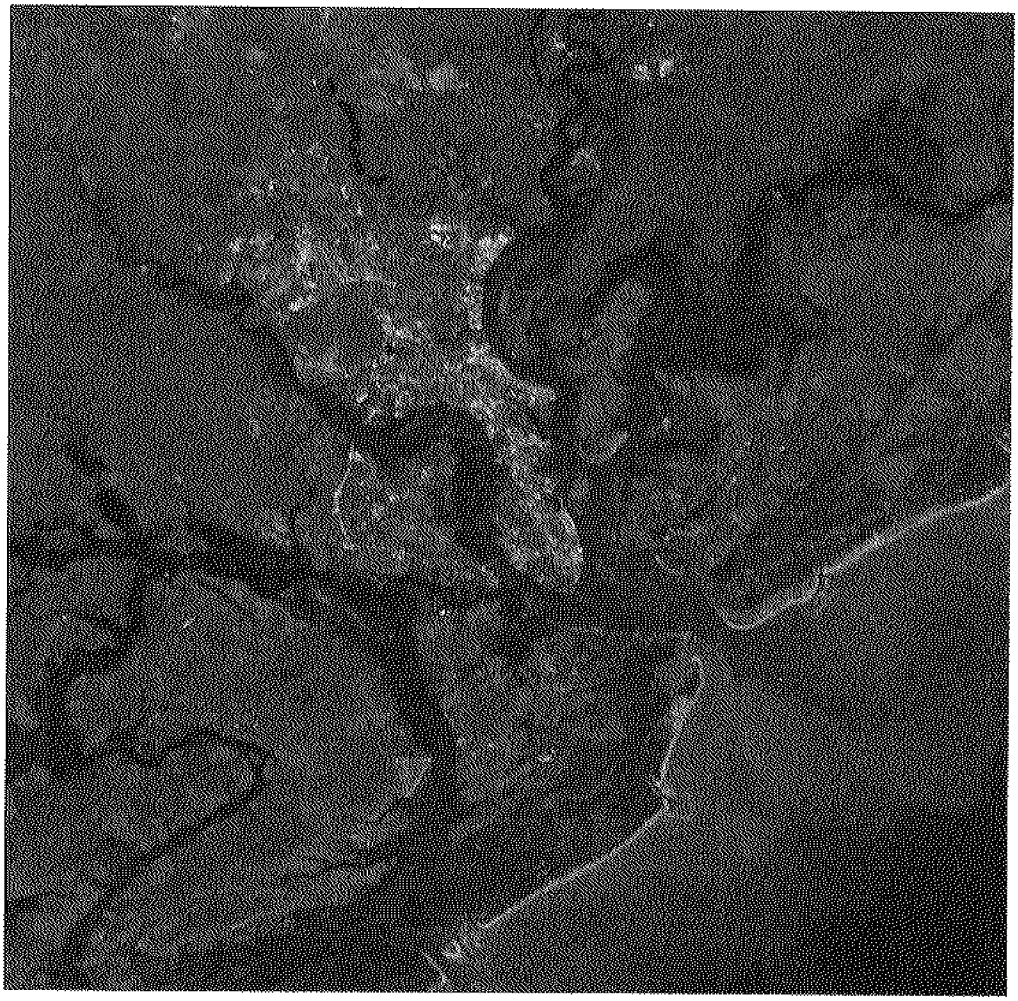
SCSGC-T-92-001 C2

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



Sea Grant
S.C. Sea Grant Consortium

Charleston, South Carolina
Volume I

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

Volume I
Charleston Harbor Estuary

South Carolina Sea Grant Consortium
Charleston, South Carolina
1992

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 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 Nybro (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.

This research was supported by the National Ocean Pollution Program Office, NOAA, U.S. Department of Commerce, under Grant Nos. NA85AA-D-SG121, Amendment 5 and NA90AA-D-SG790, Amendment 2, and the SC Sea Grant Consortium.

Cover Photo: Color composite based on Landsat TM of the Charleston Harbor estuary.

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

Executive Summary

M. Richard DeVoe
South Carolina Sea Grant Consortium
Charleston, South Carolina

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 mi^2. 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 km^2 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 km^2 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 km^2 of the basin. Of the remaining total area, the Lynches River basin composes 3,549 km^2, the Little Pee Dee River 2,849 km^2, the Black River 5,298 km^2, the Waccamaw River 2,578 km^2, and the Sampit River 622 km^2. 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 km^2. 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 km^2 of the basin. The dominant economic activity of the Pee Dee subregion is agriculture, accounting for 7,629.3 km^2 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 km^2), wetlands (52.6 km^2), and the remaining area (1.1 km^2) 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 m^3/s; after diversion the number significantly increased to 455 m^3/s. Since the Rediversion Project, the flow from the Cooper River into Charleston Harbor has become more stable with a monthly mean of 122 m^3/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 m^3/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 nonpoint 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 Charleston Harbor Estuary: 1970-1985

Kevin B. Davis
Robert F. Van Dolah

South Carolina Wildlife and
Marine Resources Department
Charleston, South Carolina

CONTENTS

List of Figures

List of Tables

List of Appendices

Abbreviations Used for Agencies

BCDCOG	Berkeley, Charleston, Dorchester Council of Governments
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Survey
PANS	The Academy of Natural Sciences of Philadelphia
SCDHEC	South Carolina Department of Health and Environmental Control
SCWMRD	South Carolina Wildlife and Marine Resources Department
SCWRC	South Carolina Water Resources Commission
USACOE	United States Army Corps of Engineers
USDOC	United States Department of Commerce
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

SYSTEM CHARACTERIZATION

SETTING

Watershed Characteristics

Charleston Harbor is located midway along the South Carolina coastline with its entrance at approximately 32° 45' N latitude and 79° 52' W longitude (Fig. II-1). The Charleston Harbor Estuary is classified as a type 2b according to the Hansen and Rattray (1966) classification, and is formed by the junction of three coastal rivers: the Cooper, the Wando, and the Ashley (Fig. II-2). Prior to 1942, these three rivers and the lower harbor basin drained a watershed area of approximately 3,625 km² (USACOE 1957a; 1966a, 1972, 1976; USDOI 1966; NOAA 1985). The majority of freshwater flow into the harbor system was from the Cooper River, with its headwaters originating in Biggin Swamp in Berkeley County, South Carolina (Mathews et al. 1980; Kana et al. 1984).

In 1942, the United States Army Corps of Engineers (USACOE) completed the Santee-Cooper Hydroelectric Project which included construction of the Wilson Dam on the Santee River forming Lake Marion, construction of the Pinopolis Dam at the headwaters of the Cooper River forming Lake Moultrie, construction of a diversion canal from Lake Marion to Lake Moultrie, and the subsequent diversion of the Santee River flow into the Cooper River (Fig. II-3) (Arthur D. Little, Inc. 1974; USACOE 1975; Kjerfve 1976). This project effectively increased the total drainage area for the Charleston Harbor watershed to approximately 41,000 km² (Fig. II-4) due to the inclusion of the Santee River drainage basin, which is one of the largest river basins on the east coast of the United States (SCDHEC 1975; Kjerfve 1976; NOAA 1985). The change in drainage increased the freshwater flow into Charleston Harbor to approximately 428 m³/s.

Prior to completion of the Santee-Cooper Hydroelectric Project, shoaling in Charleston Harbor was considered a minor problem, and was alleviated

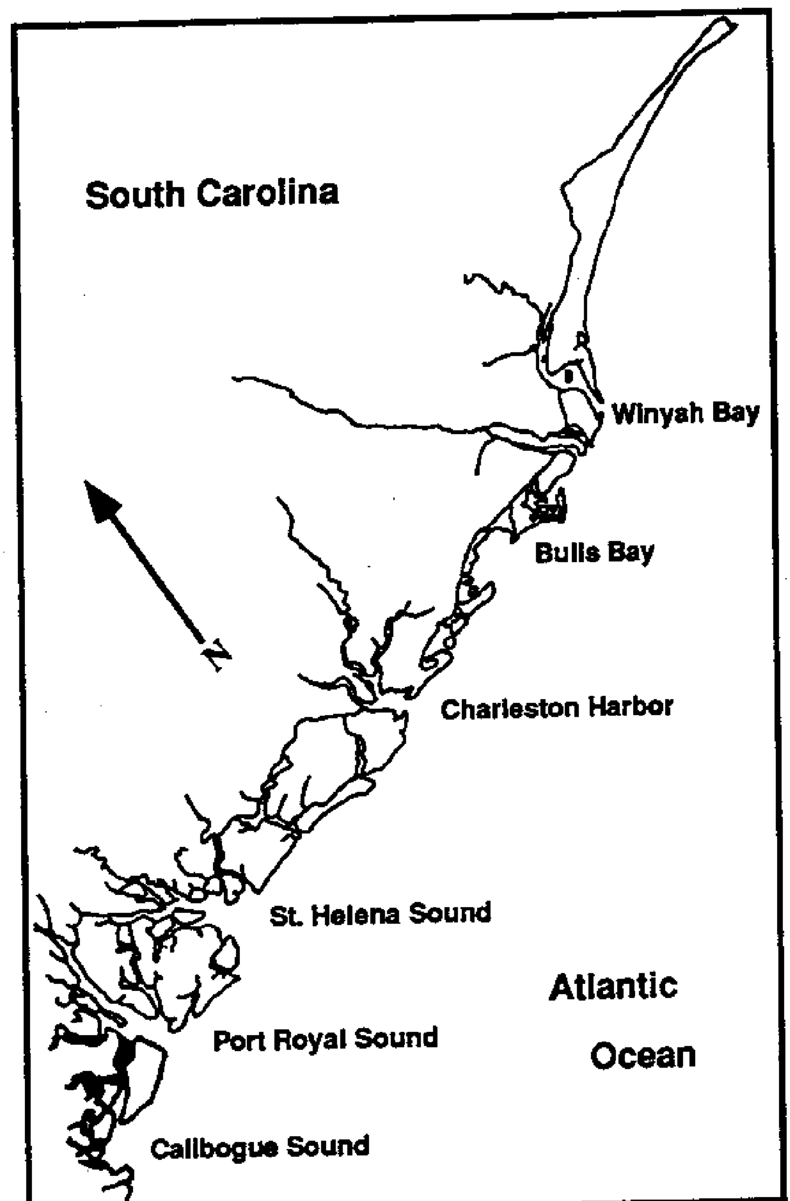


Fig. II-1. Coastline of South Carolina.

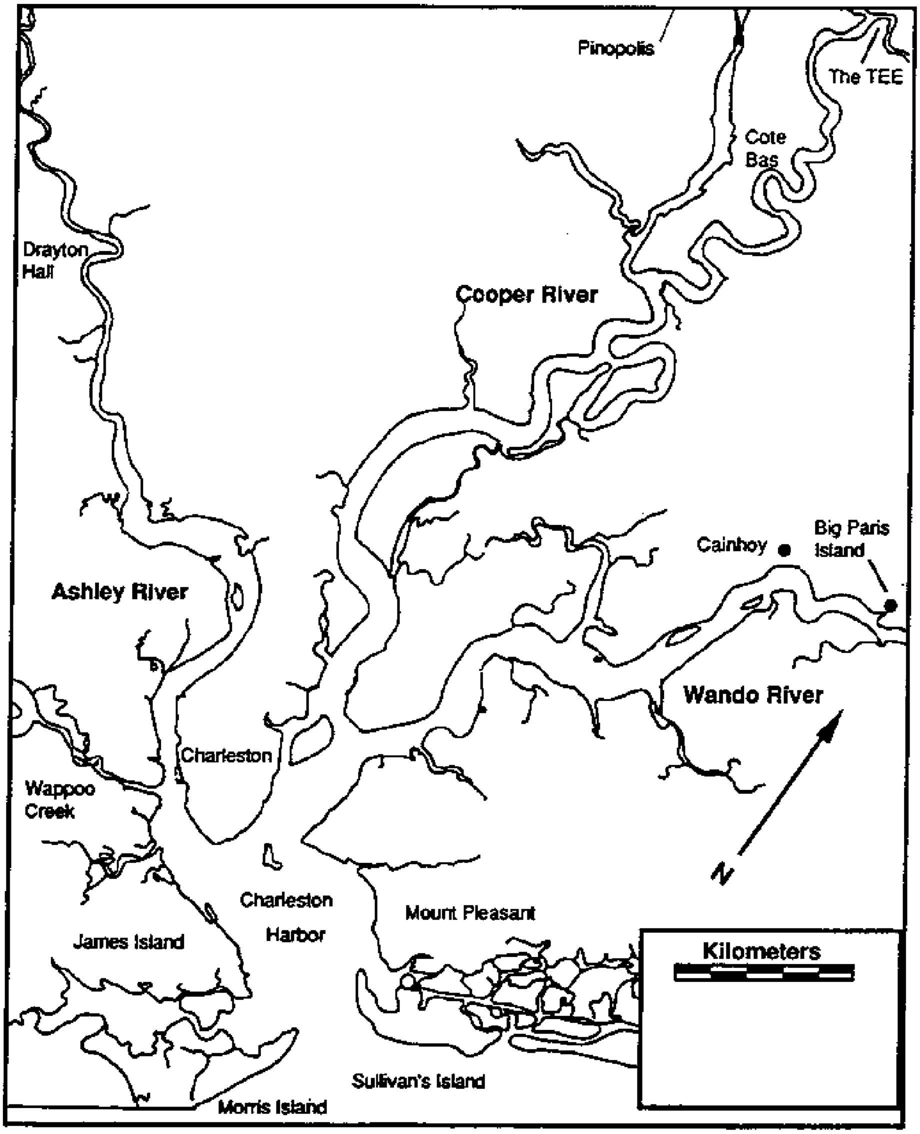


Fig. II-2. The Charleston Harbor basin is formed by the confluence of the Ashley, Cooper, and Wando rivers. Key points discussed in the text are labeled.

by the removal of approximately 137,620 m^3 of sediments per year through maintenance dredging (USACOE 1957a, 1958, 1966a, 1975; SCWRC 1979). After the project was completed, shoaling in Charleston Harbor increased to the point where removal of 7,645,350 m^3 of sediments per year was needed to maintain the navigation channels (USACOE 1966a, 1975). To alleviate the shoaling problem in Charleston Harbor, the USACOE completed the Cooper River Rediversion Project in 1985 (Fig. II-3). This project rediverted approximately 70% of the Santee-Cooper drainage back into the Santee River by way of a rediversion canal constructed between Lake Moultrie and the Santee River in the vicinity of St. Stephens, South Carolina. The monthly mean flow into the Cooper River through the Pinopolis Dam has been reduced to approximately 128 m^3/s since rediversion.

With a total drainage area of 41,000 km^2, the Charleston Harbor watershed is the second largest watershed in South Carolina (Table II-1) (NOAA 1985). In addition, it has the third largest estuarine drainage area, and the second largest inflow of fresh water from all sources in the state (NOAA 1985). The lower portion of Charleston Harbor is bound on the north by Sullivan's Island and Mount Pleasant, on the south by James Island and Morris Island, and on the west by the Charleston Peninsula, extending up the Ashley River to its junction with the Intracoastal Waterway and up the Cooper River to its junction with the Wando River (Fig. II-2) (Arthur D. Little, Inc. 1974; Mathews et al. 1980). This portion of the harbor basin covers an area of 65 km^2 and drains an additional 104 km^2 of local marsh and lowlands.

Average depth of the harbor basin at mean low water (MLW) is 3.7 m, and navigation channels were maintained at a depth of 10.7 m prior to the Charles-

Table II-1. Comparisons of drainage areas, freshwater flows, and tidal prisms of major South Carolina estuaries (NOAA 1985).

Estuary	Estuarine Drainage Area (km^2)	Total Drainage Area (km^2)	Freshwater Flow (m^3/s)	Tidal Prism (m^3)
Charleston Harbor	3,113	40,880	456	1.35×10^8
Winyah Bay	24,633	46,850	578	8.60×10^7
Santee River	3,980	12,377	130	3.94×10^8
Port Royal Sound	2,590	n/a	25	5.41×10^8
St. Helena Sound	2,372	10,484	362	1.75×10^8
Savannah River	1,860	3,414	76	2.51×10^7

ton Harbor Deepening Project (USACOE 1958, 1966a, 1975). This project, which is scheduled for completion in 1995, will increase the channel depth to approximately 12.2 m. Charleston Harbor's mean tidal range is 1.6 m and spring tides average 1.9 m. The highest astronomical tides in the harbor exceed 2.1 m (USDOC 1981).

The Ashley River flows approximately 50 km from its headwaters in Cypress Swamp in Berkeley County to its junction with the Intracoastal Waterway on the south side of the Charleston Peninsula, where it empties into the lower harbor basin (Fig. II-2) (Arthur D. Little, Inc. 1974; Mathews et al. 1980). The river basin drains a 900 km^2 area of marsh and lowlands, spread out over Berkeley and Charleston counties (Arthur D. Little, Inc. 1974). Depths of the natural channel in the river range from 1.8 m to 11.0 m, and are influenced by tidal action throughout the river's length (USACOE 1958).

The Wando River flows approximately 38 km from its headwaters in Iron Swamp in Charleston County to its junction with the Cooper River on the north side of the Charleston Peninsula (Fig. II-2) (Mathews et al. 1980). The river basin drains a 310 km^2 area of marsh and lowlands, and its depth ranges from 1.5 m to 12.8 m within its natural channel (USACOE 1957a; SCWRC 1973, 1975). The Wando River is influenced by tidal action throughout its entire length.

The Cooper River drainage basin is extremely complex due to the construction of the Santee-Cooper Hydroelectric Project, but can be divided into three distinct components. One component is the area downstream of the Pinopolis Dam, the second component includes the area above the Pinopolis Dam, including Lake Moultrie, the diversion canal and Lake Marion, and the third component is the upper Santee River drainage basin. The latter component extends approximately 400 km from the headwaters of the Santee River drainage basin in the western North Carolina Blue Ridge Mountains to Lake Marion (created by the Wilson Dam) on the Santee River (Fig. II-4) (USACOE 1958, 1966a, 1975; Arthur D. Little, Inc. 1974; SCWRC 1979). This component drains approximately 37,200 km^2 of mountains, highlands, and freshwater wetlands and includes the Broad, Catawba, Congaree, Enoree, Pacolet, and Wateree rivers, as well as Wateree Lake and Lake Murray, all of which eventually empty into the Santee River above Lake Marion (USACOE 1975; SCWRC 1979).

The middle component of the Cooper River drainage basin extends approximately 90 km from the beginnings of Lake Marion, through the diversion canal into Lake Moultrie, ending at the Pinopolis Dam (Fig. II-3). Lake Marion covers a 450 km² area, while Lake Moultrie covers a 245 km² area (SCWRC 1979). The entire component contributes approximately 900 km² of freshwater wetlands and lowlands to the total drainage area of the Cooper River.

The lower component of the Cooper River drainage basin extends approximately 80.5 km from Pinopolis Dam to the mouth of the Cooper River on the north side of the Charleston Peninsula where it flows into Charleston Harbor (Fig. II-3). This section of the river drains approximately 3,625 km² of midlands and lowlands, including fresh and brackish wetlands (USACOE 1975). The west branch of the Cooper River is 26.5 km long and flows from the Tail Race Canal at Moncks Corner to its junction with the East Branch. The east branch is approximately 12.3 km long and flows from its headwaters in Hell Hole Bay to its junction with the west branch, which is commonly referred to as the "Tee." The river then flows 28.5 km to its junction with the Charleston Harbor basin on the north side of the Charleston Peninsula. The Back River drains an area of approximately 18 km² (SCWRC 1980), and there is some exchange of water with the Cooper River via the Durham Canal (Fig. II-2). The 10.7 m deep naviga-

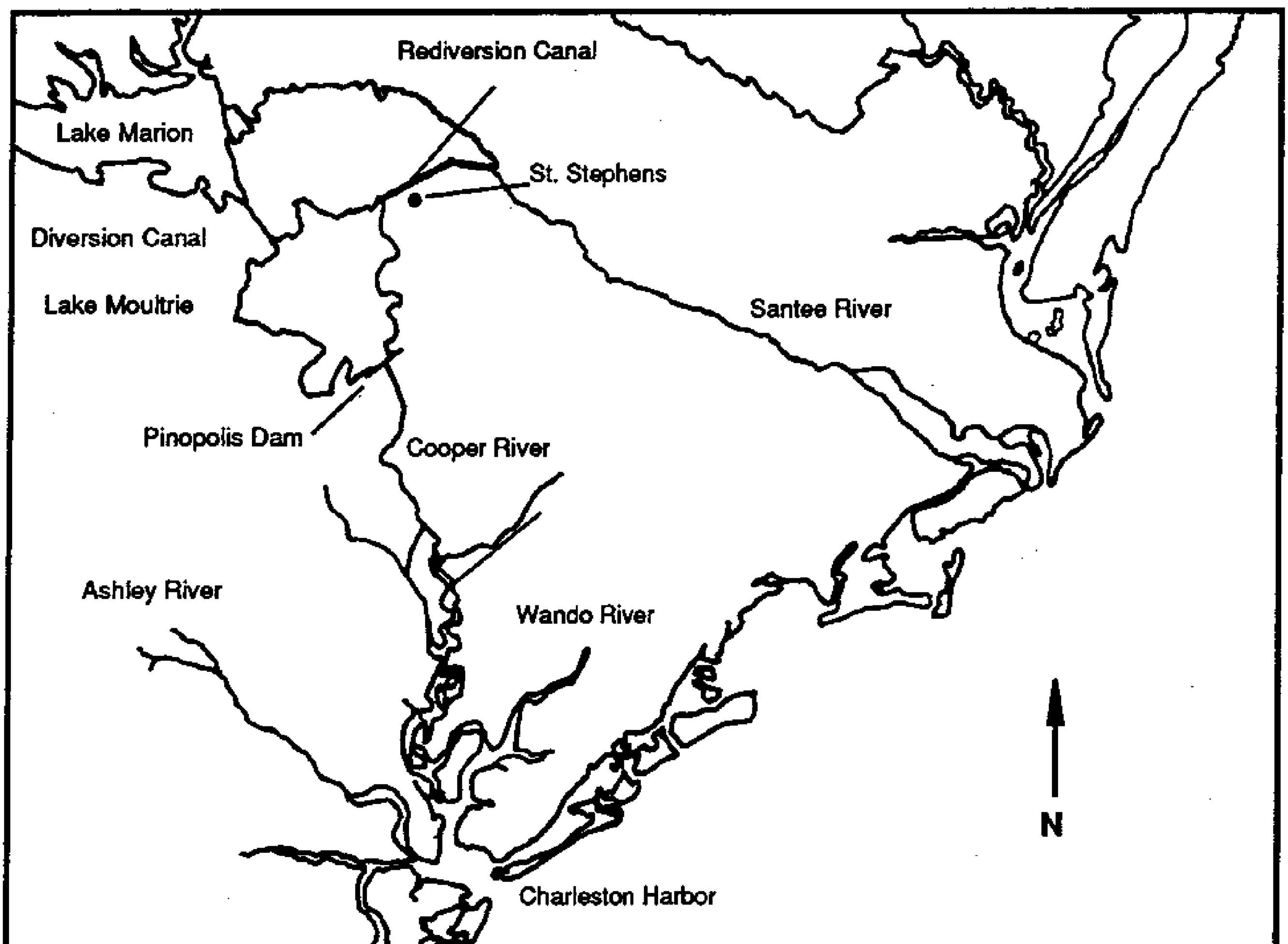


Fig. II-3. Location and extent of the Cooper River Rediversion Project, adapted from Kjerfve and Magill 1990).

