae

Cistena gouldii

Arabellidae

Arabella iricolor

Drilonerisis longa

D. magna

Notocirris spiniferus

Capitellidae

Amastigo caperatus

Mediomastus ambiseta

Heteromastus filiformis

Notomastus americanus

Notomastus latericius

Capitellidae sp. (2)

Chaetopteridae

Mesochaetopterus taylori

Spiochaetopterus costarum

Cirratulidae

Caulleriella sp.

Tharyx marioni

Tharyx sp.

Dorvilleidae

Dorvillea sociabilis

Eunicidae

Marphysa sanguinea

Flabelligeridae

Pherusa inflata

Piromus eruca

Glyceridae

Glycera americana

Glycera dibranchiata

Glycera capitata

G.lycera sp.

Goniadidae

Glycinde normanni

G. solitaria

Phyllodocidae

Phyllocidae groenlandica

Phyllocidaemucosa

Phyllocidae sp.

Pilargidae

Sigambra bassi

S. tentaculata

Polynoidae

Lepidonotus sublevis

Sabellidae

Branchioma sp.

Sigalionidae

Stenelais boa

S. limicola

Spionidae

Malacoceros vanderhorsti

Paraprionospio pinnata

Polydora ligni

Polydora sp.

Polydora sp. *I*

Polydora sp. *II*
Polydora sp. *III*
Polydora sp. *IV*
Prionospio cirrifera
P. cirrobranchiata
P. heterobranchia
Spiophanes bombyx
S. wigleyi
Streblospio benedicti
Spionidae sp.
Syllidae
Autolytus sp.
Brania clavata
Terebellidae
Pista palmata
Polycirrus eximius

Oligochaetes

Hesionidae
Gyptis brevipalpa
Parahesione luteolo
Hesionidae sp. (1)
Lumbrineridae
Lumbrineris coccinea
L. impatiens
L. tenuis
L. sp.
Magelonidae
Magelona papillicornis
M. physillae
M. sp.
Maldanidae
Axiothella mucosa
Clymenalla torquata
Nephtyidae
Aglaophamus verrilli
Nephtys picta
Nereidae
Nereis lamellosa
N. succinea
Onuphidae
Diopatra cuprea
Onuphis cremita
Ophelidae
Armandia maculata
Orbinidae
Haploscoloplos fragilis
H. robustus
Scoloplos rubra

Oweniidae
Owenia fusiformis
Palmyridae
Bhawania goodei
Palaenotus heteroseta kowalenski
Paraonidae
Aricidea fragilis
Cirrophorus lyriformis
Paraonis fulgens
Phyllodocidae
Eteone heteropoda
Eulalia sanguinea
Phyllodoce arenae

Crustaceans

Amphipods
Isopods
Tanaids
Penaeids
Crab megalope
Cumaceans
Ostracods
Shrimp zoeae
Pinnotherids
Calianassa sp.
Pinnixa sp.
Palaemonetes pugio
Palaemonetes. sp.
Ogyrides limicola
Acetes sp.
Periclimenes sp.

Mollusks

Bivalves
Shelled gastropods
Nudibranchs

Cnidarians

Hydrozoans
Burrowing anenomes

Echinoderms

Sea cucumbers
Ophiothrix sp.

Nemerteans

Sipunculids

Flatworms

Marine Insects

Arachnids

Phoronids

Chaetognaths

Hemichordates

Saccoglossus

Vertebrates

Pisces
Symphurus plagiusa
Myrophis punctatus
Gobiosoma bosci

Macrobenthic Species - Sand Substrate Sites

Polychaetes

Pectinaridae
Cistena gouldii
Arabellidae
Arabella juveniles
Capitellidae
Amastigo caperatus
Mediomastus ambiseta
Heteromastus filiformis
Notomastus americanus
Notomastus sp.
Chaetopteridae
Spiochaetopterus costarum
Cirratulidae
Caulleriella sp.
Tharyx marioni
Caulleriella killarensis
Eunicidae
Unidentified Eunicids
Glyceridae
Glycera americana
G. dibranchiata
G. oxycephala
G. capitata
Goniadidae
Glycinde solitaria
Goniadid sp.
Hesionidae
Podarke obscura
Lumbrineridae
Lumbrineris tenuis
Magelonidae
Magelona papillicornis
Magelona physillae
Magelona rosea
Maldanidae
Axiothella mucosa
Clymenalla torquata
Spionidae
Polydora ligni
Polydora sp.
Polydora sp. *3*
Prionospio cirrifera
P. cirrobranchiata
Prionospio dayi
Scolelopes squamata
Spio setosa
Spiophanes bombyx
S. wigleyi
Streblopspio benedicti
Spionidae sp.
Syllidae
Exogone dispar
Parapionosyllis longicirrata
Terebellidae
Pista palmata