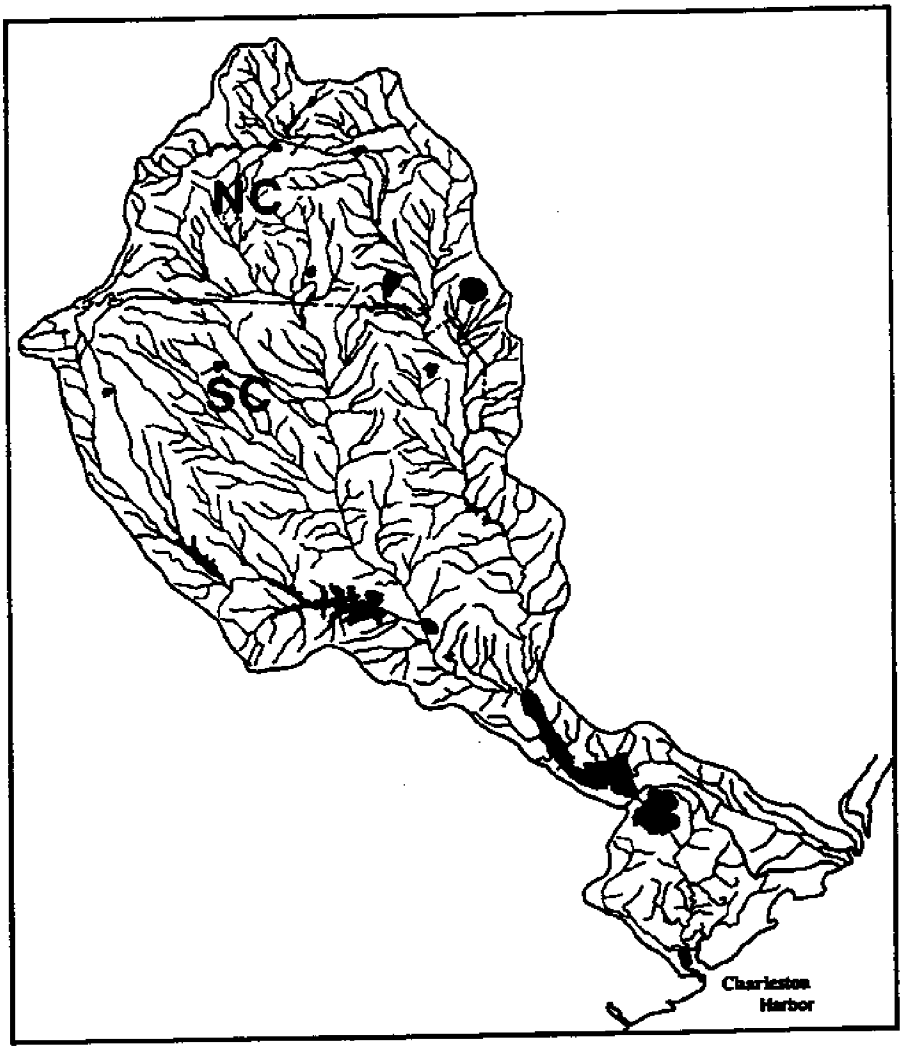


Fig. II-4. The entire Charleston Harbor and Santee River watersheds which extend into the mountains of North Carolina. Lakes and large cities are filled.

tion channel maintained in the lower Cooper River extends 32 km upstream from the mouth of the river (USACOE 1966b, 1975).

Prior to rediversion, the estuarine portion of the Charleston Harbor watershed (Fig. II-5) extended from the mouth of the harbor to points approximately 35 km upstream in the Cooper River, approximately 44 km upstream in the Ashley River, and approximately 37 km upstream in the Wando River (SCWRC 1973; Mathews and Shealy 1978, 1982). Although the estuarine extent has changed since rediversion in 1985, this report will focus on the estuary as it existed prior to August 1985.

Sedimentary Regimes and Geological History

Geological History

Charleston Harbor lies entirely within the South Carolina Coastal Plain. A detailed description of the geological *history of South Carolina can be found* in Cooke (1936), and the following summary of geological characteristics for the Charleston Harbor area is based on this source as well as Taber (1939), Cooke and MacNeil (1952), Malde (1959), Colquhoun (1969), Rankin (1977), and Mathews et al. (1980).

The Coastal Plain was once part of a large, nearly level plain covered by a thick mantle of decomposed rock. An extreme continental warping, which occurred at the end of the lower Cretaceous, raised up the region which is currently the Appalachian Mountains. This warping also tilted the land lying to the east, south, and southwest of the mountains downward, submerging much of the South Carolina Coastal Plain beneath the sea. The greater slope brought about higher flows in streams present in the nonsubmerged portions of the region, which cut into the cover of original rock, carrying decomposed feldspar, grains of quartz, and flakes of mica to form the Tuscaloosa Formation. Sea level then rose and fell several times which resulted in several additional sedimentary formations.

During the Pliocene Epoch, the seashore in the region of the South Carolina Coastal Plain was approximately 65 km inland from its present position,

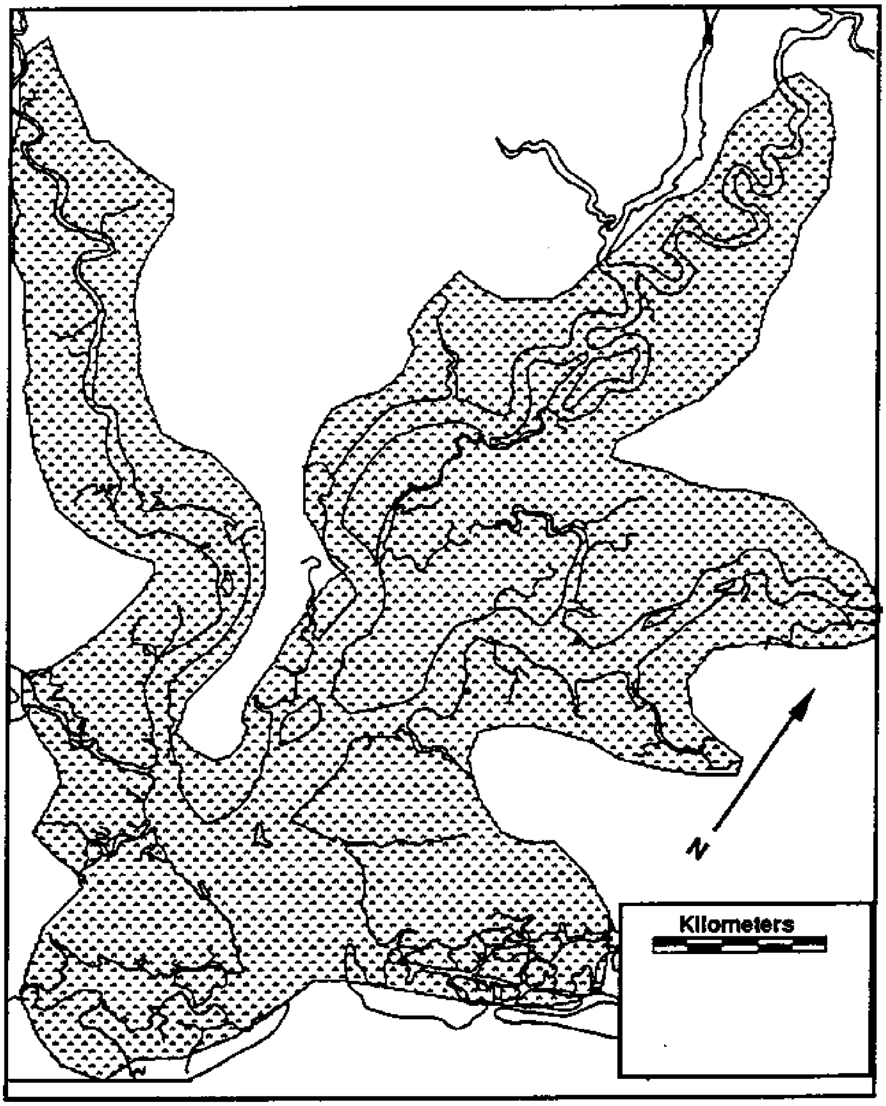


Fig. II-5. The extent of the estuarine-marsh system in the Charleston Harbor area prior to rediversion.

and sea level was approximately 30 m above its present level. The crustal movements which ended the Pliocene Epoch depressed the Coastal Plain to a depth of approximately 82 m below sea level. Since that time there have been no recognizable tectonic movements of land in the Coastal Plain region, although sea level has fluctuated widely. Sea level has gradually subsided due to an increase in the capacity of the ocean basins, brought about by seafloor spreading at the mid-Atlantic Ridge.

Stratigraphy

The Coastal Plain of South Carolina consists entirely of Pleistocene sedimentary deposits of sand, gravel, clay, marl, and limestone, all of which rest upon a basement of ancient rocks (Cooke 1936). The basement is composed of granites, schists, gneiss, and other crystalline rocks (Fig. II-6) that are similar to, and a continuation of, the rocks that underlie the adjoining Piedmont Province. Detailed descriptions of each stratum can be found in Cooke (1936), Cooke and MacNeil (1952), Malde (1959), Colquhoun and Johnson (1968), Little (1974), and Rankin (1977). Fluctuations in sea level during the Pleistocene Epoch were responsible for laying down and, in some cases, eroding away the upper layers of sediments. None of the Pleistocene Formations are very thick, and nowhere in South Carolina is there a complete series of one upon another (Cooke 1936). The younger formations generally contain less coarse materials than the older ones, and are composed largely of fine sand and clay that was washed out of the older deposits, carried to the sea, and distributed by waves and currents that were too weak to transport coarse sand and gravel.

Stratigraphic units associated with the beds of the different basins forming the Charleston Harbor Estuary include the Middle Eocene Santee Limestone, the Oligocene Cooper Marl, disconnected occurrences of Late Miocene Duplin Marl, and various Pleistocene terrace sediments, and Holocene accumulations (Cooke 1936; Taber 1939; Cooke and MacNeil 1952; Malde 1959; Colquhoun and Johnson 1968; Colquhoun 1969; USACOE 1975). The beds

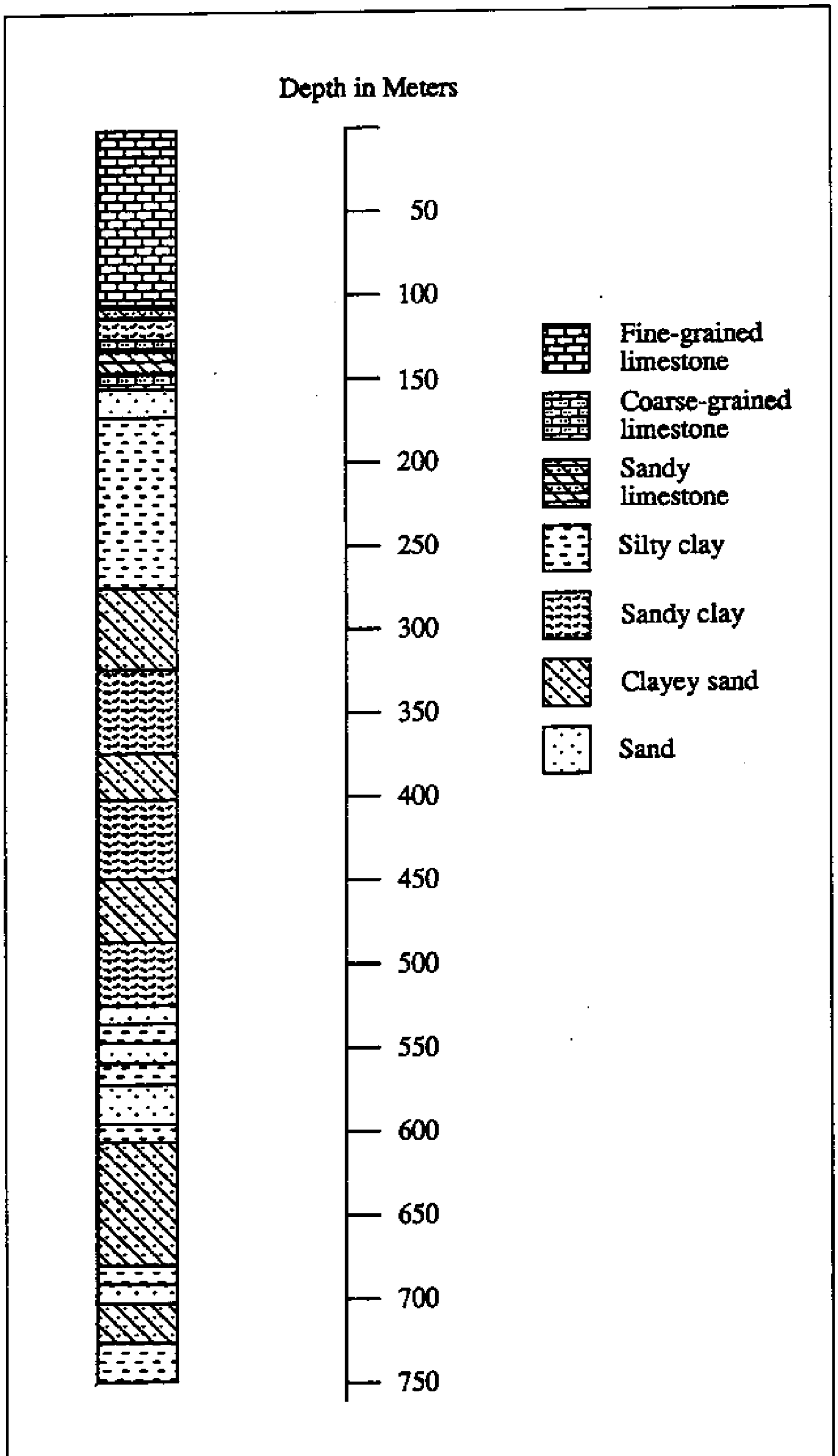


Fig. II-6. General stratigraphy in the Charleston Harbor area (adapted from Cooke and MacNeil 1952).

of the three river basins within the estuary are primarily formed by the Cooper Marl Formation overlying Santee Limestone (USACOE 1972; Arthur D. Little, Inc. 1974). This Cooper Marl is a sandy, calcareous, silty clay and is slightly to moderately phosphatic, and medium brown to olive-green color. It is very compact and contains an early Oligocene fauna in the Charleston area. In many areas of the basin, the Cooper Marl has been scoured out and eroded Pleistocene sediments have filled the depressions.

Bedrock Origins

The bed of the Cooper River alternates between scoured Cooper Marl and less consolidated sands and muds throughout its length (Fig. II-7) (USACOE 1972). The majority of the river bed is composed of loosely consolidated sediments 5 m to 8 m thick, overlying a sub-bed of Cooper Marl. In the Wando River, Cooper Marl lies at the surface of the river bed from the headwaters to Juba Island (Fig. II-7) (USACOE 1972; Arthur D. Little, Inc. 1974). There is a large sediment-filled channel system throughout a 2-km section down river from Juba Island; and downstream from that section the Cooper Marl lies at, or very close to, the bed of the river. In the Ashley River, the Cooper Marl lies beneath 3 m to 9 m of sands, clays, and sludge deposited over the past 10,000 years (Fig. II-7) (USACOE 1972). Within Charleston Harbor, the basin has a highly variable surface with much scouring having occurred in the geologic past. These valleys carved in the Cooper Marl are filled with up to 18 m of less consolidated sands and clays (Fig. II-7) (USACOE 1972).

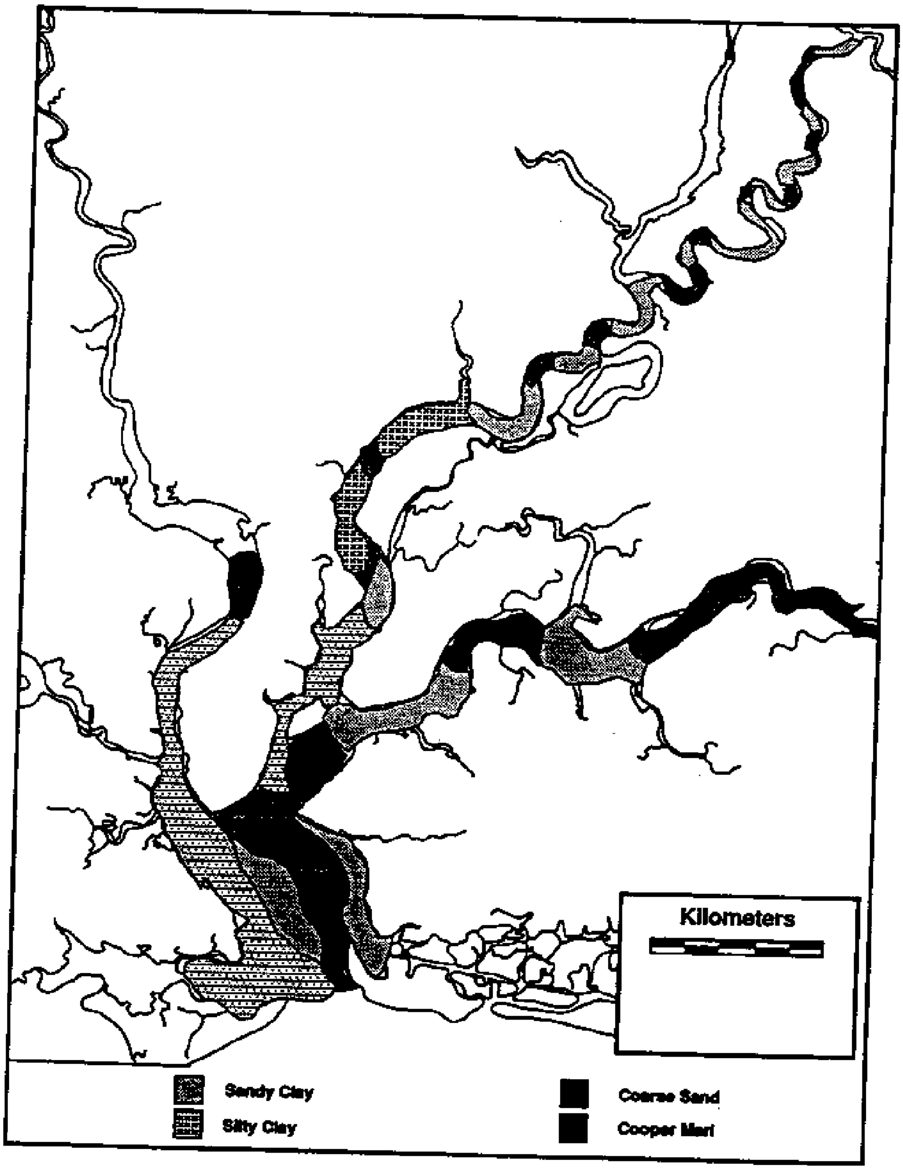


Fig. II-7. General composition of bottom sediments in the Charleston Harbor Estuary. Areas without shoaling have unknown compositions (adapted from USACOE 1972).

Presence of Faults in the Region

The seismic history of the southeastern United States is dominated by the 1886 earthquake near Charleston, South Carolina (Cooke 1936; Colquhoun 1969; Bollinger 1975; Rankin 1977). This large earthquake registered a X on the modified-Mercalli scale. Numerous smaller earthquakes have occurred during recent history in the Coastal Plain near Summerville, South Carolina (Bollinger 1975; Rankin 1977), with the majority occurring along a 15-km zone terminating at Middleton Place. Most of the earthquakes which have occurred since the 1886 earthquake are considered to be aftershocks of the 1886 earthquake (Rankin 1977). The historic record suggests that the Charleston-Summerville area had a continuum of low-level seismicity prior to 1886, and that a low-level of strain energy release continues in the same area today. A complete listing of earthquakes in the region is presented in Bollinger (1975).

The epicenters of earthquakes in this region are well within the North American Continental Plate, and are not associated with faults in the region (Bollinger 1975; Rankin 1977). The recent seismicity originates at depths of 1 km to 8 km, in the crystalline basement beneath the sedimentary rocks of the Coastal Plain (Rankin 1977).

Origins and Morphology of Sediments

Prior to the Santee River Diversion in 1942, the Charleston Harbor drainage area consisted primarily of Recent sedimentary deposits, formed during periods of fluctuating sea level (USACOE 1972, 1975). The majority of the sediments entering Charleston Harbor originate below Pinopolis Dam, but some of the sediments originate in the upper regions of the watershed. Sediments occurring in the Charleston Harbor watershed are primarily sands, silts, and clay, originating from erosion of marsh (USACOE 1954, 1957a,b,c,d, 1972, 1975; Benson 1976, 1977). Coarse to medium sands are found in the Wando River and the Cooper River, as well as along the north side of the harbor inland toward the Battery (USACOE 1972; Arthur D. Little, Inc. 1974; SCWRC 1979). Dominant silts and clay are found in the Ashley River, along the south channel of the harbor, as well as between the Battery and North Charleston. Sediments with high organic content (> 2%) occur throughout the Ashley River, in the central harbor, the lower Wando River, and throughout most of the Cooper River. Other data on sediments in the Charleston Harbor Estuary can be found in USACOE (1957a, 1957b, 1957d, 1958, 1966a, 1966b, 1966c), FWPCA (1966), Colquhoun (1972), Hoss et al. (1973), Settlemyre and Gardner (1975), SCDHEC (1975), and Benson (1976, 1977).

Changes in Sea Level

The continental ice sheets had a profound influence on the Pleistocene history of the South Carolina Coastal Plain, although the ice sheets themselves stopped far to the north of the region. The climate of South Carolina was probably not much colder than at present, but the influence of the ice sheets has included fluctuations in global sea level. During the Pleistocene, the sea flooded and subsequently retreated from the Coastal Plain on numerous occasions. These periods of inundation laid down a number of layers of sediments, which divide the South Carolina Coastal Plain into terraces. Throughout geological history, sea level has risen and fallen by over 300 m due to changes in the size of ocean basins, the amount of water in the oceans, the average density of sea water, and the emergence and submergence of land due to crustal movements (Titus 1986). Colquhoun and Johnson (1968) reported 13 major changes in sea level for the South Carolina Coastal Plain region which included five periods of sea level rise separated by periods of sea level fall or stable periods. According to the USACOE (1972), the most recent major rise in sea level reached 13 m above current mean sea level, and occurred between 147,000 and 86,000 years ago. This rise was followed by a fall in sea level which paused at 10 m, 8 m, 5 m, and 2.5 m above current mean sea level.

During more recent times, Titus (1986) indicated that sea level was rising at approximately 10 mm/yr between 17,000 and 7,000 years ago and Kana et al. (1984) reported that sea level was rising at approximately 3 mm/yr between 7,000 and 3,000 years ago. Hicks (1978) reported that sea level rise between 1922 and 1958 averaged 3.8 mm/yr, and 2.9 mm/yr between 1940 and 1975. The current rate of rise in local sea level (Charleston Harbor) is estimated at 2.5 mm/yr (Ringold and Clark 1980; Hoffman et al. 1983, 1985; Kana et al. 1984, 1986; Titus 1986).

Concerns over greenhouse effects, and their influence on global temperatures and sea level, have prompted recent research designed to predict interactions with the current rate of sea level rise. These models have incorporated complex scenarios to provide information on a wide range of effects on sea level. Recent projections (Hoffman et al. 1983, 1985; Kana et al. 1984) have predicted a rise in local sea level for Charleston Harbor of between 0.32 m and 1.00 m by the year 2060, and 1.44 m and 2.17 m by 2100. According to Hoffman et al. (1983) the rise in sea level could be as low as 0.074 m or as high as 3.45 m by the year 2100. Kana et al. (1984) predicted the effects of various accelerated sea level rise scenarios on land masses in Charleston Harbor. Models based on rise in sea level and rate of marsh formation concluded that without human intervention a 1-m rise in sea level over the next century would result in a loss of 50% of wetlands in the Charleston area, and a 1.5 m rise would result in an 80% loss (Kana et al. 1986).

Table II-2. Monthly and annual mean temperature and wind data for Charleston Harbor between 1970 and 1985 (based on NOAA 1972, 1985).

Month	Daily Max	Daily Min	Mean Speed km/hr	Prevailing Direction
January	16.4	3.1	14.8	SW
February	16.8	4.5	16.6	NNE
March	20.0	7.3	16.7	SSW
April	24.9	11.5	16.1	SSW
May	28.8	16.6	14.3	S
June	31.6	20.6	13.7	S
July	31.6	22.2	13.0	SW
August	31.5	21.4	12.1	SW
September	29.2	18.8	13.0	NNE
October	25.1	12.7	13.2	NNE
November	19.9	6.6	13.2	N
December	16.1	3.5	14.0	NNE
Annual	24.3	12.4	14.2	NNE

Climatology

The climate of the Charleston Harbor Estuary is relatively mild as compared with areas further inland (Arthur D. Little, Inc. 1974; Purvis and Rampey 1975; Mathews et al. 1980). The mountains of the northern portion of South Carolina and Georgia serve as a barrier to cold air masses from the northwest, and the Bermuda high pressure system tends to retard the progress of cold fronts into the coastal area. These conditions produce relatively mild, temperate winters. Summers are warm and humid, but relatively moderate with regard to temperature extremes, largely due to the influence of the ocean, especially the Gulf Stream (Arthur D. Little, Inc. 1974; Mathews et al. 1980).

Average monthly air temperatures for the Charleston Harbor area are presented in Table II-2. Temperatures in the Charleston Harbor area are generally moderated by marine influences and are often 2-3°C lower in the summer and 3-8°C higher in the winter than areas just a few kilometers inland of the estuary (NOAA 1972, 1978, 1983, 1985; Arthur D. Little, Inc. 1974; Purvis and Rampey 1975; Mathews et al. 1980). Temperatures higher than 38°C and lower than -6.5°C are unusual for the estuary.

Wind direction and velocity in Charleston Harbor are highly variable, and rather evenly distributed in all directions (Arthur D. Little, Inc. 1974). The inland portions of the estuary are subjected to a southwest-northeast wind regime (Mathews et. al. 1980). The prevailing winds are northerly in the fall and winter, and southerly in spring and summer (Arthur D. Little, Inc. 1974; NOAA 1985). The monthly average wind velocities and directions for the area range from a low of 12.1 kph in May to a high of 16.7 kph in March (Table II-2). The maximum recorded wind speed for the period 1960-1985 was 114 kph in March 1971 (Arthur D. Little, Inc. 1974; NOAA 1985).

The estuary receives an annual average precipitation of 124.87 cm (NOAA 1972, 1985; Arthur D. Little, Inc. 1974), which is almost exclusively rainfall. Very little precipitation (less than 0.5 cm) is recorded as snow, sleet, or hail. The greatest mean monthly precipitation is normally received in July while the smallest amountof precipitation normally occurs in November (Table II-3).

Relative humidity in the Charleston Harbor area is normally very high and fluctuates greatly. Generally, it is higher during the summer months than other times of the year, and the coastal areas exhibit a lower relative humidity than inland portions of the estuary (Arthur D. Little, Inc. 1974; Mathews et. al. 1980). The monthly mean relative humidity for four different times of day are presented in Table II-3.

Cloud cover varies widely for Charleston Harbor, with annual averages of 101 clear days, 115 partly cloudy days, and 149 cloudy days (NOAA 1972, 1985; Arthur D. Little, Inc. 1974). The mean monthly clear, partly cloudy, and cloudy days for the area are presented in Table II-3.

Tropical cyclones frequent the east coast of the United States, and almost always have some effect on the weather around Charleston Harbor. Historical accounts of tropical cyclones can be found in Dunn and Miller (1960), Ludlum (1963), Suggs and Carrodus (1969), Carter (1970), Purvis and Landers (1973), and Ho (1974). Occasionally these cyclones come close enough to the estuary to affect tides in Charleston Harbor, and if of hurricane force, they can cause extreme beach and marsh erosion. Hurricanes normally occur between August and December (Mathews et al. 1980). Tornadoes are extremely rare in the vicinity of Charleston Harbor, but have occurred in inland portions of the estuary (Mathews et al. 1980).

Table II-3. Monthly and annual mean precipitation, relative humidity, and cloud cover for Charleston Harbor between 1960 and 1985 (based on NOAA 1972, 1985).

Month	Precipitation	Relative Humidity by Time				Cloud Cover % Number of Days		
	(cm)	0100	0700	1300	1900	Clear	Partly	Cloudy
January	6.45	82	84	55	73	8	8	15
February	8.36	79	82	52	68	9	6	13
March	9.98	81	83	50	67	9	9	13
April	7.32	84	84	50	67	11	8	11
May	9.17	88	84	54	72	8	12	11
June	12.65	90	86	59	75	6	12	12
July	19.58	91	88	64	79	4	13	14
August	16.79	92	91	63	80	5	14	12
September	14.81	91	91	63	82	7	11	12
October	7.21	88	89	56	80	12	8	11
November	5.31	85	87	51	77	13	6	11
December	7.24	82	84	54	74	9	8	14
Annual	124.87	86	86	56	75	101	115	149

Table II-4. Approximate populations (1985) and area of incorporated areas found within the Charleston Harbor estuarine watershed.

	Population	Area km²
Charleston	72,000	120
North Charleston	69,000	100
Mount Pleasant	18,000	23
Hanahan	14,000	45
Summerville	12,000	110
Moncks Corner	5,500	25

Table II-5. Classification of land use patterns adjacent to the Charleston Harbor watershed. Approximate area and percent area.

Classification	Percent Area	Area km²
Agriculture	14.0	420
Forests	56.0	1,680
Urban	6.0	180
Rural	10.3	309
Open Water	6.0	180
Low Salt Marsh	2.7	81
High Salt Marsh	0.6	18
Brackish Marsh	0.5	15
Freshwater Tidal Marsh	2.5	75
Coastal Impoundments	0.7	21
Diked Disposal Areas	0.7	21
Total	100.0	3,000

Adjacent Land Use Patterns

The areas surrounding Charleston Harbor and the harbor itself are historically prominent due to the fact that this estuary has served as a critical port in the southeast since it was settled in 1670. Goodwin (1989), describing the historical changes in land around Charleston Harbor, noted that the colonial economy of the area was largely supported by cattle ranching; production of indigo; rice, and cotton crops; and mining for phosphates. The harbor also served as a critical port for both shipping and defense, and was the site where the first shots were fired in the Civil War. Charleston's rich history has made the peninsular city a major tourist attraction with numerous historical landmarks.

The port facilities currently represent the largest economic resource associated with the estuary. Currently the volume of cargo passing through the port make this harbor the second largest container port along the Atlantic seaboard. The United States Navy maintains its third largest home port in the Cooper River. These port facilities have required extensive dredging for maintenance and deepening of the shipping channels in recent years.

The lands surrounding the estuary are largely developed and support a population of more than one- half million people in Charleston, Dorchester, and Berkeley counties, which comprise an area of approximately 3,000 km². The two largest municipalities adjacent to the estuary are the cities of Charleston and North Charleston, but there are several other smaller towns and municipalities as well (Table II-4, Fig. II-2). To date, there have been no detailed analyses of land use patterns for the Charleston Harbor watershed, but general land use patterns can be determined from the literature (Tiner 1977; Mathews et al. 1980). An areal classification of land use within the watershed is summarized in Table II-5, and a brief description of the general use patterns for the areas adjacent to the estuary is provided below.

The entrance of Charleston Harbor is formed by two barrier islands: Sullivans Island, which is fully developed as a residential community, and Morris

Island, which is currently undeveloped. The entrance channel between these islands is stabilized by jetties which extend approximately 5 km into the ocean and were built in 1894. Most of the lower harbor basin is surrounded by city and urban developments. As noted previously, the harbor receives considerable shipping traffic due to the large commercial and naval port facilities located in the harbor basin as well as in the Cooper and Wando rivers. The commercial port facilities in the basin are located on the Charleston City peninsula. The Atlantic Intracoastal Waterway (AIWW) also crosses the harbor-basin between Mt. Pleasant and James Island at Wappoo Creek. Although there are no major industries located in the lower harbor area, the basin receives effluents from two large sewage treatment facilities which provide secondary wastewater treatment. These are located on Plum Island, and on Mt. Pleasant near the AIWW. Other sources of pollution affecting the lower harbor include nonpoint source runoff from the city and urban areas, several marina facilities in the lower reach of the Ashley River, and runoff from pollution sources in the three river systems. The harbor basin also has several diked disposal areas for dredged materials, with the largest being Drum Island.

The Cooper River has the greatest concentration of industrial and port facilities among the three river systems forming the Charleston Harbor Estuary. The majority of the facilities are located on the western shoreline and include naval port facilities, commercial facilities associated with the State Ports Authority, and private industries including Dupont, General Dynamics, Mobay Chemical Co., Amoco, Westvaco, and the South Carolina Electric and Gas Company. To accommodate the ship traffic, a 10.7 m deep navigation channel is maintained in the lower Cooper River, the channel extends 32 km upstream from the mouth of the river (USACOE 1966b, 1975). The eastern shoreline of the Cooper River is largely undeveloped, although there are several large diked disposal areas along the length of the maintained channel.

The Ashley River has the second largest number of industrial and commercial facilities which are located on the eastern shoreline. One of these sites, which is no longer in operation, is the Koppers facility. This site is currently under consideration for designation as an EPA Superfund site. In addition, numerous wastewater facilities for cities and subdivisions discharge into the mid and upper Ashley River, including the Charleston CPW, the town of Summerville, the Pepperhill subdivision, and the Berkeley County WSA. Much of the remaining upland areas on both sides of the river support residential developments.

The Wando River presently has the least upland development compared to the other two river systems, except in the lower reaches of the river. In that area, the State Ports Authority maintains the large Wando Terminal Facility which is located on the eastern shoreline. There are also several residential communities which are either already present or being developed on this shoreline. Large diked disposal areas are located on Daniel Island, which forms the western shoreline of this river. The only major industrial facility on this river is Detyens Shipyard located at Cainhoy (Fig. II-2).

Additional details on land use patterns surrounding Charleston Harbor, and the changes which have occurred during the 15-year review period are presented in the trends section.

The Charleston Harbor Estuary is a complex system with respect to its physical and chemical properties. Hydrographic circulation patterns, sedimentation patterns, and the distribution of basic water quality parameters, such as temperature, salinity, dissolved oxygen, pH, and nutrients are all strongly affected by climatic conditions, tides, and freshwater flow. Because freshwater flow was markedly altered in 1985 by the Cooper River Rediversion Project (Kjerfve and Magill 1990), many of the conditions described for the study period covered in this report may now be different. General changes which may occur as a result of rediversion are noted in the following sections.

Freshwater Flow

The flow of fresh water from the Cooper, Wando, and Ashley rivers into Charleston Harbor opposes the cyclic rise of the tide, and pushes salt water back downstream after high slack tide (SCWRC 1973). Charleston Harbor received a monthly average flow of 11.8 m^3/s from all sources prior to the diversion of the Santee River into the Cooper River basin in 1942 (USACOE 1966a,b,c). The Cooper River contributed 2.0 m^3/s, the Wando River 2.5 m^3/s, the Ashley River 7.4 m^3/s, and local runoff 0.1 m^3/s of fresh water flow to the harbor (Benson 1977). Diversion of the Santee River increased the flow of fresh water into the harbor to a monthly average of 455 m^3/s, with a range of 87 m^3/s to 844 m^3/s (USACOE 1966a,b,c; Kjerfve and Magill 1990).

The operation of the Pinopolis hydroelectric plant became the main source of fresh water flowing into Charleston Harbor, and salinity in the harbor became controlled by the flow (USACOE 1966a). The hydroelectric plant operates on a basis of demand for electricity, making flow through the dam quite variable (USACOE 1966a,b,c; Kjerfve and Magill 1990). The long-term daily average flow into the harbor between 1942 and 1984 was 456 m^3/s (NOAA 1985), and according to Kjerfve and Magill 1990), the monthly average Cooper River discharge was 418 m^3/s. Discharge was normally highest during the winter months (January - March) and lowest during the autumn months (September - November) during the period of diversion (Fig. II-8), with spring floods resulting in greater flows (SCWRC 1979; NOAA 1985). Since the rediversion of the Santee River in 1985, the flow from the Cooper River into Charleston Harbor has become more stable, with a monthly mean of 122 m^3/s and a range of 92 m^3/s to 147 m^3/s (Kjerfve and Magill 1990).

Tides

Charleston Harbor experiences semidiurnal tides, with two nearly equal high and low tides during a single lunar day (24.8 h) (USACOE 1966a; NOAA 1985). The tidal prism of Charleston Harbor is approximately 1.35 x 10^8 m^3 (NOAA 1985). Tidal heights and current velocities are extremely variable, and are strongly affected by winds, storms and river flow (SCWRC 1973, 1979). Flood tide cycles can be dramatically reduced during and after heavy rainfall, or greatly increased by shoreward winds and storms (Gallagher 1963). Prior to rediversion, the mean tidal amplitude (range) within the harbor was 1.6 m, and spring tide amplitudes averaged 1.8 m (SCWRC 1973; Arthur D. Little, Inc. 1974; NOAA 1985; Kjerfve and Magill 1990). Maximum tidal amplitudes of 2.5 m have been recorded, and amplitudes may range from 1.3 m above mean slack low (MSL) tide to 1.2 m below MSL (Arthur D. Little, Inc. 1974).

The Cooper, Wando, and Ashley rivers are tidally influenced throughout their lengths, with an average 1.5 m tidal amplitude extending 18 km up the

Cooper River, 20 km up the Wando River, and 12 km up the Ashley River (NOAA 1985). Tidal amplitudes within the Cooper River have been reported to be 1.3 m at Cote Bas (22.5 km upstream) and 0.5 m at Pimlico (57 km upstream) (SCWRC 1979). Prior to rediversion, the USDOC (1981) projected the high tide at Pimlico (Fig. II-2) would occur approximately 3 hours and 20 minutes later than in the harbor and low tide approximately 3 hours and 50 minutes later. In the Ashley River, tidal amplitudes average 1.6 m at Wappoo Creek (1.2 km upstream) and 1.7 m at Drayton Hall (14 km upstream), with high and low tides at Drayton Hall occurring approximately 45 minutes after they occur in the harbor (USDOC 1981). The Wando River exhibits tidal amplitudes of 1.8 m at Cainhoy (14 km upstream) and 2.0 m at Big Paris Island (22 km upstream), with high tide at Big Paris Island occurring approximately 65 minutes after it does in the harbor and low tide occurring approximately 55 minutes later (USDOC 1981).

Historical data have recorded high tides in excess of 3.2 m above MSL in the harbor, and low tides in excess of 2.2 m below MSL (Arthur D. Little, Inc. 1974). In addition, research by the United States Weather Bureau has suggested that the tide exceeded 4.4 m above MSL during a storm in the year 1752. According to Neiheisel and Weaver (1967), the general circulation within the harbor follows a counter- clockwise pattern over a tidal cycle. Normal tidal current velocities reach a maximum of 0.9 m/s to 1.1 m/s in the harbor, but ebb tide currents often reach velocities of 1.8 m/s to 2.7 m/s when river flow is high (USACOE 1958, 1966; USDOC 1967).

Probable effects of the Cooper River Rediversion Project on tidal stage, amplitude, and current velocities in different parts of the estuary were not well documented prior to 1985. Following rediversion, the National Ocean Survey (NOS) conducted an intensive study of tidal currents in Charleston Harbor Estuary in order to develop more accurate tide tables, and to resolve general current

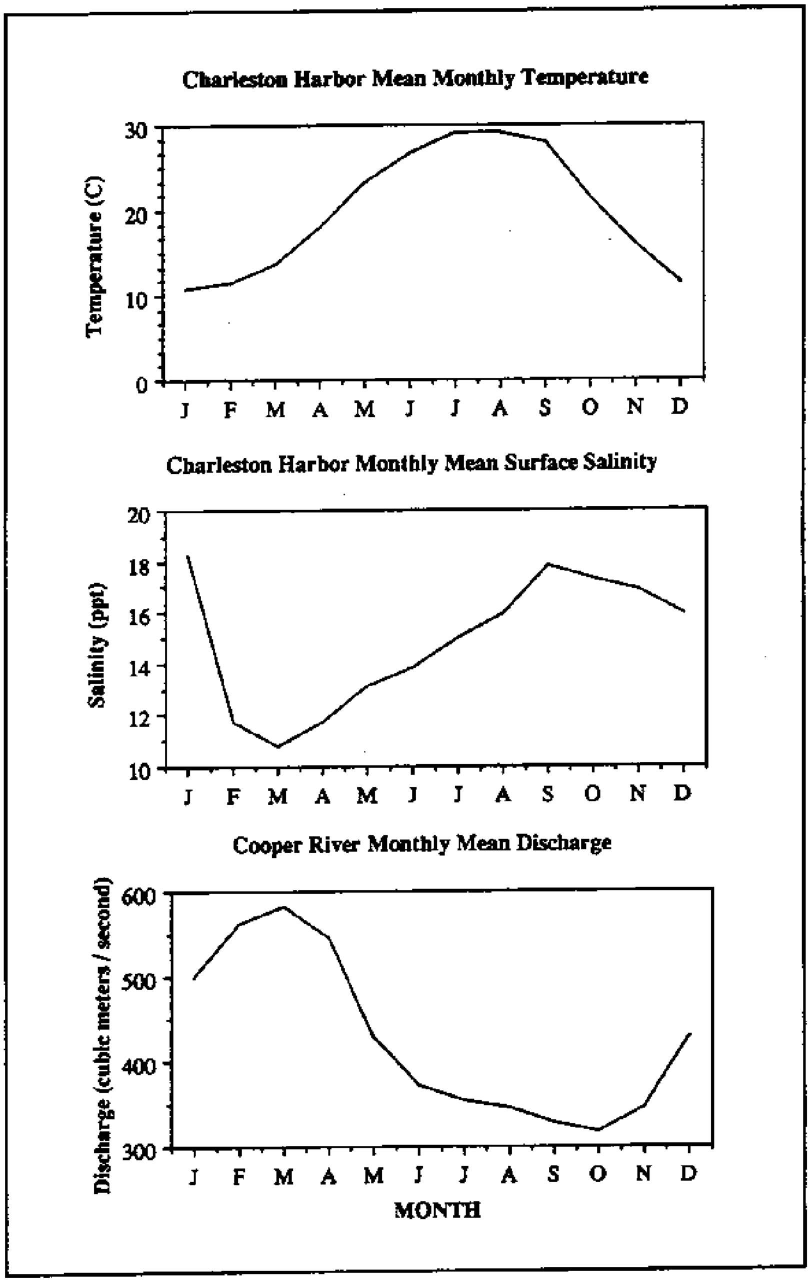


Fig. II-8. Monthly mean temperature, surface salinity, and freshwater discharge into the Charleston Harbor Estuary for 1970-1985. Discharge data is from the Pinopolis Dam. Temperature and salinity data were collected at the Custom's House in the harbor basin.

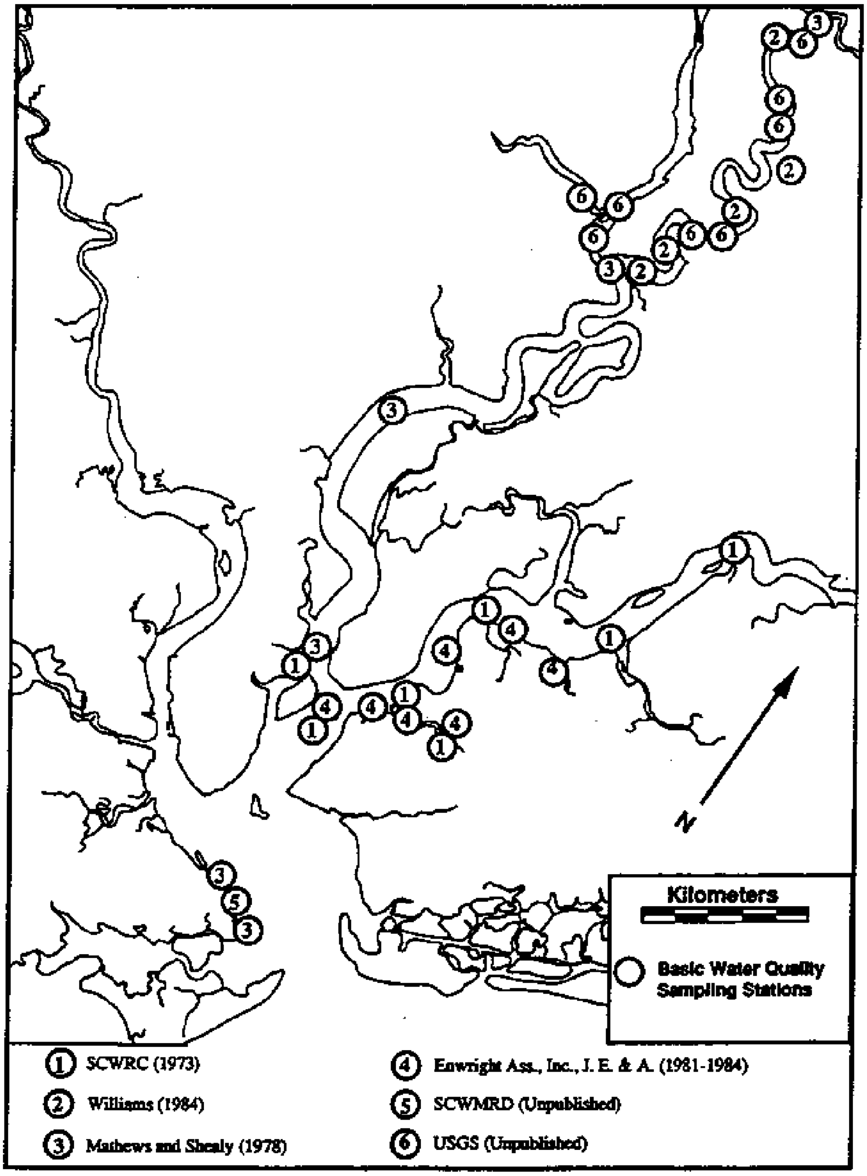


Fig. II-9. Basic water quality sampling stations in the Charleston Harbor Estuary for 1970-1984.

patterns (Wilmont and Williams 1987; Wilmont 1988). The USGS is also collecting post-rediversion data on tide stage and other parameters at several sites in the estuary (Fig. II-9) (USGS unpublished data). Results from the NOS study indicate that 1987 tide stage and current predictions far exceeded NOS error limits in many harbor areas.

Circulation Patterns and Salinity Regimes

Prior to rediversion, tides and freshwater flow were the major factors controlling circulation patterns in Charleston Harbor, while winds and longshore currents constituted minor factors (USACOE 1966). Following rediversion, freshwater flow has been greatly reduced, and presumably plays a lesser role. Circulation patterns in the harbor are characterized by reversals of both surface and bottom currents over a single tidal cycle. These patterns change from one tidal cycle to another, depending on differences in tidal amplitude and freshwater flow.

Charleston Harbor is a stratified estuary with a net downstream flow in a relatively freshwater surface layer, a net upstream flow in a bottom saline layer, and a net bottom to surface flow of water (USACOE 1958, 1966a; Lindner 1960; SCWRC 1973; Van Nieuwenhuise 1978; Kjerfve and Magill 1990). As the tide begins to flood, a bottom salt wedge begins moving upstream, while the fresher surface layer is still flowing downstream. The surface layer begins to move upstream and the majority of the upstream flow follows a path along the northern portion of the estuary. The salt wedge is most strongly defined in this area due to the freshwater discharge from the Cooper River. As the tide begins to turn, the surface layer becomes slack and then begins to ebb, while the bottom layer continues to flood. The salt wedge begins to ebb, resulting in an attenuated salt wedge. During ebb tide, the majority of the flow follows a path through the southerly portion of the estuary.

Maximum surface current velocities during normal cycles in the harbor range from 1.0 m/s to 1.5 m/s during ebb tide, and 0.5 m/s to 1.3 m/s during flood tide. Current velocities at the bottom are generally lower than at the surface. According to Mathews et al. (1980), surface current velocities are greater in the northern portion of the harbor than in the southern portion during maximum flood, and the reverse is true during maximum ebb.

Prior to rediversion, few detailed circulation studies were conducted. The USACOE constructed a scale model of the harbor at the Waterways Experiment Station (WES) in Vicksburg, Mississippi, and a number of studies were conducted with the model to determine the effects of varying flow and topography within the harbor (USACOE 1954, 1957a,b,c). A few studies were also conducted in the estuary to determine the validity of the model (USACOE 1977). In addition, limited dye-dispersion studies have been conducted in the Wando and Cooper rivers (SCWRC 1973; Arthur D. Little, Inc. 1974). Additional studies were being conducted by the NOS to better define post-rediversion circulation patterns (Wilmont and Williams 1987; Wilmont 1988).

Sedimentary Patterns

Charleston Harbor has been utilized as a seaport since colonial times, and during the 20th century, the harbor has been dredged to maintain channel depths. Average prediversion dredging resulted in the removal of approximately 137,620 m^3 of material per year. After diversion of the Santee River into the Cooper River and completion of a channel deepening project, sedimentation in the harbor increased dramatically. Dredging efforts increased to keep up with the added deposition, averaging approximately 7,645,350 m^3/yr during the period 1943 through 1985. As a result, many studies evaluated the sources, distribution, and mechanisms of sediment deposition in Charleston Harbor (Neiheisel 1959; USACOE 1966a, 1972; Neiheisel and Weaver 1967; Settlemyre and Gardner 1975; Mathews and Shealy 1978, 1982; Van Nieuwenhuise 1978). A summary of information provided by these references follows.

There are three major sources of sediments entering the harbor: marine material, Holocene deposits within the Cooper River basin, and material transported from the upper Santee River basin through lakes Marion and Moultrie. The amount of material settling in the harbor from marine sources has been estimated at approximately 919,750 m^3/yr. Scouring and runoff from the Cooper River basin contributes approximately 752,500 m^3/yr of a wide size spectrum of sand, silt, and clay which settles in Charleston Harbor. Fine sands and silt capable of being transported through lakes Marion and Moultrie from the upper Santee River basin contribute an additional 1,421,400 m^3/yr to the volume of material settling in Charleston Harbor.

Marine sands are concentrated in the harbor mouth as well as along the northern half of the estuary in the vicinity of Mount Pleasant. Marine sands are also found in the navigation channels to approximately 18 km above the harbor mouth. Bottom samples from the vicinity of the jetties and landward between Fort Sumter and Fort Moultrie contain over 90% sand size particles. Upstream of these locations, the sand is mixed with silt and clay of both marine and riverine origins. Marine silts are widely found in the harbor entrance, less in the harbor basin, and extend into the Ashley River.

Sands originating from recent Holocene deposits occur in bottom sediments in both the Wando and Cooper rivers. Similar deposits occur in the Ashley River, but are covered by recently deposited silts and clays. The harbor basin is dominated by fluvial and mixed silts, described as dark-gray sludge, composed of more than 75% silt and clay, with the content of silt and clay increasing abruptly toward the west, and more gradually toward the north. The distribution of river-derived silts throughout the harbor is due to the net seaward flow of the surface layer.