Oligochaetes

Crustaceans
Amphipods
Isopods
Stomopods
Crab megalope

Mysids
Ostracods
Calianassa sp.
Pinnixa sp.
Oxyurostylis smithi
Palaemonetes vulgaris
Pagurus longicarpus
Periclimenes sp.

<u>Mollusks</u>

Bivalves
Shelled gastropods
Nudibranchs
Nephtyidae
Aglaophamus verrilli
Nephtys bucera
N. incisa
N. picta
Nereidae
Nereis succinea
Onuphidae
Onuphis jenneri
O. microcepphala
O. cremita
Ophelidae
Armandia agilis
A.rmandiamaculata
A.rmandia sp.
Travisia parva
T.ravisia sp.
Orbinidae
Haploscoloplos fragilis
H. robustus
Scoloplos rubra
Scoloplella sp.
Oweniidae
Owenia fusiformis
Paraonidae
Aricidea fragilis
Aricidea fragilis sp. A
Cirrophorus lyriformis
Paraonis fulgens
Phyllodocidae
Eteone heteropoda
Eulalia sp.
Paranaites polynoides
Phyllodoce arenae
P. mucosa
P. panamensis
Pilargidae
Sigambra bassi
S. tentaculata
Ancistrosyllis carolinensis
Polynoidae
Lepidonotus sublevis
Spionidae
Dispio uncinata
Paraprionospio pinnata

<u>Cnidarians</u>
Hydrozoans
Renilla reniformes

<u>Echinoderms</u>
Sea cucumbers

<u>Nemerteans</u>

<u>Sipunculids</u>

<u>Flatworms</u>

<u>Hemichordates</u>
Saccoglossus kowalenski

<u>Vertebrates</u> - Pisces
Symphurus plagiusa
Myrophis punctatus

Meiobenthos - Mud Habitat

<u>Nematodes</u>

Adoncholaimus sp.
Aegialoalaimus sp.
Anoplostoma hirtum
Anoplostoma sublatum
Anticoma spp.
Antomicron sp.
Araeolaimidae spp.
Axonolaimus paraponticus
Axonolaimus spinosus
Axonolaimus spp.
Bathylaimus sp.
Bobella spp.
Calptonema maxweberi
Ceramonema sp.

Chromadoridae spp.
Cyartonema spp.
Cyatholaimidae spp.
Daptonema erectum
Desmodoridae spp.
Desmodora spp.
Dichromadora geophyla
Dorylaimopsis metatypica
Eleutherolaimus sp.
Enoplidae spp.
Enoplides spp.
Enoplolaimus sp.
Enoplus sp.
Eurystominidae spp.
Eurystomina spp.
Gomphionema fellator
Graphonema sp.
Halichoanolaimus raritensis
Halalaimus cuthemon
Halalaimus longisetosus
Halalaimus sapeloi
Halalaimus sublatus
Halalaimus spp.
Hypodontolaimidae spp.
Innocuonema chitwoodi
Laimella filipjevi
Laimella longicaudata
Leptosomatidae sp.
Leptolaimus sp
Linhomoeus ilensis
Linhomoeidae spp.
Longicyatholaimus longicaudatus
Marlynnia spp.
Metachromadora chadleri
Metachromadora merdiana
Metachromadora obesa
Metachromadora pulchra
Metachromadora remanei
Metachromadora spp.
Microlaimus dimorphus
Microlaimus spp.
Monhystera parva
Monhysteridae spp.
Monoposthia sp.
Metalinhomoeus spp.
Neochromadora spp.
Neotonchus sp.
Oncholaimoides elongatus
Oncholaimoides striatus
Odontophora spp.
Oxystomina affinis
Oxystomina spp.
Paracomesoma spp.
Paratarvaia sp.
Paracanthoncus caecus
Phanodermopsis longisetae
Parodontophora brevamphida
Ptycholaimellus hibernus
Ptycholaimellus pandispiculatus
Pareurystomina spp.
Thabdocoma americana
Sabatieria americana
Sabatieria kelleti
Sabatieria hilarula
Sabatieria punctata
Sabatieria sp.
Sphaerolaimus spp.
Spirinia parasitifera
Steineria sp.
Tarvaia sp.
Terschellingia communis
Terschellingia longicaudata
Terschellingia spp.
Theristus miamiensis
Theristus mirabilis
Theristus spp.
Tricoma sp.
Tripyloides gracilis
Viscosia brachylaimoides
Viscosia spp.