The shoals in Charleston Harbor are dominated by silt and clay-size sediments, representing the lowest average median diameter (0.06 mm) of all sediments in the harbor. The salt water wedge mechanism constitutes the major factor responsible for sedimentation in Charleston Harbor. Simmons (1965) concluded that the landward flow along the bottom prevented sediments from being transported past points of no-net-motion (nodal points). Sediments associated with the wedge move back and forth over the bottom with tidal cycles, being deposited at the nodal points.

In Charleston Harbor, the salt wedge is most strongly developed in the western portion of the harbor, and the Cooper River carries the majority of upstream sediments. Therefore, sedimentation occurs most significantly in this area. According to Van Nieuwenhuise (1978), three major nodal points exist within the estuary, migrating from 8 miles to 11 miles inland over a single tidal cycle. In addition, the nodal points represent the landward boundary for deposition of most marine derived material, as well as the seaward boundary for the majority of river-derived material.

Flocculation is another important mechanism in the deposition of river sediments within the estuary, particularly in the areas having higher salinities, higher concentrations of suspended solids, and lower turbulence. According to the USACOE (1966a), the effects of a spring tide and lower than average freshwater flow promote flocculation at points further upstream, while neap tides and higher than average flows promote deposition further down in the harbor.

Neiheisel and Weaver (1967) noted that the bottom suspended sediment load is greater at flood tide than at ebb in most parts of the harbor, although

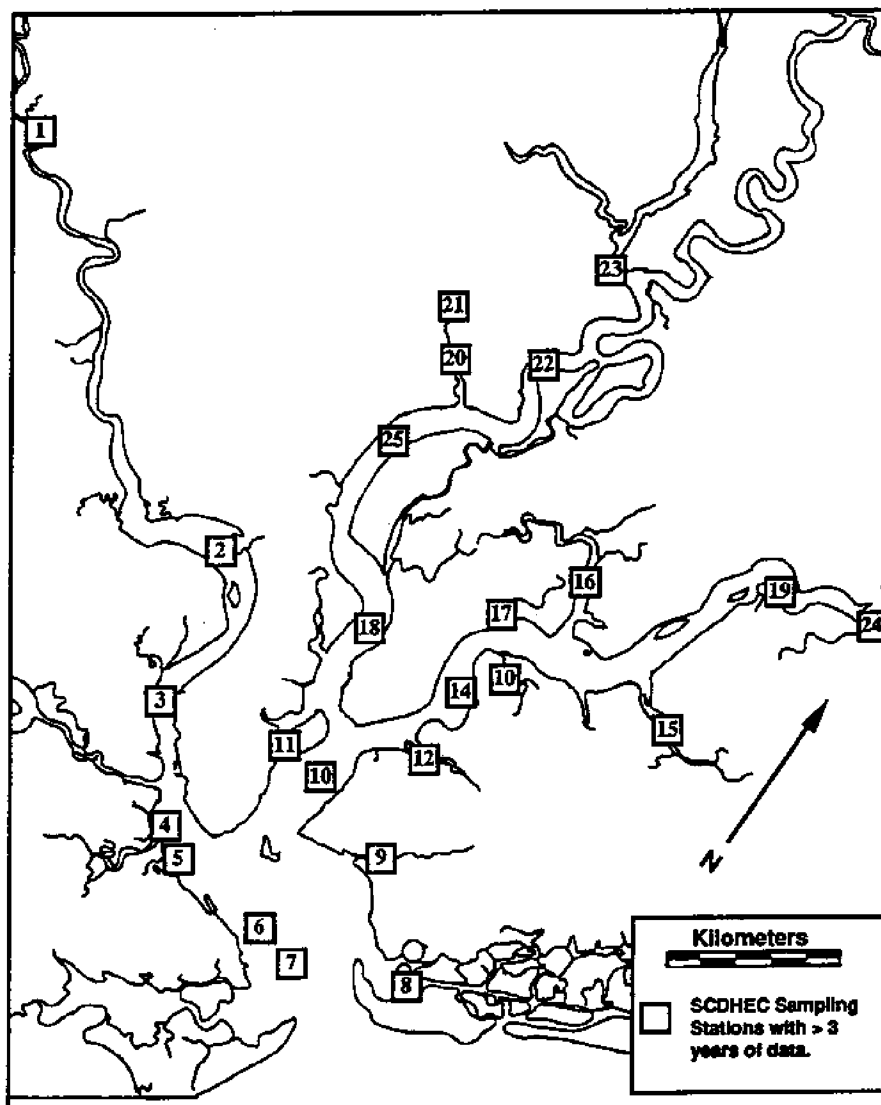


Fig. II-10. Station locations for the South Carolina Department of Health and Environmental Control's monitoring program with three years or more data during the 1970-1985 survey period. Stations are identified in Table II-6.

Table II-6. Identifications and the years sampling took place for the SCDHEC stations plotted in Fig. II-10.

Station	SCDHEC Designation	Years Sampled
1	MD-049	1970-1985
2	MD-135	1970-1985
3	MD-052	1970-1985
4	MD-020	1972-1985
5	MD-034	1970-1985
6	MD-165	1972-1985
7	MD-048	1972-1985
8	MD-070	1970-1985
9	MD-071	1970-1985
10	MD-046	1974-1985
11	MD-047	1970-1985
12	MD-500	1979-1982
13	MD-501	1979-1982
14	MD-198	1974-1985
15	MD-504	1979-1982
16	MD-503	1979-1982
17	MD-502	1979-1982
18	MD-045	1974-1985
19	MD-115	1972-1985
20	MD-113	1970-1985
21	MD-114	1970-1985
22	MD-043	1974-1985
23	MD-152	1972-1985
24	MD-505	1979-1982
25	MD-044	1974-1985

the reverse situation was found in some areas. They also found that at the north end of the harbor, more bottom sediment is entering the harbor than leaving, whereas at the southern end more sediment was leaving than entering the harbor. The suspended sediments in the northern part of the harbor are primarily sands, while those in the southern part are primarily silts and clays. Mathews and Shealy (1978, 1982) observed total suspended solids in Charleston Harbor ranging from 14.00 mg/l to 57.84 mg/l for surface samples and 22.96 mg/l to 144.40 mg/l for bottom samples. Nelson (1974) reported total nonfilterable residue concentrations of 12 mg/l to 63 mg/l in surface samples.

The Cooper River Rediversion Project will presumably reduce sedimentation rates in Charleston Harbor. Actual changes in sedimentation rates have not been documented to date, and it may take many years before average rates in different portions of the estuary can be defined. The Charleston Harbor Deepening Project, which was initiated after rediversion, will undoubtedly delay the determination of post-rediversion sedimentation rates in the harbor.

Basic Water Quality Parameters

A number of sources exist for basic water quality data in the Charleston Harbor Estuary (Figs. II-9, II-10, and II-11). The majority of these sources consist of short-term sampling periods conducted for specific research projects or environmental impact statements. The most comprehensive data base is that of the South Carolina Department of Health and Environmental Control (SCDHEC), which has collected water quality data at numerous stations for many years (Figs. II-10 and II-11, Table II-6).

Temperature

Water temperatures within Charleston Harbor average 19.8°C and range between 6.2°C and 29.9°C throughout the year (USACOE 1966a; Mathews and Shealy 1978, 1982; Kjerfve and Magill 1990). Large diurnal variations (> 3°C) in temperature are uncommon in Charleston Harbor, and differences between surface and bottom temperatures range between 0.5°C and 2.0°C (USACOE 1966a, 1972; Mathews and Shealy 1978, 1982). According to Mathews and

Shealy (1978,1982), the average diurnal variation in water temperature is 1.5°C, and may be as high as 2.5°C at the surface and 2.7°C on the bottom. In addition, SCDHEC monitoring during the period 1970-1985 revealed a seasonal range of water temperatures from 1.50°C to 35.00°C throughout the entire estuary (Appendix A).

Salinity

The mean harbor salinity as measured in the harbor basin was 16.8‰, with a range of 7.7‰ to 29.5‰ prior to rediversion (Kjerfve and Magill 1990). Mathews and Shealy (1978, 1982) reported that saline conditions extended approximately 25 km up the Cooper River from the mouth of the harbor, and that the salt wedge extended upstream to Big Island. They also reported that bottom salinities decreased from approximately 27‰ at Cummings Point to fresh water at the confluence of the east and west branches of the Cooper River. Average salinities were between 4.5‰ and 5.3‰ at the mouth of the Cooper River, average salinities between 16.0‰ and 18.5‰ were observed at the mouth of the harbor. Mathews et al. (1980) stated that isohalines were very compressed from the lower harbor to the mouth of the Cooper River, and then become more spread out. Mathews and Shealy (1978) reported that salinities may range between 2‰ and 22‰ over a single tidal cycle in the harbor basin. They also reported average ranges of salinities over a tidal cycle of 10‰ to 12‰ at the surface, and 14‰ at the bottom. SCDHEC monitoring during the period 1970-1985 revealed a range of 0.0‰ to 35.6‰ within the watershed.

Prior to rediversion, salinity regimes in Charleston Harbor were predominantly controlled by freshwater flow, exhibiting distinct seasonal trends (FWPCA 1966; USACOE 1966a,b,c; Kjerfve and Magill 1990). At high river discharges the estuary is strongly stratified and salinity distribution becomes dependant on the stage of the tide. At freshwater flows less than 280 m^3/s, the estuary is less vertically stratified (FWPCA1966; USACOE 1966a, 1972; Kjerfve and Magill 1990). In addition, the rate at which salinity moves upriver is influenced by the tidal range as

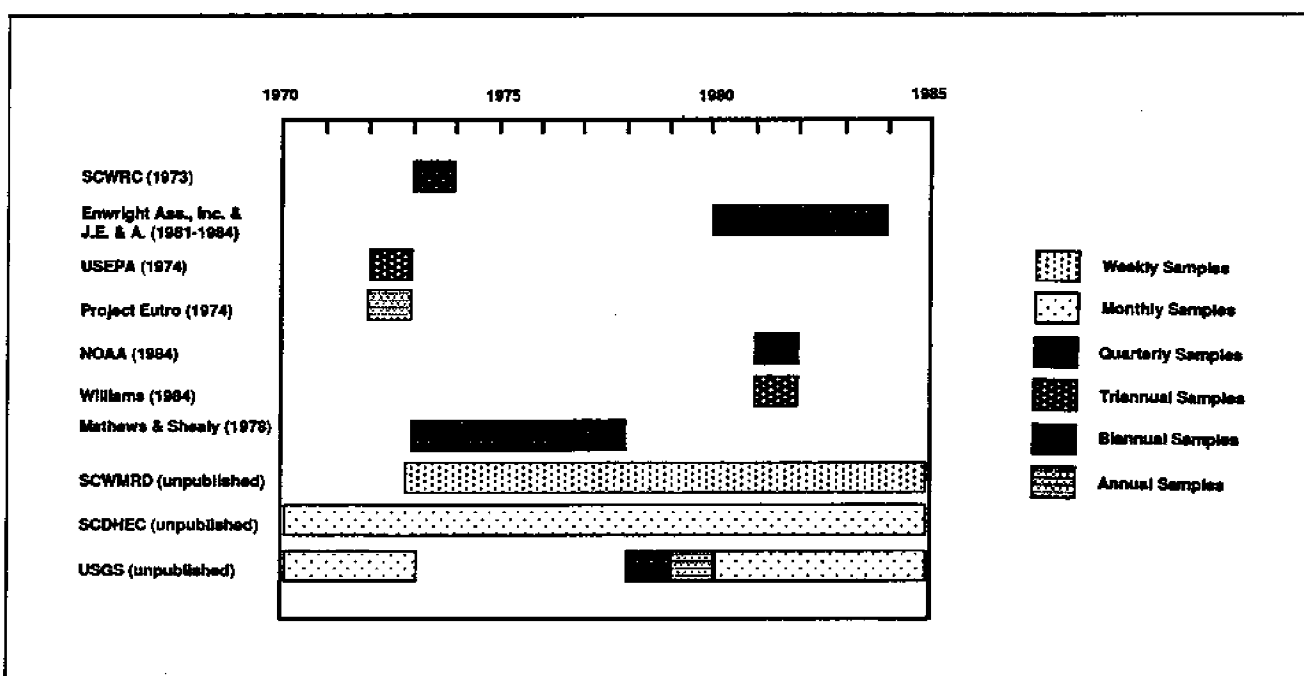


Fig. II-11. Studies which collected basic water quality data in the Charleston Harbor Estuary during the 1970-1985 review period.

well as the prevailing downstream flow (FWPCA 1966; SCWRC 1979), and a difference in tidal amplitude has a pronounced effect on salinity distribution (Van Nieuwenhuise 1978). At high discharges the characteristics of mixing and stratification also become strongly dominated by channel geometry, and there is restricted mixing between surface and bottom layers. Spring tide conditions result in an increased response in the surface layer related to more intense mixing at the bottom layer-surface layer interface, created by higher shearing velocities.

One important anomaly in the circulation within the Charleston Harbor Estuary occurs in the Wando River. High and low slack tides occur in the southerly portion of the Wando River approximately 40 minutes before they occur in the Cooper River. At low slack tide, the flow of water from the Cooper River often moves upstream into the Wando River (USACOE 1966a). Similarly, at high slack tide, water may flow up the Cooper River from the Wando River. Under certain conditions, the salinity 13 km up the Wando River is higher than that encountered at its mouth.

Dissolved Oxygen

Dissolved oxygen levels within the Charleston Harbor Estuary fluctuate widely on tidal, diurnal, and seasonal cycles (FWPCA 1966; USACOE 1966a, 1972; Mathews and Shealy 1978, 1982; Mathews et al. 1980). SCDHEC monitoring during the period 1970-1985 revealed dissolved oxygen concentrations ranged from 0.00 mg/l to 17.05 mg/l, with an average of 7.46 mg/l for the entire estuary (Appendix A). Dissolved oxygen concentrations were generally higher in the colder months than in the summer months due to the lower temperature and reduced consumption of oxygen by organisms (FWPCA 1966; USACOE 1966a; Arthur D. Little, Inc. 1974). Arthur D. Little, Inc. (1974) reported concentrations of dissolved oxygen between 4.9 mg/l and 9.4 mg/l in bottom waters and between 5.2 mg/l and 10.6 mg/l in surface waters. According to the FWPCA (1966), low dissolved oxygen concentrations (less than 3 mg/l) were commonly reported from the Ashley River during the 1950's and 1960's. USACOE (1966a) reported saturation of dissolved oxygen in bottom waters of 52% in the upper harbor and 77% in bottom waters of the lower harbor. Mathews and Shealy (1978) reported saturation of dissolved oxygen of 80% near the mouth of the harbor and 90% to 95% at the mouth of the harbor.

Dissolved oxygen levels in the estuary are influenced by many factors. At high river flow and strong stratification, mixing between the surface and bottom layers is restricted, and the source of dissolved oxygen for the bottom layer is offshore, oceanic waters (FWPCA 1966). Consequently, the concentration of dissolved oxygen in the bottom layer is dependant on factors affecting bottom flow. Also, at high river flow the dissolved oxygen percent saturation is fairly constant throughout the estuary (FWPCA 1966; USACOE 1966a). At low river flow, surface aeration is the major source of dissolved oxygen throughout the estuary. The dissolved oxygen concentration in the estuary is generally lower during low river flow, and drops markedly in the upstream direction (FWPCA 1966). Other factors such as water temperature and phytoplankton concentrations exhibit seasonal influences on dissolved oxygen levels in the estuary (FWPCA 1966; USACOE 1966a; Arthur D. Little, Inc. 1974).

Rediversion of the Cooper River was expected to markedly affect some of the physical and chemical properties of the estuary, while other properties would go unchanged. Water temperatures will not be affected, while salinity regimes up the Cooper River were expected to increase markedly. Speculation has abounded on the effects of rediversion on parameters such as dissolved oxygen concentration and pollutant resident times within the estuary, but the actual

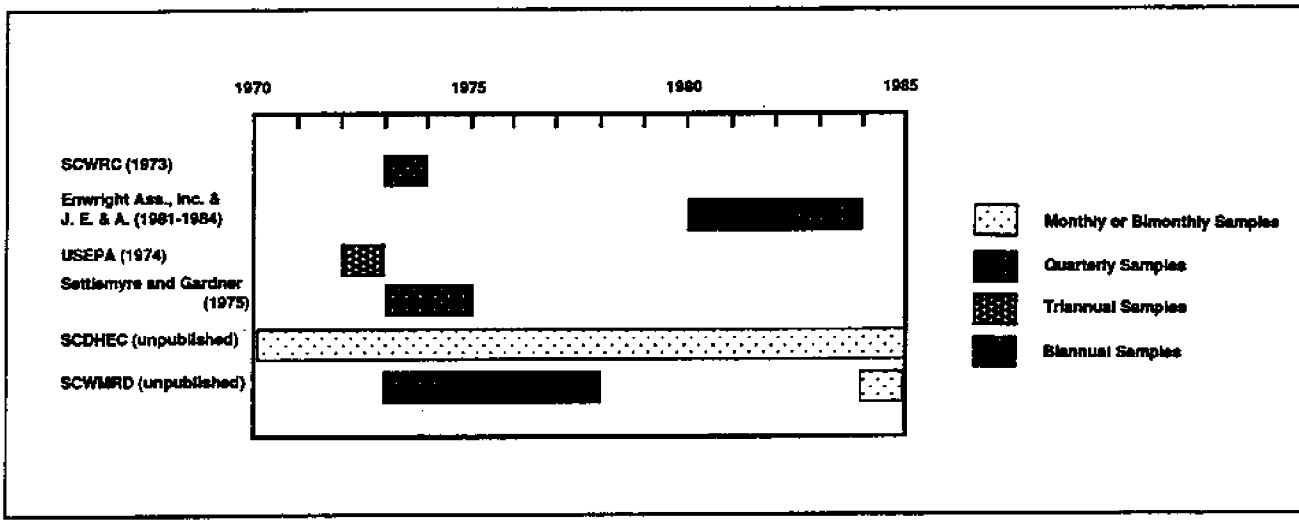


Fig. II-12. Studies which collected nutrients data from Charleston Harbor Estuary during 1970-1985.

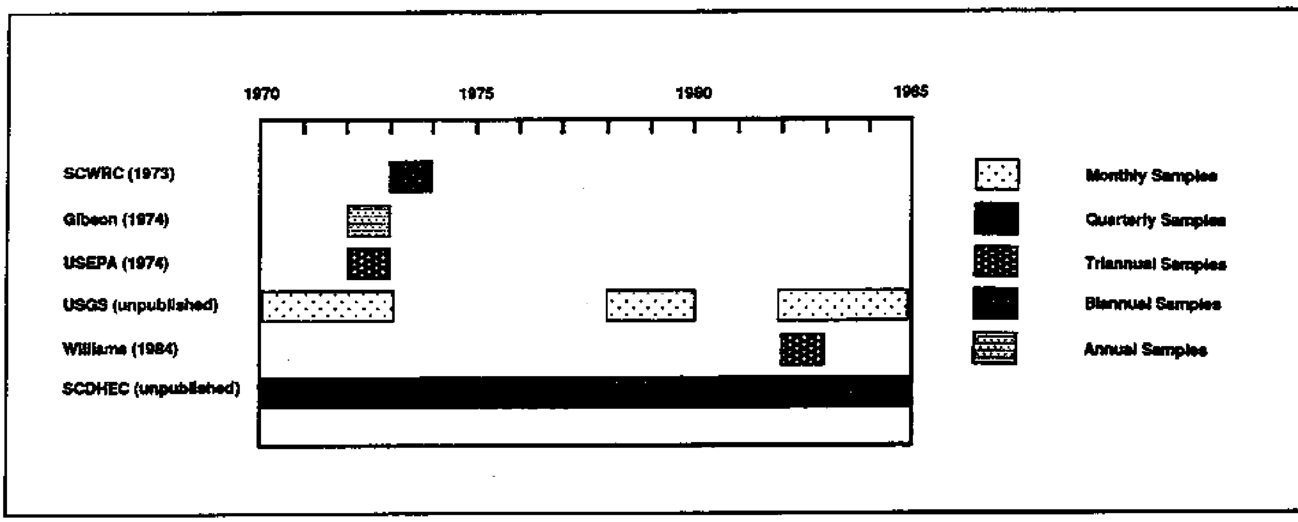


Fig. II-13. Studies which collected metals data from Charleston Harbor Estuary during 1970-1985.

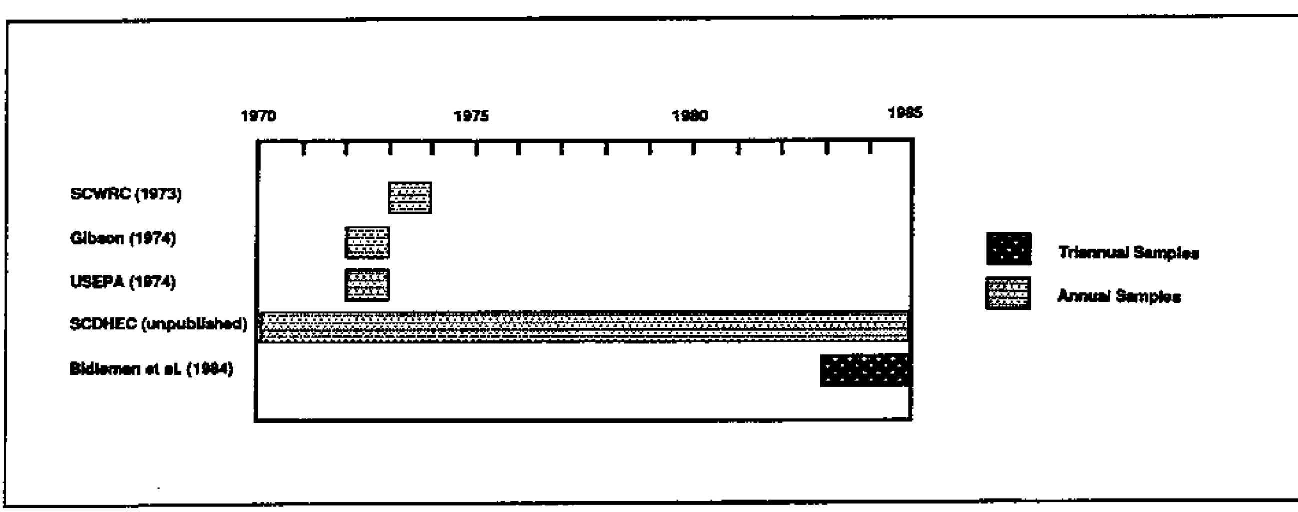


Fig. II-14. Studies which collected organic pollutants data from Charleston Harbor Estuary during 1970-1985.

Table II-7. Concentration ranges of metals in the water column in the Charleston Harbor Estuary between 1970 and 1985 at 46 SCDHEC stations.

Metal	Min (µg/l)	Max (µg/l)
Copper	< 0.02	2,000.00
Iron	< 0.02	10,310.00
Cadmium	< 0.02	260.00
Chromium	< 0.02	1,080.00
Lead	< 0.02	420.00
Mercury	< 0.02	80.00
Nickel	< 0.02	380.00
Zinc	< 0.02	670.00

effects may not be known for many years. A study was initiated by SCWMRD in 1984 to document the changes in physical and chemical parameters following rediversion. Sampling for this study was completed in 1988, and a final report was recently published (Van Dolah et al. 1990).

Nutrients

A number of studies sampled for nutrients in the estuary during the period 1970-1985, (seen in Fig. II-12) but the only long-term source for nutrients data is the SCDHEC monitoring program. This monitoring program recorded ranges of Kjeldahl nitrogen between 0.04 mg/l and 19.90 mg/l, nitrate-nitrite between 0.00 mg/l and 6.65 mg/l, orthophosphate between 0.00 mg/l and 1.56 mg/l, total phosphate between 0.02 mg/l and 4.60 mg/l, and total ammonia between 0.02 mg/l and 13.00 mg/l (Appendix A).

Pollutants

Six sources of metals data (Fig. II-13) and four sources of organics data (Fig. II-14) were found for the Charleston Harbor Estuary. The SCDHEC monitoring program sampled for numerous metals in the water column on a quarterly basis, and for organics and metals in sediments on an annual basis. Ranges for metals in the water column are presented in Table II-7, and the sediment contaminants are presented in the trends section. Only three sources for biochemical oxygen demand (BOD), chemical oxygen demand (COD) and coliform data were identified (Fig. II-15). Again, the only long-term data set is from the SCDHEC monitoring program, and it contains ranges of 0.10 to 11.00 mg/l for BOD, 0.00 mg/l to 930.00 mg/l for COD, and 1 colony/ml to 31,500 colonies/100 ml for fecal coliform.

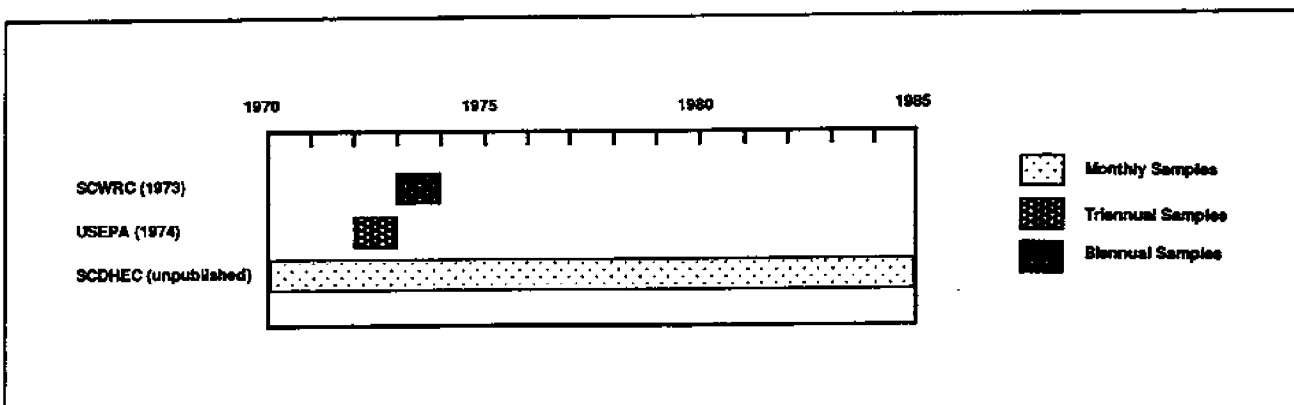


Fig. II-15. Studies which collected BOD, COD, and/or coliforms data from Charleston Harbor Estuary during 1970-1985.

The Charleston Harbor Estuary supports a vast array of biological communities due to the abundance of marsh and other diverse habitats. Numerous recreationally and commercially important species of finfish and invertebrates utilize the estuary during some portion of their life history. Studies of vegetation and fauna found within the Charleston Harbor Estuary, however, are limited in comparison to geological and hydrographic data available for the system. Information from these studies is summarized below for the various biological components.

Intertidal Vegetation

Marsh vegetation bordering the Charleston Harbor Estuary is quite extensive, largely due to a relatively high tidal range combined with a low coastal topography. The estimated acreage of marshes in the system exceeds 21,000 ha (SCWMRD 1972; Duncan 1975; Tiner 1977), of which approximately 2,000 ha lie within coastal impoundments, 7,500 ha consist of freshwater marsh, and 11,500 ha consist of brackish and salt marsh (Tiner 1977).

The best description of the marsh vegetation present in the estuary is provided by Tiner (1977), who completed a general inventory of all coastal marshes throughout South Carolina. Additional surveys have been conducted by others (SCWMRD 1972; Batson 1974; Stalter 1974; Duncan 1975; Williams 1984; Jensen and Davis 1986; USFWS unpublished data), but these generally have been limited to small portions of the estuary (Figs. II-16, II-17, and II-18). All of these studies document a diverse assemblage of plant species which are typically found throughout the southeast, with distribution patterns of the species determined pri-

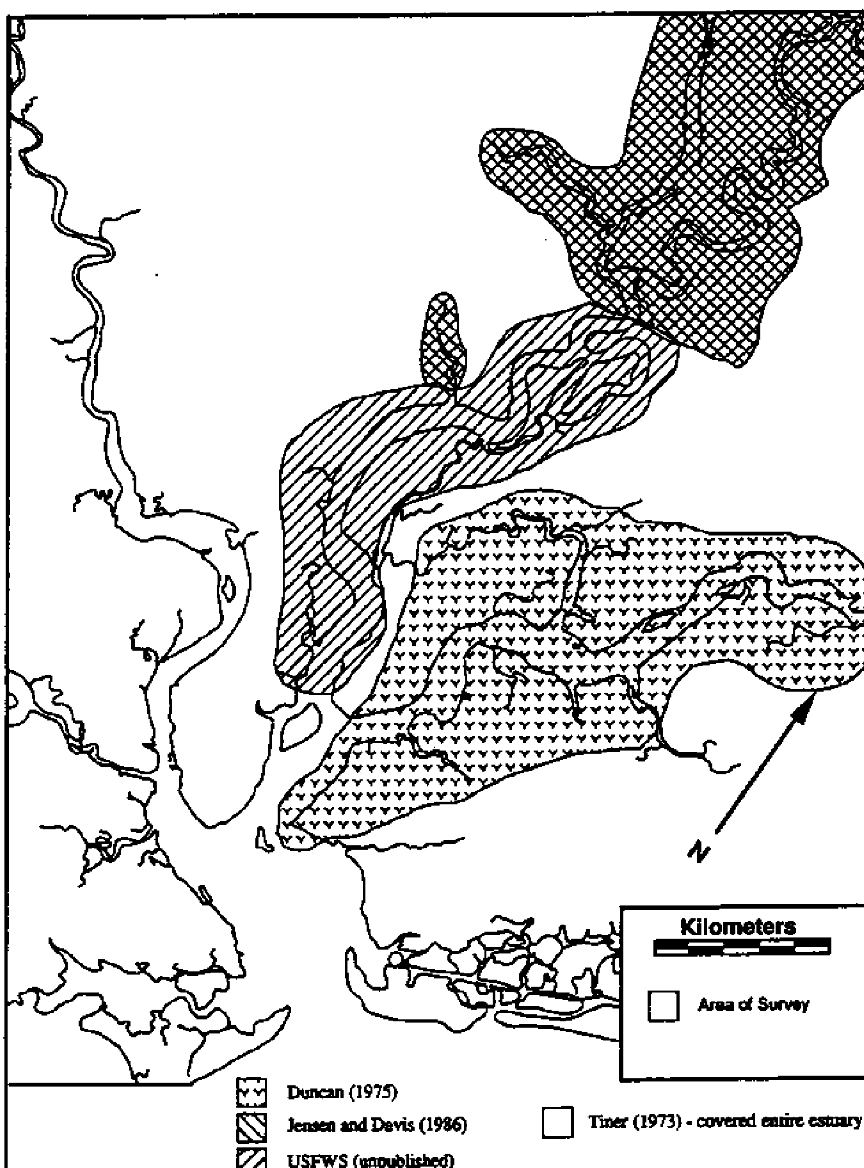


Fig. II-16. Area covered by aerial studies of the vegetation of Charleston Harbor Estuary during 1970-1985.

marily by salinity and duration of tidal flooding (Stalter 1974). The general distribution pattern of the dominant plant species is summarized in Table II-8, and a complete list of marsh plants reported from the estuary is present in Appendix B.

Table II-8. Dominant species of marsh vegetation found in the Charleston Harbor Estuary (by type of marsh and vertical zonation).

	Low Marsh	High Marsh
Saline		
	Spartina alterniflora	*Juncus romerianus*
		Borrichia sp.
		Distichlis spicata
		Salicornia sp.
		Spartina patens
Brackish		
	Juncus romerianus	*Pontederia cordata*
	Spartina cynosuroides	*Juncus romerianus*
	Scirpus validus	*Sagittaria* sp.
	Sagittaria sp.	
Fresh		
	Scirpus validus	*Zizaniopsis miliaceae*
	Pontederia cordata	*Alternanthera philoxeroides*
	Sagittaria spp.	*Pontederia cordata*
		Saururus cernus

Tidal marshes in the Ashley and Wando rivers reflect a strong marine influence, exhibiting salt and brackish marsh vegetation throughout almost their entire length. Duncan (1975) reported that *Juncus romerianus* occupied the higher marsh zone within the lower reaches of the Wando River, and became the dominant vegetation within the upper reaches. The Cooper River marshes, on the other hand, exhibit a wide range of vegetation, changing markedly from salt to brackish to freshwater types between its mouth at the harbor and the upper estuarine extent at the confluence of the east and west branches of the Cooper River (Tiner 1977; Williams 1984). Remnant stands of *J. romerianus* are present in the freshwater marshes of the upper Cooper River, owing to the prediversion brackish conditions.

Few studies have addressed the role of marshes with regard to primary productivity within the estuary, although Duncan (1975) utilized remote sensing techniques to examine the marshes of the Wando River-Clouter Creek area, categorizing the marsh into four productivity classes. In addition, Williams (1984) determined the total annual production of a freshwater marsh at Dean Hall Plantation to be on the order of 1,600 g/m^2 (plant material), with the seasonal fluctuations in the total live biomass ranging from a low of approximately 200 g/m^2 in April to a peak of approximately 1,000 g/m^2 in September. Standing dead material and litter also exhibited distinct seasonal trends which were consistent with growth patterns of the dominant vegetation (Williams 1984).

The effects of rediversion on marsh vegetation in the estuary are still unknown. A redistribution of plant species may occur along the estuarine gradient, and some plant communities in the upper Cooper River may be influenced by changes in the water level due to low flow conditions. The best data on changes in the Cooper River may come from a detailed survey conducted by the USFWS (unpublished data) from 1981 to 1983. This study utilized low altitude infrared imagery combined with ground-

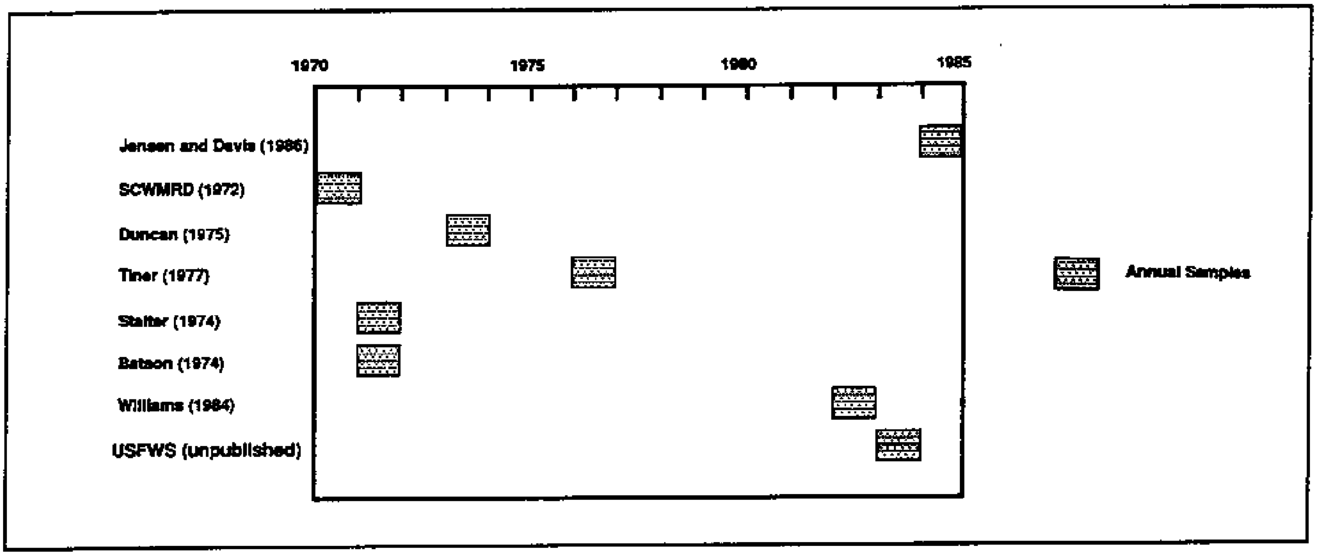


Fig. II-17. Studies which collected vegetation data from Charleston Harbor Estuary during 1970-1985.

truthing transects at several sites in the river to determine species composition. Equivalent surveys planned for the future should define distributional shifts in the assemblages observed in that study. Another study in the upper Cooper River conducted by Kelly et al. (1990) includes a quantitative comparison of vegetated plots in several remnant impoundments and a qualitative survey of one open marsh area on the upper Cooper River. These areas have also been sampled prior to and following rediversion by other studies. Additionally, the extensive aerial imagery available for the Charleston Harbor system should provide ample opportunities for researchers to compare pre- and post-rediversion distribution of vegetation throughout the entire estuary in the future.

Subtidal Vegetation

In contrast to many other estuarine systems along the Atlantic Coast, the Charleston Harbor Estuary is not known to support extensive subtidal seagrass beds or benthic macroalgae communities, except in the upper Cooper River where *Egeria densa* beds are common. This may be due to high turbidity levels in this estuary combined with a lack of suitable shallow water substrate in the subtidal zone. Only a few algal species have been collected in trawl or dredge samples taken within the harbor (Sandifer et al. 1980), although beds of *Porphyra* sp. and *Ulva* sp. have been observed in the shallow subtidal and intertidal areas of the lower harbor basin. A complete list of benthic macroalgae species reported from the estuary is present in Appendix II-C.

Periphyton

A number of studies have collected information on the periphyton communities in the estuary, but the data are generally limited and qualitative (Figs. II-19 and II-20). Batson and Blackwelder (1974) examined the vertical distribution of epiphytic algae on *S. alterniflora* from transects on the Cooper and Wando rivers and reported 15 species consisting of nine cyanophytes, three chlorophytes and three rhodophytes. The dominant species were *Chaetomorpha minima* and *Entophysalis conferta*. Diatoms and other small forms were not examined. The authors reported that many samples contained no algae at all, and noted that these results were quite different from those obtained in other South Carolina estuaries where species diversity was high.

Williams (1984) also conducted a seasonal study of periphyton within the Cooper River and identified 117 taxa of algae dominated by chlorophytes, dia-

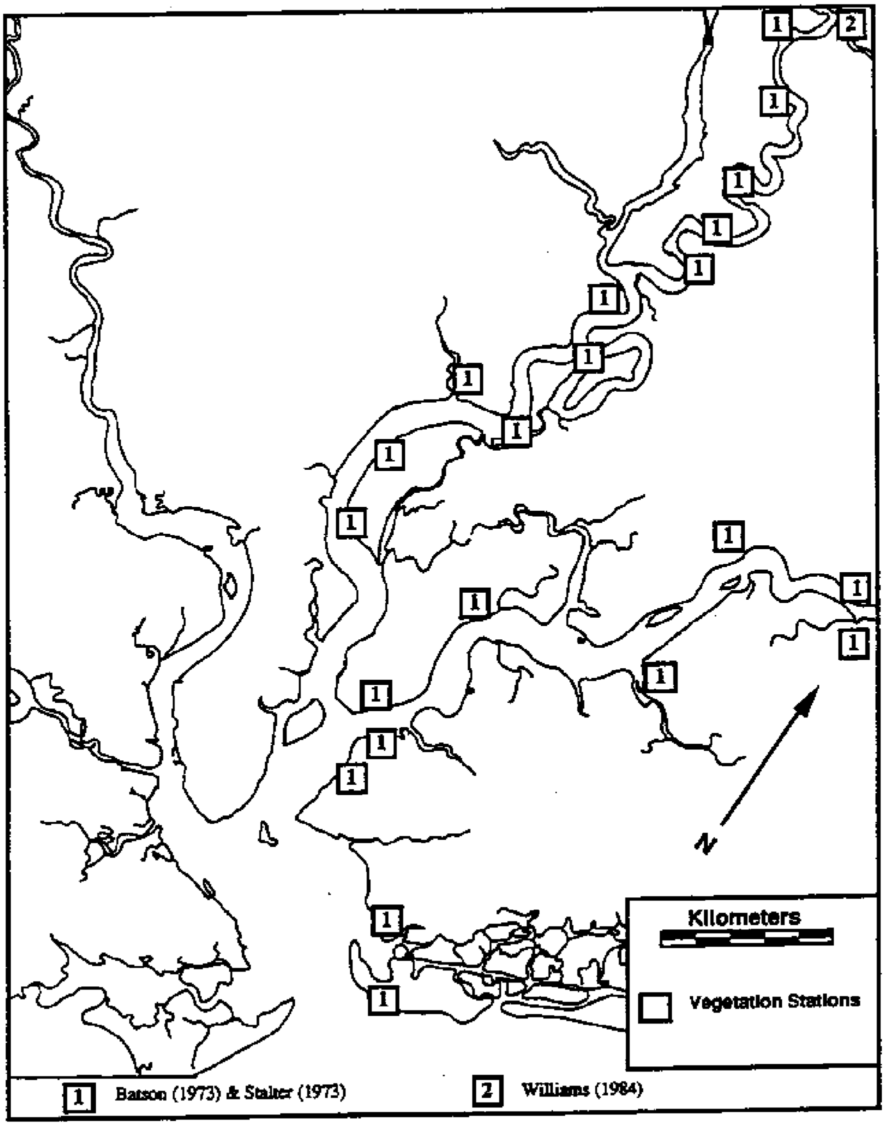


Fig. II-18. Location of ground survey stations for vegetation studies in Charleston Harbor Estuary during 1970-1985.

should be greatest in the Cooper River relative to the other river systems; however, we are not aware of any studies evaluating the changes in these communities.

Plankton

Relatively few studies have been published which examined the phytoplankton and zooplankton communities in Charleston Harbor during the review period (Bears Bluff 1964; FWPCA 1966; Enwright Laboratories, Inc. 1977). The location and sampling periods of those studies, as well as some unpublished studies that have sampled planktonic assemblages are shown in Figures II-19 and II-20. These studies have identified over 450 species of phytoplankton and more than 130 zooplankton taxa (appendices D and E).

The more recent unpublished studies provide the most comprehensive information on the planktonic assemblages in the harbor. Davis (SCWMRD) collected 472 phytoplankton samples from throughout the estuary (Fig. II-19) between December 1983 and December 1984. These samples contained 451 different species of phytoplankton, including 170 diatoms, 152 chlorophytes, 48 dinoflagellates, 36 cyanophytes, 29 euglenophytes, 10 chrysophytes, and 6 cryptomonads. The data indicated distinct trends in both community structure and abundance with salinity. Species composition ranged from oceanic species collected in the lower harbor; to brackish species collected in the upper harbor, lower Cooper River, and throughout

toms, and cyanophytes. His results demonstrated that the dominant taxa were quite similar at all stations, and the author concluded that the abundant populations observed during all seasons indicated eutrophic water quality. No trends in chlorophyll values were observed with salinity gradient, although the cell concentrations enumerated were among the highest reported for freshwater habitats.

Increased saltwater intrusion resulting from rediversion will presumably affect the periphyton community structure by allowing saline-dependant species to grow further up the estuary. These changes

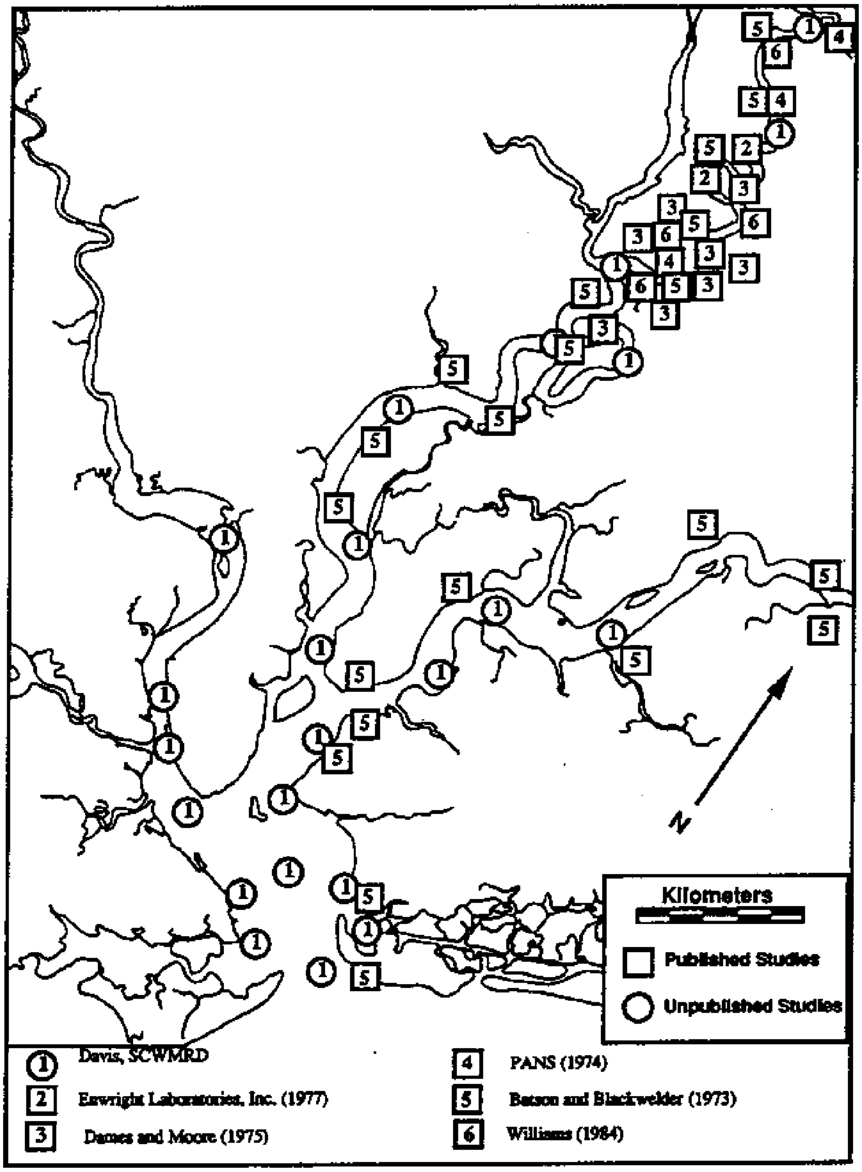


Fig. II-19. Station locations for studies which collected periphyton, phytoplankton, and/or zooplankton data from Charleston Harbor Estuary during 1970-1985.

the Wando and Ashley rivers; to freshwater species collected in the upper Cooper River. The phytoplankton samples were dominated by *Skeletonema costatum* and three other diatoms, one cyanophyte, and one chlorophyte (Table II-9).

Higher abundances of all phytoplankton occurred at higher salinities, and distributions with salinity in all areas of the harbor were identical, with the exception of larger numbers of cyanophytes being found in the upper Ashley River. Davis also observed seasonal trends in species composition, with diatoms dominating the spring and early fall periods, and cyanophytes and small flagellates dominating the summer and winter periods. Seasonal trends observed in abundance for the entire estuary are summarized in Figure II-21.

Only one report (Enwright Laboratories, Inc. 1977) described zooplankton communities in the Charleston Harbor Estuary during the review period. That study involved a short-term assessment of zooplankton populations in a portion of the Cooper River during 1976 (Fig. II-19). Many of the species reported are typically characterized as benthic organisms. Among the 88 taxa noted amphipods were the most abundant organisms with *Gammarus* sp.

Table II-9. Mean number of cells per ml and percent occurrence of dominant phytoplankton in Charleston Harbor Estuary (Davis, SCWMRD, unpublished data).

Species	Mean # cells/ml	% Occurrence
Skeletonema costatum	1641.7	85.8
Asterionella glacialis	390.0	76.5
Asterionella japonica	340.9	81.8
Thalassiosira nordenskioldii	111.3	53.0
Spirulina subsalsa	110.8	59.5

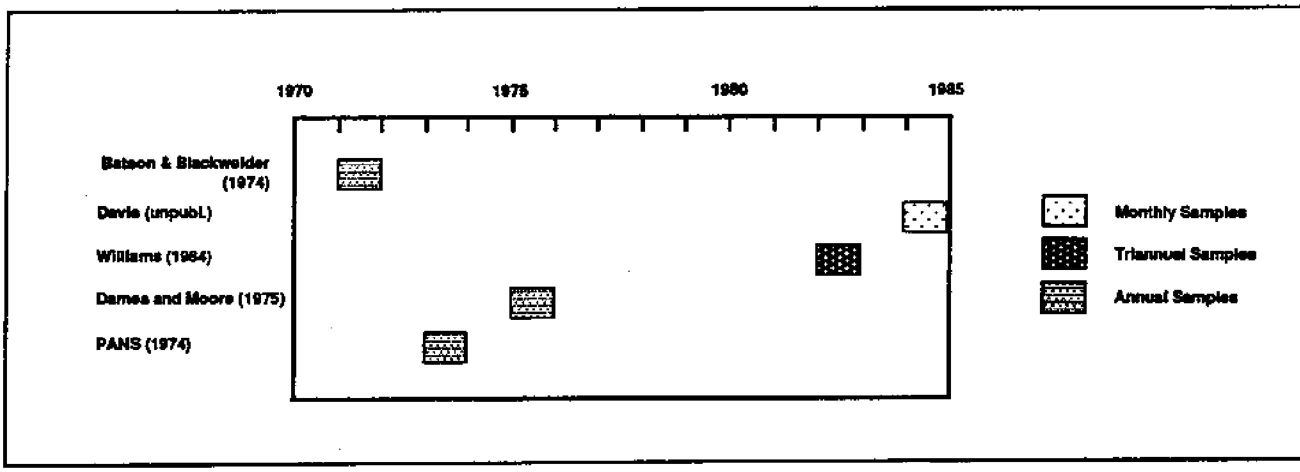


Fig. II-20. Studies which collected periphyton and/or phytoplankton data for the Charleston Harbor Estuary during 1970-1985.

and *Hyalella azteca* being the dominant species. Isopods (primarily *Cyathura polita, Cassidinidea lunifrons*, and *Chiridotes* sp.) were the second most abundant organisms, and pelecypods were the third most abundant organisms. The remaining organisms were a mixture of flatworms, other aquatic worms, insects, snails, water mites, crabs and shrimps. Postlarvae and megalopae of *Callinectes sapidus* were collected during four months of the study, while postlarvae of *Penaeus setiferus* were collected only in September. The only seasonal trend observed by Enwright Laboratories, Inc. (1977) was an increase in amphipod densities during August and September.