Meiobenthos Sand Substrate

Nematodes

Actinonema sp.
Adoncholaimus spp.
Aegialoalaimus sp
Anticoma sp.
Antomicron sp.
Araeolaimidae spp.
Astomonema jenneri
Axonolaimus paraponticus
Axonolaimus spinosus
Axonolaimus villosus
Axonolaimus spp.
Bathylaimus stenolaimus

Bathylaimus sp.
Bobella spp.
Calptonema maxweberi
Catanema spp.
Ceramonema sp.
Chromadorita brachypharynx
Chromadorita sp.
Chaetonema sp.
Choanolaimidae spp.
Chromadoridae spp.
Cobbia spp.
Comesomatidae spp.
Cervonema sp.
Cyatholaimidae spp.
Cyartonema spp.
Daptonema erectum
Desmoscolecidae spp.
Desmodora spp.
Dicramphidus seta
Diplopeltinae spp.
Dorylaimopsis metatypica
Enoplides spp.
Enoplolaimus spp.
Enoplidae
Enoplus sp.
Eubostrichus sp.
Eurystominidae spp.
Eurystomina spp.
Gomphionema fellator
Graphonema sp.
Halichoanolaimus sp.
Halalaimus cuthemon
Halalaimus longisetosus
Halalaimus sp.
Hypodontolaimidae spp.
Ironidae spp.
Latronema sp.
Lauratonema sp.
Leptolaimus sp
Leptsomatidae sp.
Linhomoeus ilensis
Linhomoeidae spp.
Marlynnia spp.
Mesacanthion spp.
Metacomesoma spp.
Metachromadora chadleri
Metachromadora meridiana
Metachromadora remanei
Metachromadora spp.
Microlaimus dimorphus
Microlaimus spp.
Metoncholaimus sp.
Monhysteridae spp.
Monoposthia sp.
Metalinhomoeus spp.
Neochromadora spp.
Noffsingeria sp.
Oncholaimoides striatus
Oncholaimoides sp.
Oncholaimidae spp.
Odontophora spp.
Oxystomina affinis
Oxystomina paraclavicauda
Oxystomina spp.
Paracomesoma hexasetosum
Paracomesoma spp.
Paramonhystera mutila
Paratarvaia sp.
Paracyatholaimodes sp.
Paracanthoncus caecus
Pierrickia sp.
Paralinhomoeus sp.
Paramonohsteria wiseri
Pareurystomina sp.
Parodontophora brevamphida
Parapomponema macrospiralis
Pomponema spp.
Prochromadora sp.
Pselionema sp.
Ptycholaimellus hibernus
Ptycholaimellus pandispiculatus
Rhabdocama americana
Rhadinema flexile
Rhynchonema sp.
Sabatieria americana
Sabatieria aramata
Sabatieria kelleti
Sabatieria hilarula
Sabatieria longisetosa
Sabatieria punctata
Sabatieria spp.
Scaptrella cincta
Selachinematinae sp.
Sphaerolaimus spp.
Spirinia parasitifera
Steineria sp.
Synonchiella hopperi
Tarvaia sp.
Terschellingia longicaudata
Terschellingia spp.
Theristus floridensis

Theristus miamiensis
Theristus mirabilis
Theristus spp.
Tripyloides gracilis
Tripyloides sp.
Viscosia brachylaimoides
Viscosia spp.
Xenella sp.
Senolaimus sp.
Xyala striatus