Prior to the review period, Bears Bluff Inc. (1964) studied the zooplankton in the Cooper River over a one-year period and concluded that the overall abundance of zooplankton was lowest among the rivers studied in South Carolina. The abundance of zooplankton fluctuated seasonally, with peak abundances noted in June and July and lowest abundance observed in December. Larvae and postlarvae of commercial fish and shellfish species were present in the Cooper River at various times of the year, but were also collected in low numbers compared to the other river systems, except for penaeid shrimp. Coelenterate hydromedusae and copepods were the two most abundant taxa. Fish larvae and postlarvae (primarily *Micropogonias undulatus, Leiostomus xanthurus, Brevoortia tyrannus,* and *Anchoa mitchilli*) were noted to be less abundant in the Cooper River than in either the Ashley or Wando rivers.

Since 1985, several additional unpublished studies have examined the ingress and distribution of postlarval organisms in the estuary. These include

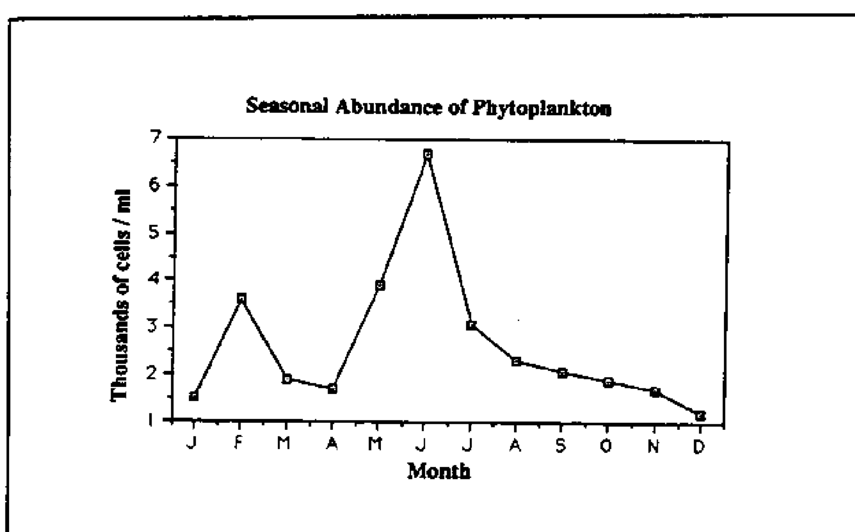


Fig. II-21. Seasonal abundance of phytoplankton in the lower Charleston Harbor basin during 1984-1985, all species combined.

Table II-10. Mean number of dominant macroinvertebrates per square meter in the mid Cooper River (Enwright Laboratories, Inc. 1977).

Species	Jul.	Aug.	Nov.	Mean
Peloscolex multisetosus	310	800	180	430
Hyalella azteca	90	390	140	270
Corbicula manilensis	220	170	10	133
Cura foremanii	300	0	40	113
Limnodrilus hoffmeisteri	40	140	50	77
Cyathura polita	190	0	10	67
Asellus communis	180	0	0	60
Sphaerium sp.	20	160	0	60
Hydrolimax grisea	110	0	10	40

studies of the penaeid shrimp postlarvae and blue crab megalopae (Wenner SCWMRD), and studies of finfish species (Hoffman SCWMRD).

Macroinvertebrates

Charleston Harbor supports a diverse assemblage of benthic invertebrate species, but detailed ecological studies of the macroinfaunal communities were limited prior to 1984 (Calder and Boothe 1977a; Jones, Edmunds and Assoc. 1983; Enwright Laboratories, Inc. 1984; Williams 1984). To our knowledge, no studies have been conducted on the meiofauna in the estuary. The location and dates of published and unpublished studies on the macrofauna are shown in Figures II-22 and II-23 and a list of the macroinvertebrates reported from the estuary is provided in Appendix F.

Among the studies reviewed, data collected by Calder and Boothe (1977a,b) suggest that polychaete worms were the most abundant organisms at high salinity stations, while lower salinity stations supported larger populations of amphipods, isopods, and bivalves. Their sampling, however, encompassed only eight sites in the estuary which were sampled once or twice during a two-year period.

Enwright Laboratories, Inc. (1977) sampled the benthic community in the middle and upper reaches of the Cooper River in 1976 and reported that oligochaetes and amphipods were the most abundant organisms, comprising 49% of the total abundance. Gastropods and pelecypods were the third and fourth most abundant organisms collected, representing 23% and 10% of the total respectively. Dominant species from each group are listed in Table II-10. With the exception of the dominance of oligochaetes, similar species composition and abundances were observed by Williams

Table II-11. Quarterly mean number of dominant macroinvertebrates per square meter in the Wando River between 1981 and 1984 (Enwright Laboratories, Inc. 1984).

Species	Feb.	May.	Aug.	Nov.	Mean
Streblospio benedicti	748	433	292	784	564
Balanus sp.	1134	43	239	0	354
Mulinia lateralis	138	359	29	14	135
Paraprionospio pinnata	176	96	2	132	102
Nereis succinea	103	67	85	58	78
Heteromastus filiformis	62	127	36	5	58
Membranipora sp.	7	78	121	0	52
Tellina sp.	0	0	54	147	50

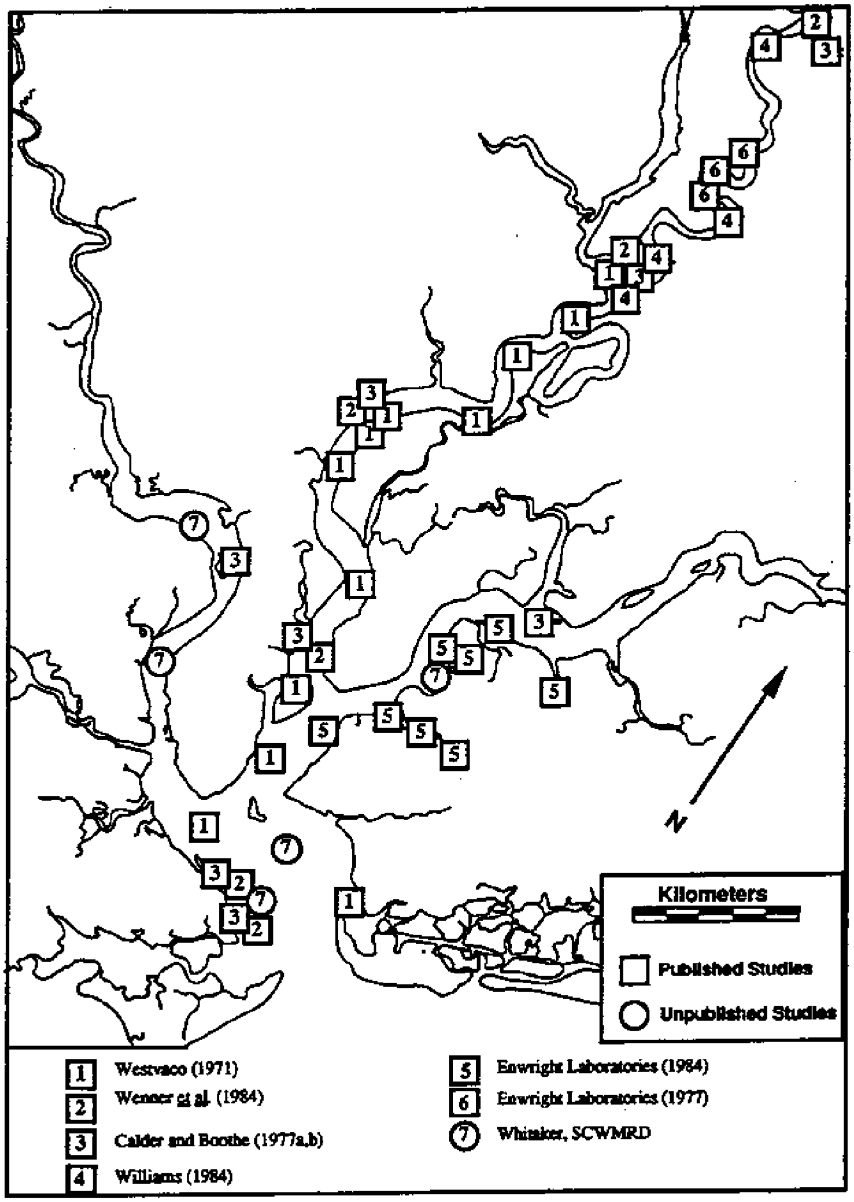


Fig. II-22. Station locations for studies which collected benthic macroinvertebrate data for Charleston Harbor Estuary during 1970-1985.

(1984) and the PANS (1975) using artificial substrate samplers in the upper Cooper River.

The only other published surveys of the macrobenthos in Charleston Harbor which were completed during the review period includes quarterly assessments of the infauna at several sites in the lower Wando River from 1981 to 1984 [see Enwright Laboratories (1984) for review]. Dominant species observed in those surveys are listed in Table II-11.

In 1984, the SCWMRD began a study of the macrobenthos in the harbor basin and all three river systems as part of a larger study designed to characterize the hydrographic and biological conditions in the estuary following rediversion. This study involved quarterly sampling at several index sites over a four-year period and a one-time assessment of sediments and benthic assemblages at 178 sites in the harbor basin and lower reaches of the three rivers. A list of species observed at the index sites sampled in 1984 is included in the species list of macroinvertebrates reported from the estuary in Appendix F. The composition of benthic communities within the estuary following rediversion is described by Wendt and Van Dolah (1990).

The larger epifaunal invertebrate species have been sampled more extensively in the harbor system than the benthic assemblages, largely owing to the existence of a number of recreationally and commercially important species. The Wando, Ashley, and Cooper rivers support large populations of penaeid shrimps (primarily *Penaeus setiferus* and *P. aztecus*) and blue crab (*Callinectes sapidus*), and also serve as nursery grounds for their juveniles (Bears Bluff, Inc. 1966; FWPCA 1966; Westvaco 1972; Arthur D. Little, Inc. 1974; Turner and Johnson 1974; Enwright Associates, Inc. 1977; Shealy and Bishop 1977; Wenner et al. 1984; Williams 1984; Archambault et al. in press). Other crustacean species are also abundant throughout the estuary. For example, Wenner et al. (1984)

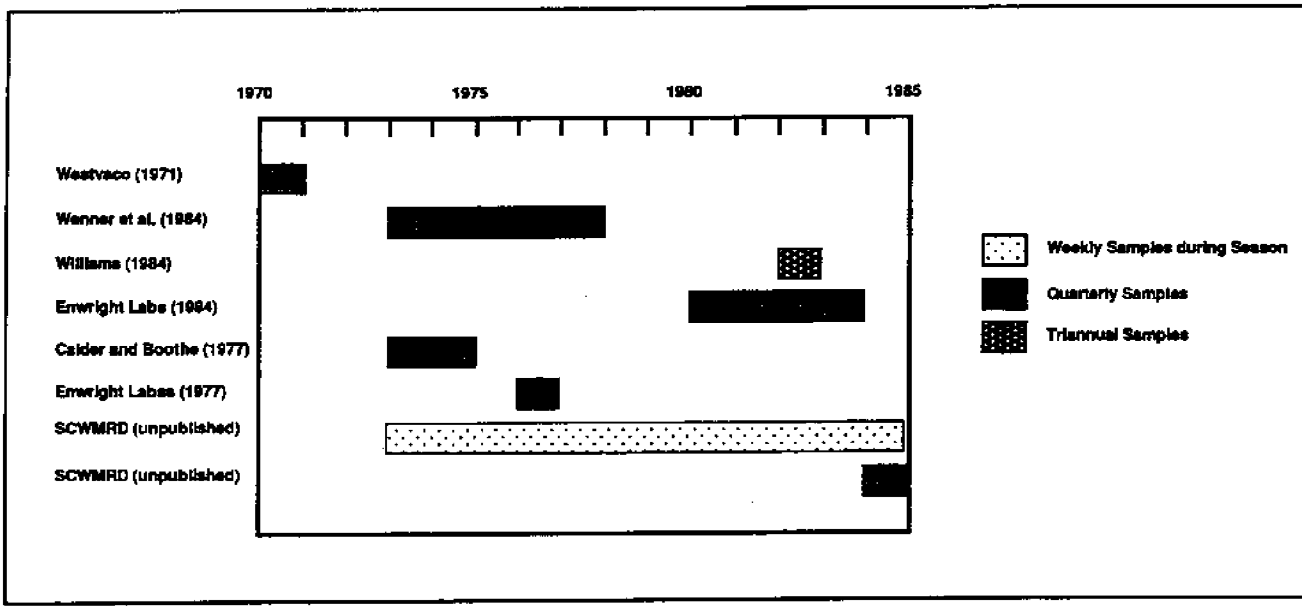


Fig. II-23. Studies which collected data for benthic macroinvertebrates in the Charleston Harbor Estuary during 1970-1985.

reported a total of 44 species of decapod crustaceans from trawl samples taken in the estuary between 1973 and 1977. Five of these species accounted for more than 97% of the total number and 98% of the total biomass of decapod crustaceans (Table II-12). The average density for decapod crustaceans reported in this study was 678 individuals/ha and an average biomass of 4.98 kg/ha was noted for the entire estuary. The mean numbers of decapod crustaceans were highest at the high salinity stations, and species richness decreased in the upstream direction.

Both *P. setiferus* and *P. aztecus* utilize the tidal creeks of the three river systems within the estuary on a seasonal basis (Bears Bluff, Inc. 1965; FWPCA 1966; Westvaco 1972; Arthur D. Little, Inc. 1974; Turner and Johnson 1974; Bishop and Shealy 1977; Enwright Associates, Inc. 1977; Wenner et al. 1984; Williams 1984). *Penaeus setiferus* are usually first collected from the estuary in July, reach peak abundance in September and October, and decrease in abundance throughout the rest of the year (Bears Bluff, Inc. 1966; Bishop and Shealy 1977; Wenner et al. 1984; SCWMRD unpublished data).

Penaeus aztecus utilize the estuary in smaller numbers and for shorter periods of time; they are present between May and September and most abundant in June and July. This species appears to be more abundant in higher salinity areas than *P. setiferus*, and they are generally found only in the lower areas of the estuary (Bishop and Shealy 1977; Wenner at al. 1984).

Table II-12. Percent total number and total biomass of dominant decapod crustaceans from the Charleston Harbor Estuary (Wenner et al. 1984).

Species	% Total Number	% Total Biomass
Penaeus setiferus	82.62	69.20
Penaeus aztecus	8.30	7.97
Xiphopenaeus kroyeri	2.74	0.69
Callinectes sapidus	1.97	19.36
Callinectes similis	1.48	1.55

Callinectes sapidus are present throughout the estuary, although they were generally least abundant upstream (Wenner et al.1984; Archambault et al. 1990). The distribution of this species varies with size and sex. Small *C. sapidus* of both sexes have been found in the harbor throughout the year, being abundant in October (Archambault et al. 1990). The small crabs prefer lower salinity areas, and migrate to higher salinity areas as they mature. According to Archambault et al. (1990), mature females exhibit a stronger preference for high salinities than mature males. While Archambault et al. (1990) reported finding many more female than male blue crabs, other authors reported that between 70% and 90% of all adult crabs collected were male (Bears Bluff, Inc. 1966; Arthur D. Little, Inc. 1974; Turner and Johnson 1974).

The distribution of other decapod species which are abundant but not commercially or recreationally important is described by Bears Bluff, Inc. (1966), Enwright Associates, Inc. (1977), Turner and Johnson (1974), and Wenner et al. (1984) for the review period. Descriptions of the distribution of these fauna after rediversion are provided by Stender and Martore (1990) and Wenner et al. (1990).

Shellfish populations are also abundant in the Charleston Harbor Estuary. Beds of intertidal *Crassostrea virginica* occur throughout much of the estuary (Fig. II-24), but most of the grounds have been closed to collecting for consumption due to poor water quality restriction (SCWRC 1973; SCDHEC 1976, 1985a). Total areas covered by oyster beds in 1982 were 7.5 ha 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 (SCWMRD unpublished Oyster Survey data). Large beds of *Mercenaria mercenaria* have also been found in the lower portion of the estuary (SCWMRD unpublished data).

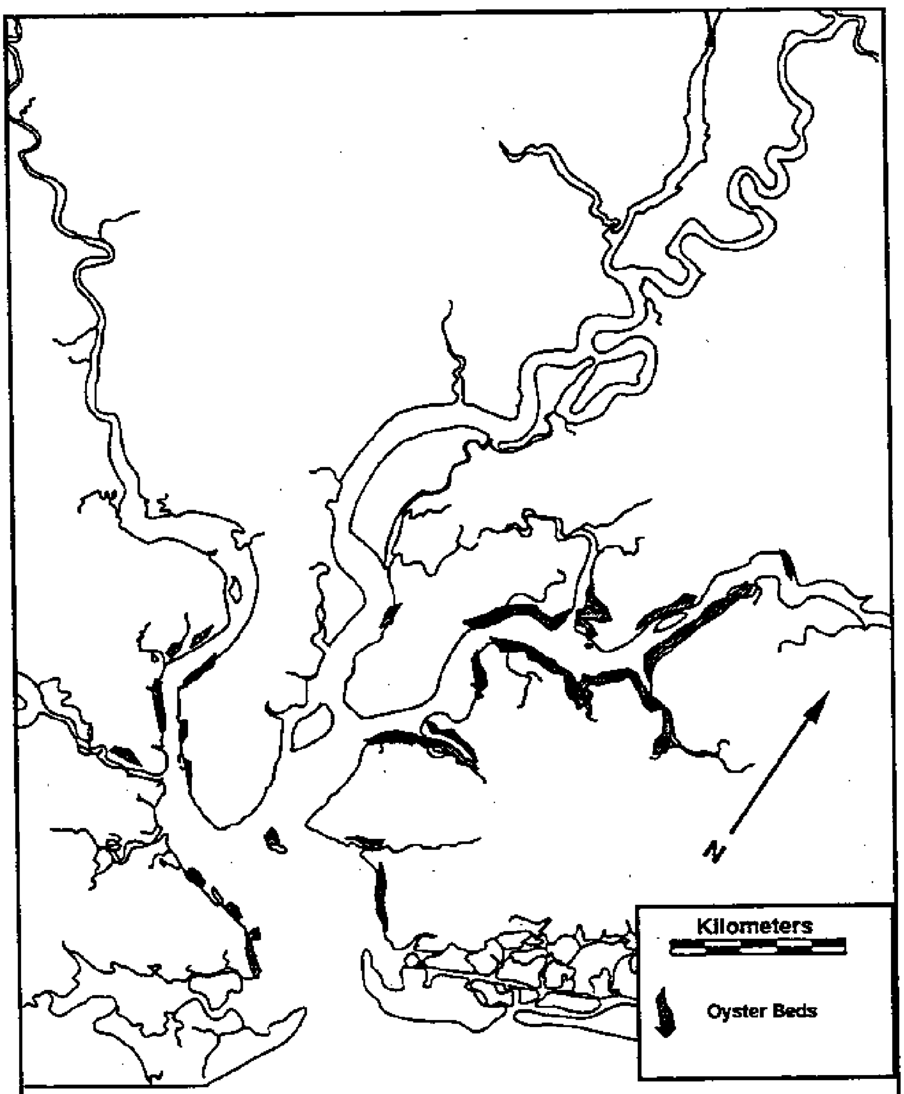


Fig. II-24. Areas of subtidal and intertidal oyster beds.

Finfish Communities

Finfish communities in the Charleston Harbor Estuary have been examined in numerous published studies (Figs. II-25 and II-26) (PANS 1974; Shealy et al. 1974; Turner and Johnson 1974;

Dames and Moore 1975; Curtis 1976; Enwright Laboratories, Inc. 1977, 1984; Jones, Edmunds and Associates 1984; Wenner et al. 1984; Williams 1984). These studies have documented that the estuary supports a diverse assemblage of finfish species, including large populations of many commercially and recreationally valuable species such as *Leiostomus xanthurus, Micropogonias undulatus, Cynoscion nebulosus, Sciaenops ocellatus, Paralichthys lethostigma, P. dentatus, Morone americana, Ictalurus catus, I. furcatus, I. punctatus*, and several other species which are less abundant.

The distribution of finfish throughout the estuary changes along the salinity gradient up the Cooper River, and in the different habitats provided by the tidal creeks. In general, abundance and biomass of fish decrease in the upstream direction toward fresher water (Bears Bluff, Inc. 1965; Shealy et al. 1974; Wenner et al. 1984; Williams 1984). Wenner et al. (1984) reported that finfish biomass and density were greatest during spring and winter, while other studies reported that greater numbers of fish were present in the summer than at other times of the year (Bears Bluff, Inc. 1966; Arthur D. Little, Inc. 1974; Shealy et al. 1974; Turner and Johnson 1974; Williams 1984). According to Shealy et al. (1974), the finfish communities of the Wando and Ashley rivers are similar to those on the Cooper River, but are usually less abundant.

Studies throughout the estuary have reported more than 125 species of finfish, dominated by *Stellifer lanceolatus, Anchoa mitchilli, Micropogonias undulatus, Brevoortia tyrannus*, and *Leiostomus xanthurus* (Bears Bluff, Inc. 1965; Shealy et al. 1974; Turner and Johnson 1974; Dames and Moore 1975; Enwright Laboratories, Inc. 1977, 1984; Williams 1984). Four species of anadromous fish (*Alosa aestivalis, A. mediocris, A. sapidissima*, and *Morone saxatilis*) and one species of catadromous fish (*Anguilla rostrata*) are found throughout the estuary during different times of the year. The seasonal and temporal distributions of the

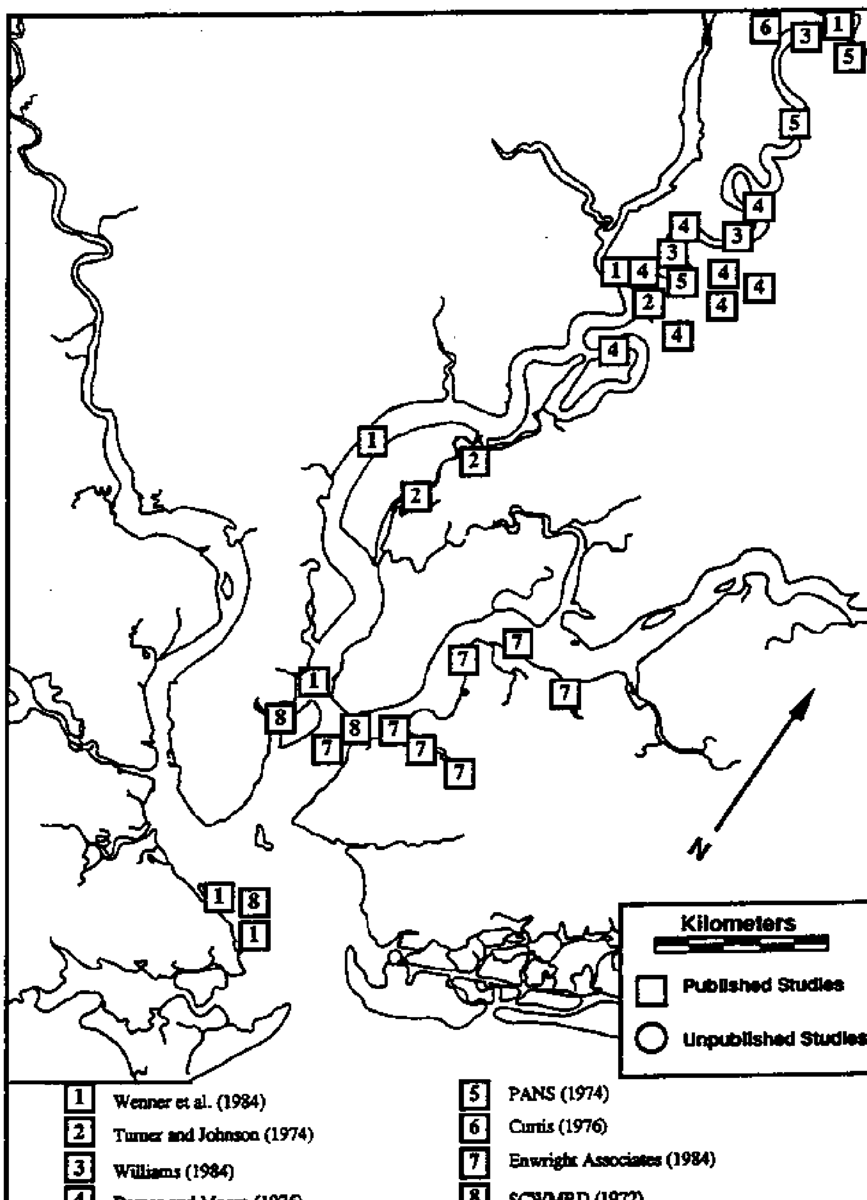


Fig. II-25. Station locations for studies which collected finfish data in the Charleston Harbor Estuary during 1970-1985.