Zooplankton

Copepoda
- Calanoida
  - *Acartia tonsa*
  - *Centropages hamatus*
  - *Centropages typicus*
  - *Eurytemora affinis*
  - *Labidocera aestiva*
  - *Parvocalanus crassirostris*
  - *Pseudodiaptomus coronatus*
  - *Temora turbinata*
- Cyclopoida
  - *Corycaeus* sp.
  - *Oithona colcarva*
  - *Oithona* sp.
  - *Oncaea venusta*
  - *Paracyclopina* sp.
  - *Saphirella* sp.
- Harpacticoida
  - *Alteutha* sp.
  - *Amphiascopsis cincutus*
  - *Clytemennstra rostrata*
  - *Euterpina acutifrons*
  - *Metis holothuriae*
  - *Metis ignea*
  - *Mesochra pygmaea*
  - *Thalestris gibba*

Copepodids

Copepod nauplii

Bivalve larvae

Chaetognatha

Cirripedia nauplii

Cladocera

Coelenterata

Crab zoeae

Echinoderm pluteus larvae

Gastropod larvae

Oikopleura sp.

Ostracoda

Polychaete larvae

Shrimp zoeae

Appendix II. Winyah Bay Estuary Compiled Species List

Phylum Annelida
- *Ancistrosyllis jonesi*
- *Diopatra cuprea*
- *Glycera dibranchiata*
- *Glycinde nordmanni*
- *Hemipodus roseus*
- *Heteromastus filiformis*
- *Hydroides dianthus*
- *Nereis succinea*
- *Oligochaeta*
- *Paraprionospio pinnata*
- *Polydora ligni*
- *Sabellaria vulgaris*
- *Sigambra tentaculata*
- *Streblospio benedicti*

Phylum Arthropoda
- *Alpheus heterochaelis*
- *Alpheus normanni*
- *Balanus improvisus*
- *Balanus niveus*
- *Callinectes ornatus*
- *Callinectes sapidus*
- *Callinectes similis*
- *Callinectes* sp.
- *Caprellidae*
- *Chiridotea almyra*
- *Chiridotea coeca*
- *Cleantis planicauda*
- *Clibanarius vittatus*
- *Hexpanopeus angustifrons*
- *Libinia emarginata*
- *Lubinia* sp.
- *Lubinia dubia*
- *Macrobrachium ohione*
- *Milita nitida*
- *Mysidopsis bigelowi*
- *Nymphopsis duodorsospinosa*
- *Ovalipes ocellatus*
- *Ovalipes stehpensoni*
- *Pagurus longicarpus*
- *Pagurus pollicaris*
- *Palaemonetes pugio*
- *Palaemonetes* sp.
- *Palaemonetes vulgaris*
- *Panopeus herbstii*
- *Panopeus occidentalis*
- *Penaeus aztecus*
- *Penaeus duorarum*
- *Penaeus setiferus*
- *Portunus gibbesii*
- *Portunus spinimanus*
- *Rhithropanopeus harrisii*
- *Squilla empusa*
- *Tanystylum orbiculare*
- *Trachypenaeus constrictus*
- Xanthidae
- *Xiphopenaeus kroyeri*

Phylum Bryozoa
- *Aeverrillia setigera*
- *Alcyonidium polyoum*
- *Alcyonidium hauffi*
- *Anguinella palmata*
- *Antropora leucocypha*
- *Bowerbankia gracilis*
- *Conopeum tenuissimum*
- *Cryptosula pallasiana*
- *Electra monostachys*
- *Hippoporina verrilli*
- *Membranipora arborescens*
- *Membranipora tenuis*
- *Microporella ciliata*
- *Shizoporella errata*

Phylum Chlorophyta
- *Ulva lactuca*

Phylum Chordata
- Subphylum Urochordata
  - *Aplidium constellatum*
  - *Aplidium* sp.
  - *Ascidiacea A*
  - *Clavelina picta*
  - *Clavelina* sp.
  - *Didemnum candidum*
  - *Molgula manhattensis*
  - *Molgula occidentalis*
  - *Styela plicata*
- Subphylum Vertebrata
  - *Acipenser brevirostrum*
  - *Acipenser oxyrhynchus*
  - *Alosa aestivalis*
  - *Alosa sapidissima*
  - *Anchoa hepsetus*
  - *Anchoa mitchilli*
  - *Ancylopsetta quadrocellata*