Table II-13. Dominant species of finfish by season and location (from Wenner et al. 1984).

	Winter	Spring	Summer	Fall
Upper Cooper:				
(C001)	*I. nebulosus*	*I. catus*	*A. aestivalis*	*A. aestivalis*
	I. punctatus	*A. rostrata*	*D. petenense*	*O. oglinum*
	A. rostrata	*M. undulatus*	*T. maculatus*	
	T. maculatus	*I. punctatus*	*I. nebulosus*	
Mid Cooper:				
(C002)	*I. catus*	*A. mitchilli*	*B. chrysura*	*I. catus*
	D. petenense	*M. undulatus*	*D. petenense*	*A. mitchilli*
	T. maculatus	*I. catus*	*A. mitchilli*	*T. maculatus*
	A. mitchilli	*B. tyrannus*	*L. xanthurus*	*B. chrysura*
Lower Cooper:				
(C003)	*B. tyrannus*	*A. mitchilli*	*L. xanthurus*	*A. mitchilli*
	A. mitchilli	*M. undulatus*	*A. mitchilli*	*C. regalis*
	T. maculatus	*I. catus*	*C. regalis*	*B. chrysura*
	A. aestivalis	*B. tyrannus*	*M. undulatus*	*S. plagiusa*
Lower Cooper:				
(C004)	*B. chrysura*	*S. lanceolatus*	*S. lanceolatus*	*S. lanceolatus*
	B. tyrannus	*M. undulatus*	*A. mitchilli*	*A. mitchilli*
	S. lanceolatus	*A. mitchilli*	*C. regalis*	*S. plagiusa*
	M. undulatus	*U. regius*	*M. undulatus*	*M. undulatus*
Upper Harbor:				
(J001)	*S. lanceolatus*	*M. undulatus*	*S. lanceolatus*	*S. lanceolatus*
	B. tyrannus	*S. lanceolatus*	*S. plagiusa*	*S. plagiusa*
	A. mitchilli	*L. xanthurus*	*L. xanthurus*	*B. chrysura*
	S. plagiusa	*A. mitchilli*	*M. undulatus*	*A. mitchilli*
Lower Harbor:				
(J003)	*S. lanceolatus*	*U. regius*	*M. undulatus*	*S. lanceolatus*
	B. tyrannus	*A. mitchilli*	*C. regalis*	*A. mitchilli*
	S. plagiusa	*S. plagiusa*	*L. xanthurus*	*S. plagiusa*
	A. mitchilli	*M. undulatus*	*A. mitchilli*	*M. americana*

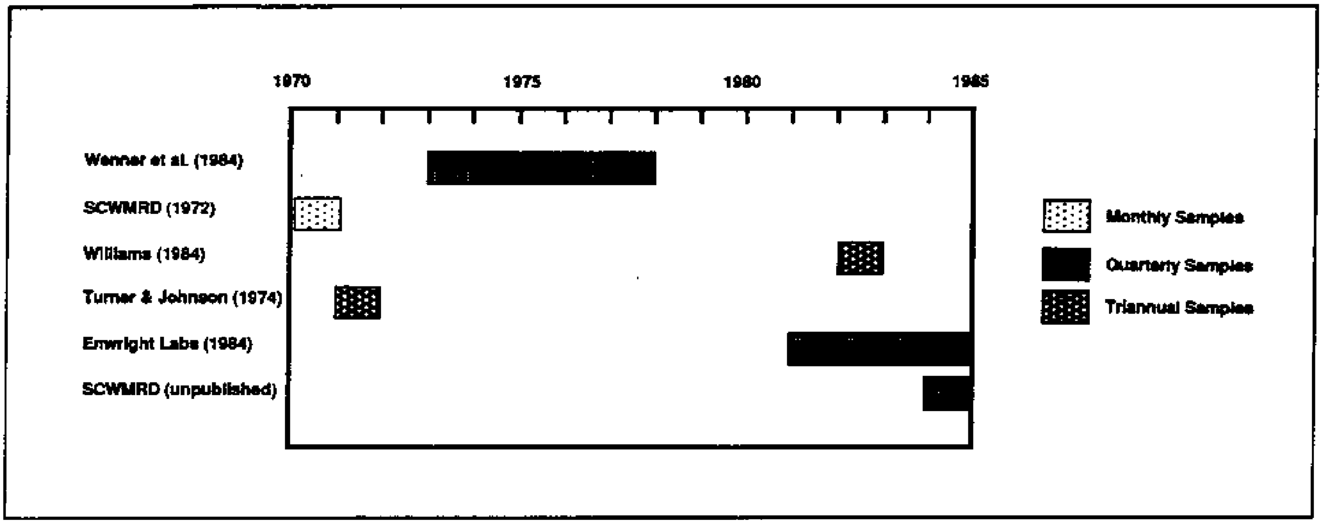


Fig. II-26. Studies which collected finfish data for the Charleston Harbor Estuary during 1970-1985.

most abundant species of finfish collected in the estuary during 1973-1978 are summarized in Table II-13 and described more completely in the above references. A complete list of all species reported from the estuary is presented in Appendix G. Additional descriptions of finfish composition and distribution after rediversion are provided by Van Dolah et al. (1989) and Stender and Martore (1990).

LONG-TERM TRENDS

RESOURCE TRENDS

Relatively few of the physical, chemical, and biological studies described in the preceding sections involved collecting data over a sufficient period of time to be useful for trends analyses. Additionally, the studies which do provide data from multiple years often did not involve consistent sampling or analytical methodologies required for rigorous statistical analyses. These problems also limited comparisons among studies during the 15-year review period. Despite these limitations, some basic trends are evident in the data available for land and water use, fisheries resources, basic water quality parameters, and pollutant concentrations in sediments.

Land and Water Use

Changes in land and water use within the Charleston Harbor watershed are not well documented, but general trends can be inferred from (1) population and housing data for the Berkeley-Charleston-Dorchester County region, (2) the number and volume of discharges into the watershed, and (3) recreational boating figures for the tricounty area. The estuary lies within Berkeley, Charleston, and Dorchester counties, with very little of the area forming these counties excluded from the watershed. A general land-use pattern map for much of the Charleston Harbor watershed was presented by Davis et al. (1980), although no summary statistics for the region were included. A statewide map of land use patterns is being prepared by the South Carolina Land Resources Commission. This map will provide data by county.

Population in the tricounty region increased steadily during the 1970-1985 survey period (Fig. II-

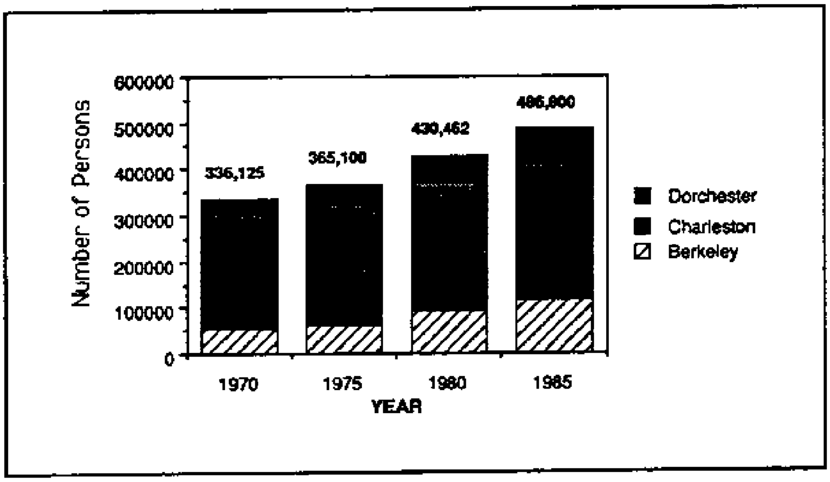


Fig. II-27. Population of the tricounty region of the Charleston Harbor Estuary between 1970 and 1985. Data for 1975 and 1985 are estimated.

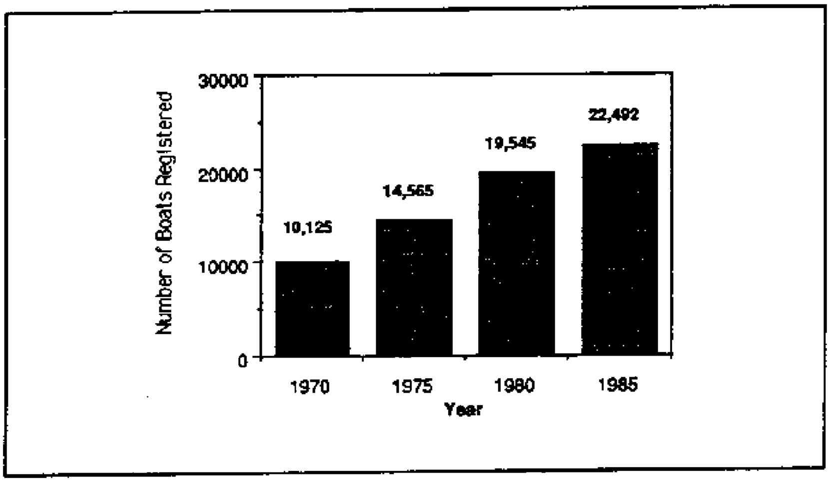


Fig. II-28. Number of boats registered with the South Carolina Wildlife and Marine Resources Department, Division of Boating. The 1970 figure is estimated.

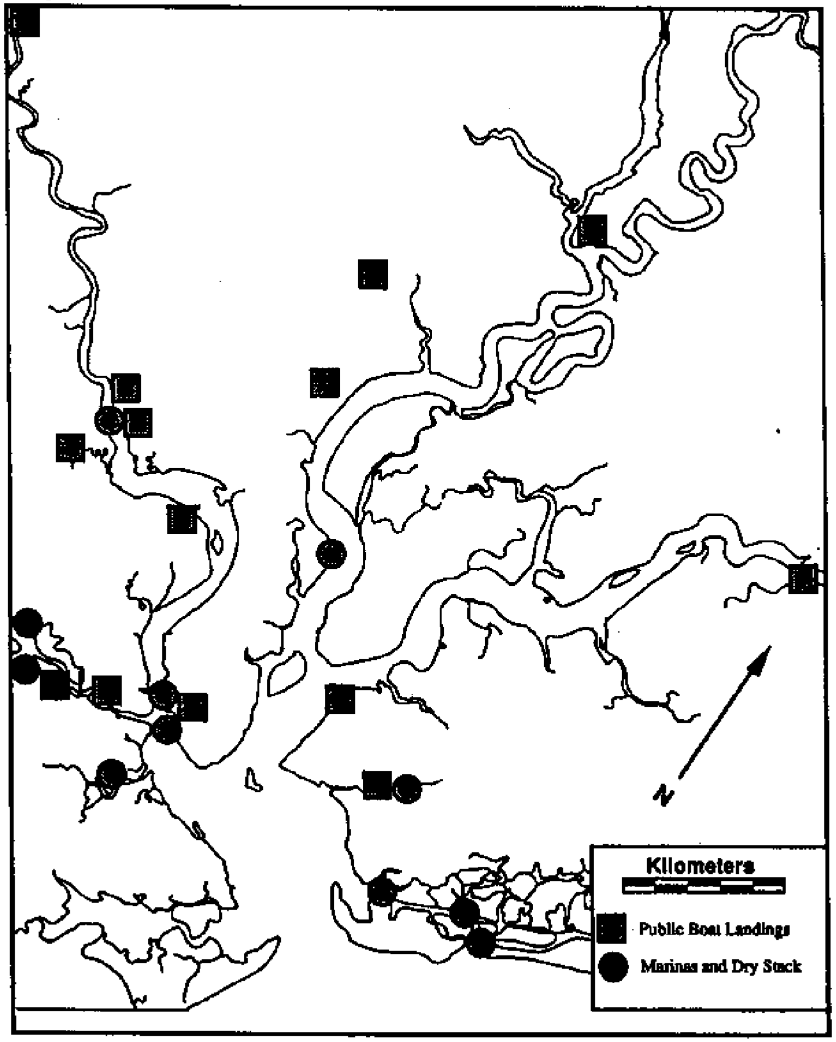


Fig. II-29. Locations of public boat landings, marinas, and dry storage facilities in the Charleston Harbor Estuary as of 1986.

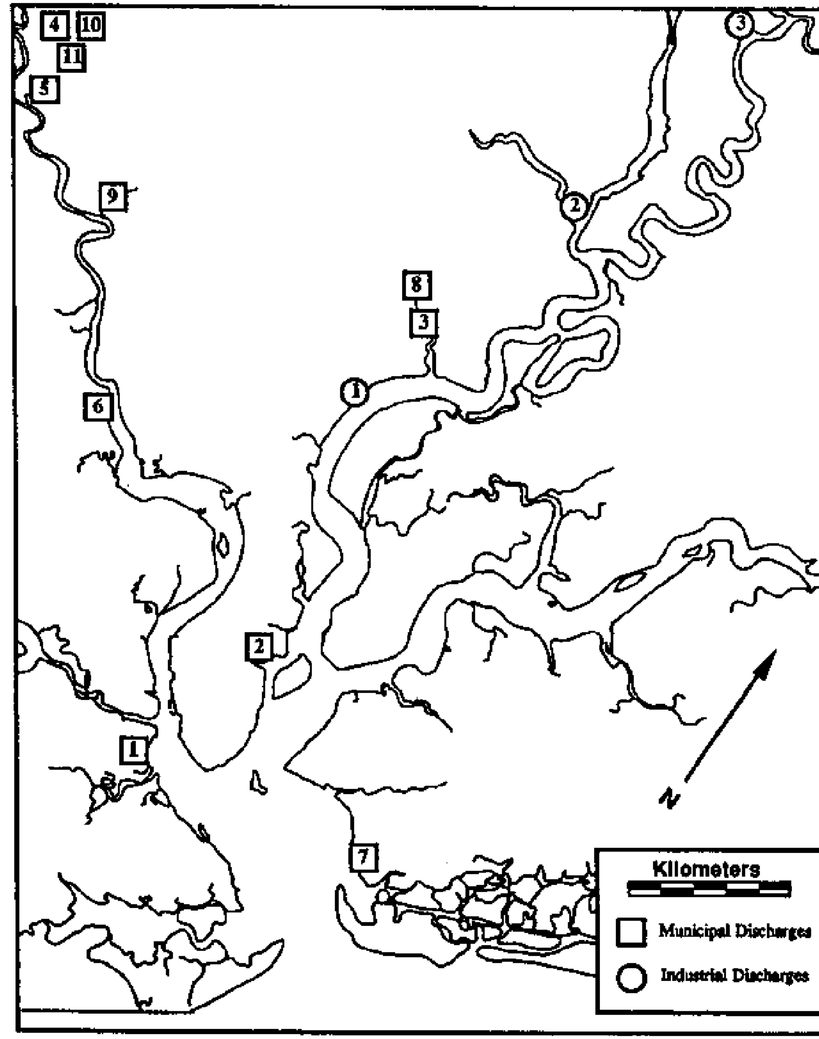


Fig. II-30. Approximate locations of major municipal and industrial dischargers in the Charleston Harbor Estuary as of 1987. Locations are listed in Table II-15.

Table II-14. Total number of discharges and millions of gallons per day (MGD) effluent in the Charleston Harbor Estuary in 1969 and 1986 by category.

	1969		1986	
	Number	MGD	Number	MGD
Ashley Basin	51	149.9	28	32.9
Cooper Basin	51	61.5	42	59.4
Wando Basin	1	0.1	3	0.05
Harbor Basin	12	0.9	5	0.5
Municipal	91	32.4	48	62.2
Industrial	24	180.0	30	30.7
Total	115	212.4	78	92.9

Table II-15. Identification and volume of discharge for major municipal and industrial dischargers located in Fig. II-30.

Dischargers	Discharge (MGD)
Municipal:	
1. Charleston CPW	18.0
2. North Charleston Sewer	18.0
3. Berkeley County WSA I	10.0
4. Town of Summerville	6.0
5. Dorchester Public Works	2.0
6. St. Andrews PSD	1.5
7. Town of Mount Pleasant	1.4
8. Town of Hanahan	1.25
9. Pepperhill SD	1.2
10. Summerville Water Plant	1.1
11. Berkeley County WSA II	1.0
Industrial:	
1. Westvaco	20.0
2. Mobay Chemical	6.5
3. DuPont Chemical	1.2

27) as have the number of jobs, dwelling units, and total residential acreage (BCDCOG 1987). The primary areas of growth have been in Berkeley and Dorchester counties. This has in turn increased the population density in the Charleston metropolitan area and resulted in the conversion of fringing rural areas to urban areas (BCDCOG 1988).

The influx of people to the tricounty area has resulted in a substantial increase in the recreational use of the harbor. From 1970 to 1985 the number of boat registrations for the three counties increased by approximately 45% (Fig. II-28). Additionally, 10 of the 11 marinas and 13 of the 14 public boat landings currently sited in the estuary (Fig. II-29) have been constructed since 1970.

Commercial use of the harbor also grew considerably between 1970 and 1985. In 1970, the Port of Charleston received more than 1,400 ships and barges, and handled approximately 168,000 tons of container cargo. By 1985, vessel traffic had increased to more than 1,800 vessels and the container cargo handled during that year exceeded 2.8 million tons (South Carolina State Ports Authority personal communication). All of the port facilities within the estuary were expanded during the review period, including the major addition of the Wando River Terminal. In 1991, the Port of Charleston was the second largest port on the eastern seaboard in terms of container tonnage handled.

The United States Navy has also expanded its port facilities since 1970. Currently, the Navy maintains numerous docking facilities that serve as home port for more than 70 surface vessels and submarines, a shipyard, and a weapons station. All of these facilities are located in the Cooper River. Due to the expansion of naval facilities, dredging operations were conducted during the review period in the Cooper River to accommodate larger ships and maintain existing channels.

The number of municipal and industrial discharges within the estuary actually decreased during the review period from a total of 115 in 1969 to a total of 78 in 1986 (SCDHEC 1970; BCDCOG 1987a) (Table II-14). In addition, the total volume of discharges dropped from 212.4 to 92.9 million gallons per day (MGD) (Table II-14). In 1969, 149.9 MGD were being introduced into the Ashley River basin by 51 dischargers, as compared with 32.9 MGD introduced by 28 dischargers in 1986. Decreased discharges into the Cooper River basin were not as great, with 61.5 MGD released by 51 dischargers in 1969, compared with 59.4 MGD by 42 dischargers in 1986. The lower harbor basin received 0.9 MGD of effluent from 12 dischargers in 1969, and 0.5 MGD from five dischargers in 1986. The Wando River basin has always received the lowest amount of effluent when compared with the other systems, with 0.1 MGD being discharged by one discharger in 1969, and 0.05 MGD by three dischargers in 1986. The major (> 1 MGD) dischargers in the estuary as of 1986 are plotted on Figure II-30 and summary statistics for these discharges are presented in Table II-15.

Two long-term data sets exist which contain physical and chemical data for the entire survey period of 1970-1985. The first data set was collected by National Oceanic and Atmospheric Administration (NOAA) at the Charleston Custom's House and was analyzed by Kjerfve and Magill (1990). This data set contains daily measurements of surface salinity and temperature which are not standardized by time or tidal stage. Kjerfve and Magill (1990) compared these measurements against flow data for water entering the Cooper River through the Pinopolis Dam and concluded that salinity in Charleston Harbor, prior to rediversion, exhibited distinct seasonal trends which were primarily controlled by the freshwater flow (Fig. II-8). On average, salinities were highest during the summer months when freshwater flow was lowest. Long-term trends were not detected in the Custom's House data set by Kjerfve and Magill (1990), most likely due to the control of harbor salinity by freshwater flow.

The second long-term data set was collected by the South Carolina Department of Health and Environmental Control (SCDHEC), and is available through the US Environmental Protection Agency's STORET database (SCDHEC 1985c; Chestnut 1989; USEPA, Research Triangle Park, NC). This database includes measurements of numerous physical and chemical parameters collected at many sites throughout much of the estuary, and is summarized by Chestnut (1989). Data were collected throughout the survey period as part of SCDHEC's water quality monitoring program. However, sampling of water quality parameters at these stations was not standardized by tidal stage, and the tidal stage was not always recorded in the data files.

A study conducted from 1973 to 1978 by the SCWMRD (Estuarine Survey Program unpublished data; Mathews and Shealy 1978, 1982) documented large changes in several water quality parameters during different stages of a tidal cycle in the harbor basin. For example, surface and bottom salinities measured at the same station during 25-hour sampling periods varied as little as 4‰ and as much as 21‰ over a single tidal cycle. The variability in these measurements was dependant, in part, on the tidal amplitude and the position of the station within the estuary. Therefore, a lack of standardized sampling procedures, along with numerous gaps in the STORET data available for most stations, precludes detailed time series analyses for many parameters using normal procedures.

The SCDHEC STORET database contains some monthly measurements for a number of basic water quality parameters from 49 stations throughout the Charleston Harbor Estuary. Twenty-five of these stations were sampled for at least a 3-year period during the 15-year survey period (Fig. II-10). Four of these stations, however, were not sampled continuously for 3 years, so data from the remaining 21 stations were analyzed for geographic and temporal trends in basic water quality parameters.

To determine if geographic trends in water quality existed during the survey period, all values for nine water quality parameters at the 21 SCDHEC stations were averaged and are presented below. The raw data were then tested for normality and homogeneity of variance (Kolmogrov-Smirnov and Bartlett's tests). Where appropriate (i.e., high variance, outliers, non-normality), the data was common-log transformed and again tested for normality and homogeneity of variance. If proper assumptions were met (Sokal and Rolf 1981), the next step would have been to test for significant differences among stations with ANOVA and post-hoc tests. However, transformations did not yield either normality or homogeneity of variance, even when smaller (3-5 year) data sets with contiguous samples were extracted from the raw data for analysis. Further analyses may yield valid statistical conclusions about the observed differences in means, but these analyses are beyond the scope of this review. The reader is warned that the observed differences in the plots of mean values by stations are not meant to imply statistically significant differences.

Basic water quality parameters at the 21 SCDHEC stations were also analyzed for temporal trends over the 15-year survey period. Two goals of this analysis were to determine if seasonal trends existed in these parameters, and if non-seasonal long-term trends occurred. These analyses were initiated by first plotting raw data for appropriate surface or bottom parameters over time. The stations with the largest amount of data from the six areas of the estuary for bottom dissolved oxygen and surface fecal coliform, total nitrite-nitrate, total ammonia, and ortho-phosphate are plotted over time in the figures that follow. These time series plots demonstrate the high variability within the data set, as well as the high frequency of occurrence of missing values. Data for other parameters and other stations were collected, but the series have even larger gaps and are not presented here.

Data were analyzed for long-term trends using modifications of the methods of Box and Jenkins (1976). Raw data, except the fecal coliform data, were smoothed using a moving average function (lag = 3). The fecal coliform data were windsorized to remove outliers and subsequently smoothed with a series of moving median functions (Velleman and Hoaglin 1981). Due to large gaps in the series and the unequal periodicity of sampling, Fourier analysis was not performed on the data. Instead, Cleveland's (1979) scatterplot smoothing was utilized to analyze the series for functional relations, which allows for the unequal periodicity of sampling. No linear trends were observed for any 15-year series and all series were assumed to be nonlinear. Series analyses were also performed on smaller, 5-year sets of data when the complete series introduced extreme variability due to missing values or disjoint sampling of a station over time.

Autocorrelation plots were applied to both raw and smoothed series to test initial transformations and identify subsequent transformations needed. These plots suggested seasonality (autocorrelations at lag = 12) in the dissolved oxygen and water temperature series for all stations utilized. Seasonal models were estimated using ARIMA techniques, and the resultant models identified distinct seasonal trends in both water temperature and dissolved oxygen parameters. Seasonally detrended series for dissolved oxygen and water temperature showed no significant increase or decrease in these parameters over the 5-year period from 1980 to 1984. Autocorrelation plots of series for other parameters demonstrated numerous autocorrelations at various points, however, and subsequent smoothing transformations did not help to identify models for these parameters. The data for these other parameters were abandoned for statistical trends analysis at this point. Further analyses may reveal distinct seasonal and/or long-term trends in these data series, but are beyond the scope of this review.