Anguilla rostrata
Archosargus probatocephalus
Ariosoma balearicum
Arius felis
Astroscopus y-graecum
Bagre marinus
Bairdiella chrysura
Brevoortia tyrannus
Centropomus sp.
Centropristis philadelphica
Centropristis striata
Chaetodipterus faber
Chilomycterus schoepfi
Chloroscombrus chysurus
Citharichthys macrops
Citharichthys spilopterus
Conger oceanicus
Cynoscion nebulosus
Cynoscion nothus
Cynoscion regalis
Cyprinus carpio
Dasyatis sabina
Dorosoma cepedianum
Dorosoma petenense
Etropus crossotus
Etropus sp.
Gobiesox sturmosus
Gobionellus shufeldti
Hypsoblennius hentzi
Hypsoblennius ionthas
Ictalurus catus
Ictalurus nebulosus
Ictalurus platycephalus
Lagodon rhomboides
Larimus fasciatus
Leiostomus xanthurus
Lepisosteus osseus
Lepomis auritus
Lepomis gulosus
Lepomis microlophus
Lepomis punctatus
Lutjanus griseus
Menticirrhus americanus
Menticirrhus littoralis
Micropogonias undulatus
Micropterus salmoides
Monacanthus hispidus
Morone americana
Morone chrysops
Morone saxatilis
Mugil cephalus
Myrophis punctatus
Ogcocephalus rostellum
Ophidion marginata
Ophidion marginatum
Opsanus tau
Paralichthys dentatus
Paralichthys lethostigma
Peprilus alepidotus
Peprilus triacanthus
Pogonias cromis
Pomatomus saltatrix
Prionotus carolinus
Prionotus evolans
Prionotus salmonicolor
Prionotus scitulus
Prionotus tribulus
Raja eglanteria
Rhinoptera bonasus
Sciaenops ocellata
Scophthalmus aquosus
Scorpaena calcarata
Selene setapinnis
Selene vomer
Sphoeroides maculatus
Stellifer lanceolatus
Stephanolepis hispidus
Symphurus plagiusa
Syngnathus louisianea
Trichiurus lepturus
Trinectes maculatus
Urophycis floridana
Uropyhcis regia

Phylum Cnidaria

Actiniaria
Actiniaria A
Actiniaria B
Actiniaria C
Aglaophenia trifida
Aiptasia eruptaurantia
Astrangia astreifomis
Astrangia astreiformis
Bougainvillia rugosa
Bougainvillia sp.
Bunodosoma cavernata
Calliactis tricolor
Campanopsis sp.
Campanulina sp.
Clytia cylindrica
Clytia cylindrica
Clytia fragilis

Clytia kincaidi
Cuspidella humilis
Diadumene leucolena
Epizoanthus americanus
Eudendrium sp.
Eudendrium sp.
Garveia franciscana
Halecium sp.
Hydractinia echinata
Leptogorgia virgulata
Obelia bidentata
Obelia dichotoma
Pandeidae (undet.)
Paranthis rapiformis
Plumularia floridana
Renilla reniformis
Scyphozoa (undet.)
Sertularia stookeyi
Stomolophus meleagris (polyp)
Tamoya haplonema
Telesto fruticulosa
Tubularia crocea
Tubulariidae A
Turritopsis nutricula

Phylum Ctenophora
Ctenophora (undet.)

Phylum Echinodermata
Asterias forbesi
Astropecten duplicatus
Mellita quinquesperforata
Ophiuroidea (undet.)

Phylum Entoprocta
Barentsia laxa
Loxosomella sp.

Phylum Mollusca
Anadara ovalis
Brachidontes exustus
Busycon caraliculatum
Crassostrea virginica
Doridella sp.
Hiatella arctica
Macoma balthica
Martesia cuneiformis
Mercenaria mercenaria
Mulinia lateralis
Mytilidae (undet.)
Ostrea equestris
Petricola pholadifomis
Polinices duplicatus
Sinum perspectivum
Tellina versicolor
Urosalpinx cinerea

Phylum Phaeophyta
Sargassum natans

Phylum Platyhelminthes
Stylochus ellipticus

Phylum Porifera
Cliona sp.
Endectyon tenax
Haliclona sp.
Homaxinella rudis
Ircinia campana
Pedicellina cernua
Tenaciella obliqua

Phylum Rhodophyta
Rhodymenia pseudopalamata
Arenaeus cribrarius
Hepatus epheliticus
Loliguncula brevis
Menippe mercenaria
Neopanope sayi
Persephona mediterranea