Salinity

Average salinity values for stations during the survey period are presented in Figure II-31 as a representation of the salinity regimes found throughout the estuary. The 21 stations are plotted in Figure II-10 and identified in Table II-6.

Turbidity

Average turbidity values ranged from 6.31 Hach FTU to 20.67 Hach FTU throughout the estuary and suggest higher turbidities in the upper Ashley River (Fig. II-32). The BCDCOG (1987a) identified the upper Ashley River and many of its tributaries as areas highly impacted by runoff, which would explain the high turbidity and nutrient loadings as well as the low dissolved oxygen concentrations in this area.

Dissolved Oxygen

The mean dissolved oxygen values for the 21 stations during the survey period were similar for almost all stations (Fig. II-33), although the total range was from 1.40 mg/l to 7.43 mg/l. The two exceptions were the Goose Creek Reservoir and the upper Ashley River where mean values were lower. The raw data plots of the bottom dissolved oxygen (DO) concentration in the six areas of the estuary suggest a seasonal trend in DO, but do not lend themselves to distinguishing geographic trends in the estuary (Fig. II-34). The COD was higher in the lower Ashley and lower harbor sediments than other areas of the estuary during both time periods (Fig. II-35), and average CODs ranged from 0.4 mg/g to 62.25 g/g. Individual COD measurements ranged from 1.4 mg/l to 150.0 mg/g during the review period.

The mean orthophosphate values (Fig. II-36) ranged from 0.04 mg/l to 0.46 mg/l and suggest that higher concentrations occurred in the upper Ashley River and Goose Creek Reservoir during the survey period. The same trend is also evident from the mean total phosphate values presented in Figure II-37. Average total phosphate values ranged from 0.08 mg/l to 0.43 mg/l. Mean Kjeldahl nitrogen values ranged from 0.60 mg/l to 1.38 mg/l during the 15-year survey period (Fig. II-38), again showing geographic trends similar to those for phosphates, with higher concentrations in the upper Ashley River and Goose Creek Reservoir. Average nitrite-nitrate values, however, were higher in the upper Ashley River but not in the Goose Creek Reservoir during the survey period (Fig. II-39). The mean nitrite-nitrate values ranged from 0.06 mg/l to 0.26 mg/l over the 21 stations during the survey period. The mean total ammonia values ranged from 0.12 mg/l to 0.33 mg/l, and suggest a lower concentration of ammonia in the

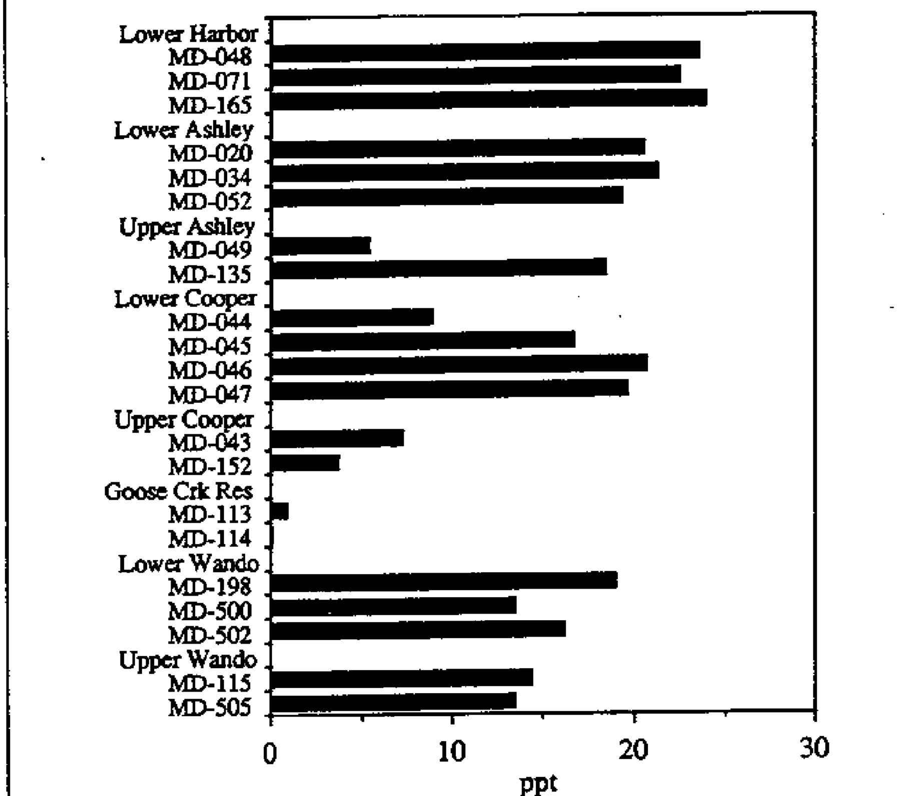


Fig. II-31. Mean salinity values for SCDHEC stations sampled during 1970-1985. Mean values are for all dates and all depths combined.

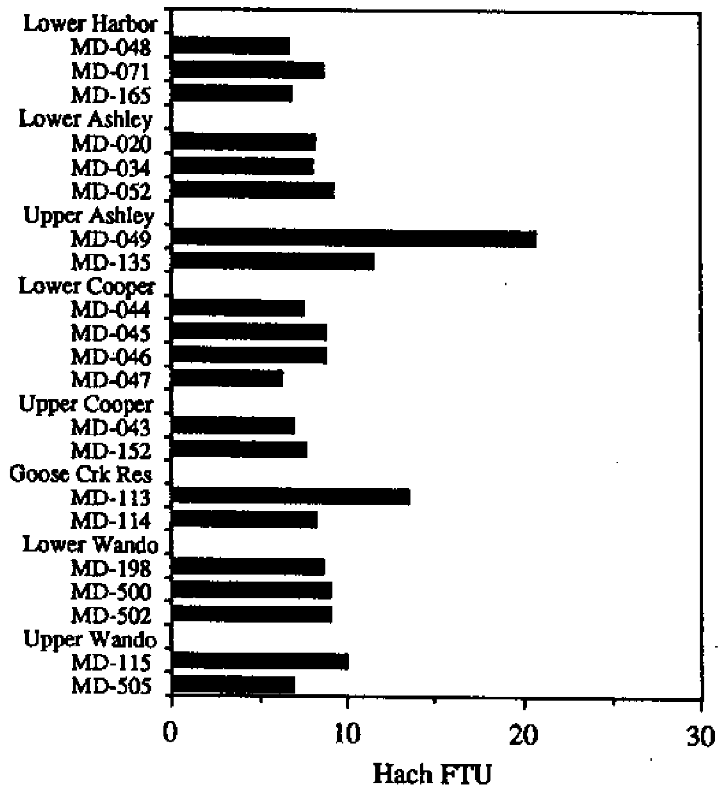


Fig. II-32. Mean turbidity values for SCDHEC stations sampled during 1970-1985. Mean values are for all dates and all depths

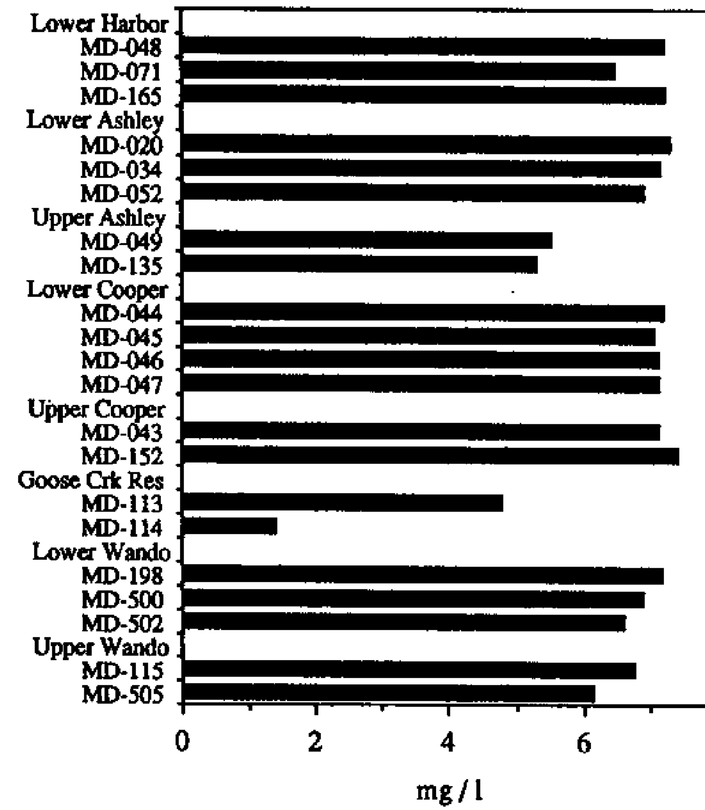


Fig. II-33. Mean dissolved oxygen values for SCDHEC stations during 1970-1985. Mean values are for all dates and all depths

Fig. II-34. Bottom dissolved oxygen from six SCDHEC stations in the Charleston Harbor Estuary between 1970 and 1985. Absence of vertical bars means no sample was taken. Station locations are shown in Fig. II-10.

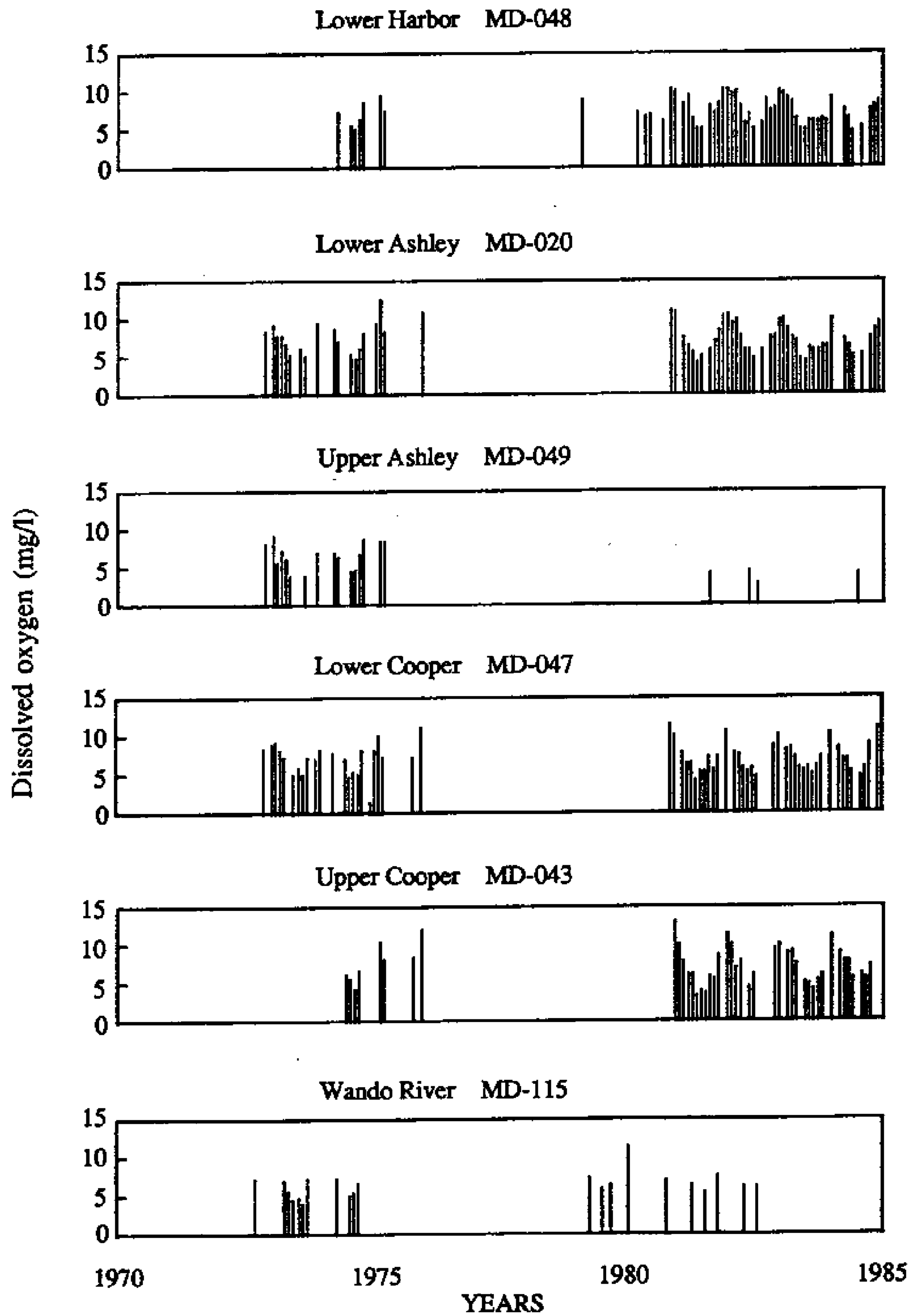
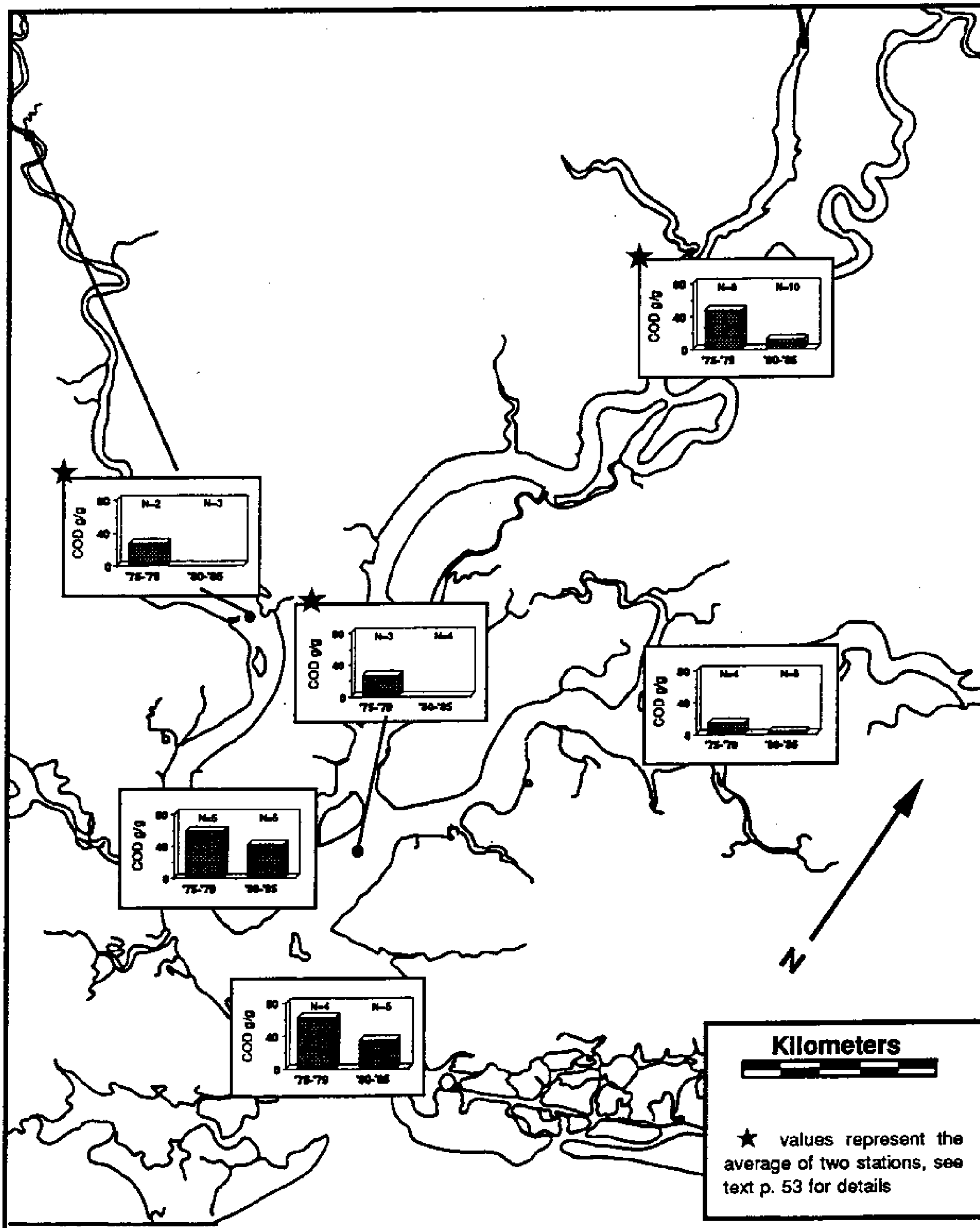


Fig. II-35. Average values for chemical oxygen demand (COD) in sediments in six areas of the estuary during the periods 1975-1979 and 1980-1985. The N value is the number of SCDHEC samples averaged over each period. Stations are located beneath graphs or are depicted by lines.



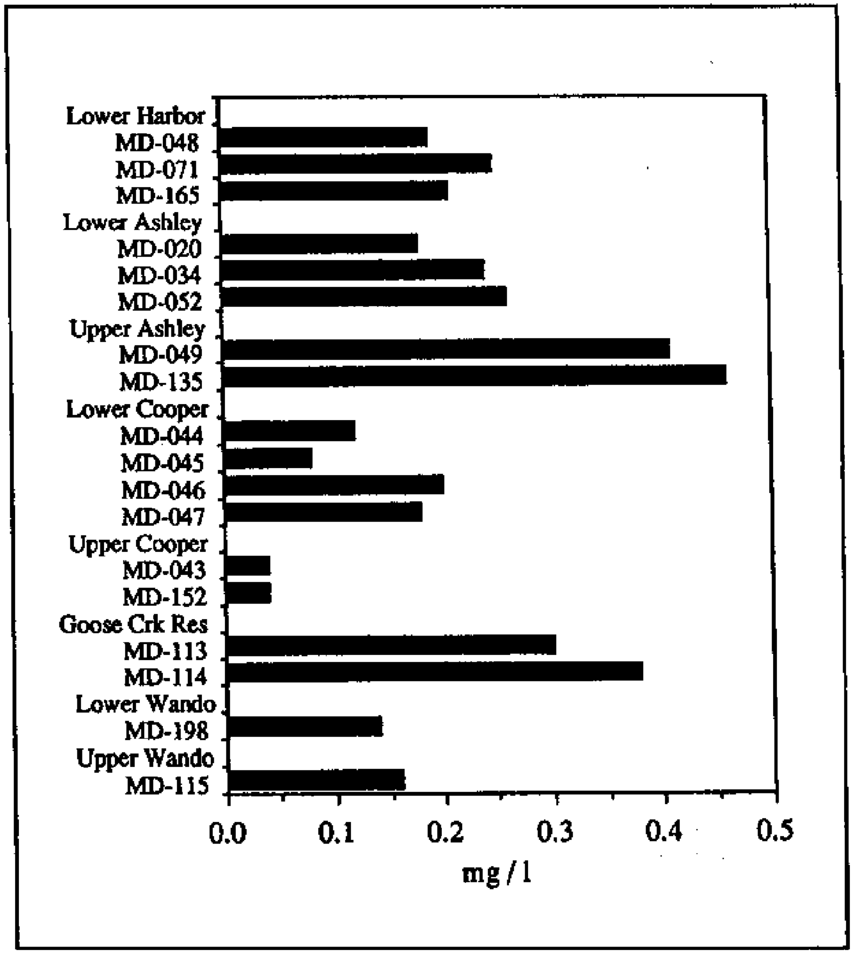


Fig. II-36. Mean orthophosphate values for SCDHEC stations sampled period 1970-1985. Means are for all dates and all depths combined.

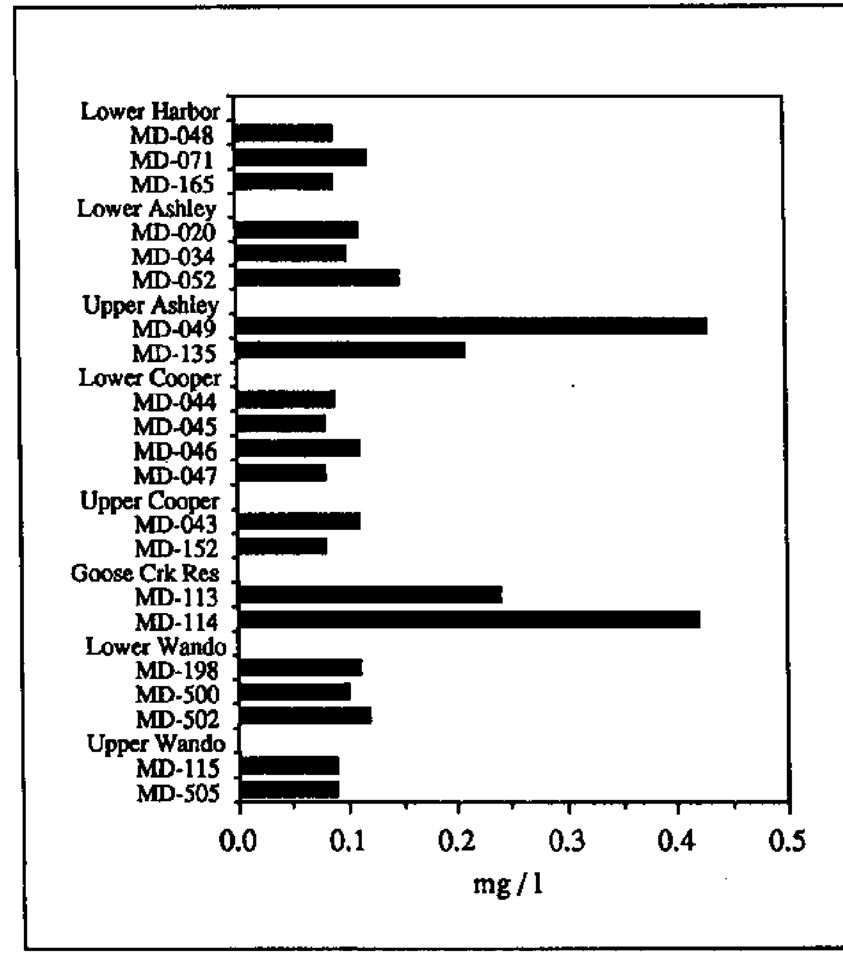


Fig. II-37. Mean total phosphate values for SCDHEC stations sampled during 1970-1985. Mean values are for all dates and all depths

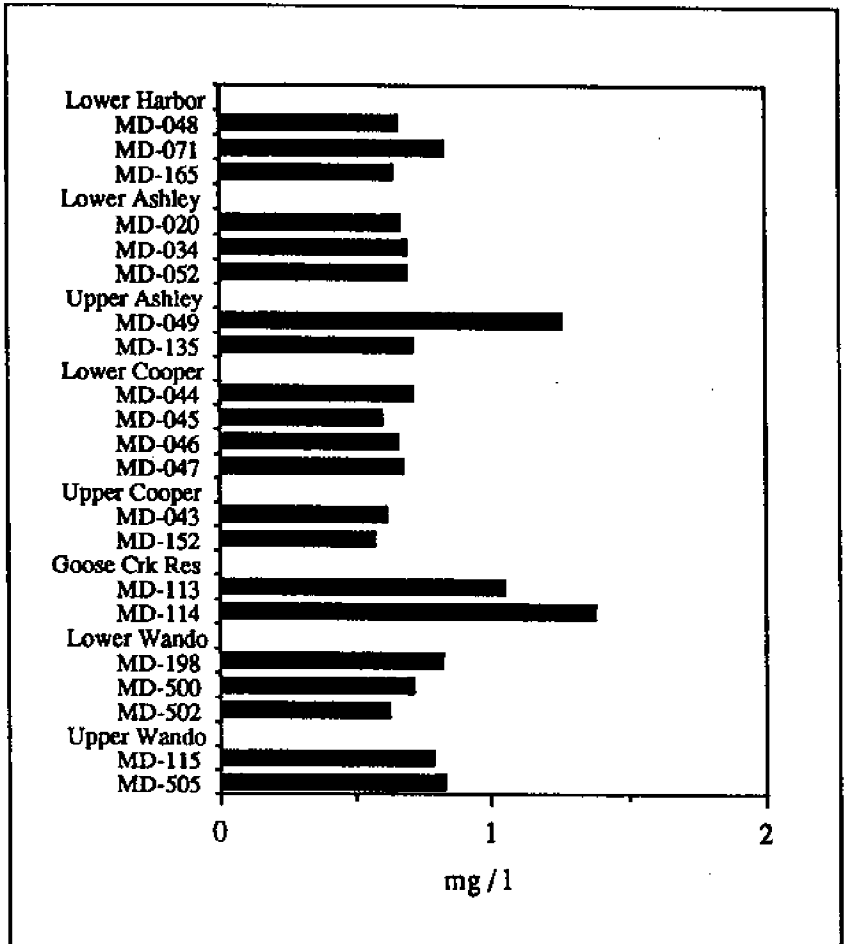


Fig. II-38. Mean Kjeldahl nitrogen values for SCDHEC stations sampled during 1970-1985. Means are for all dates and all depths combined.

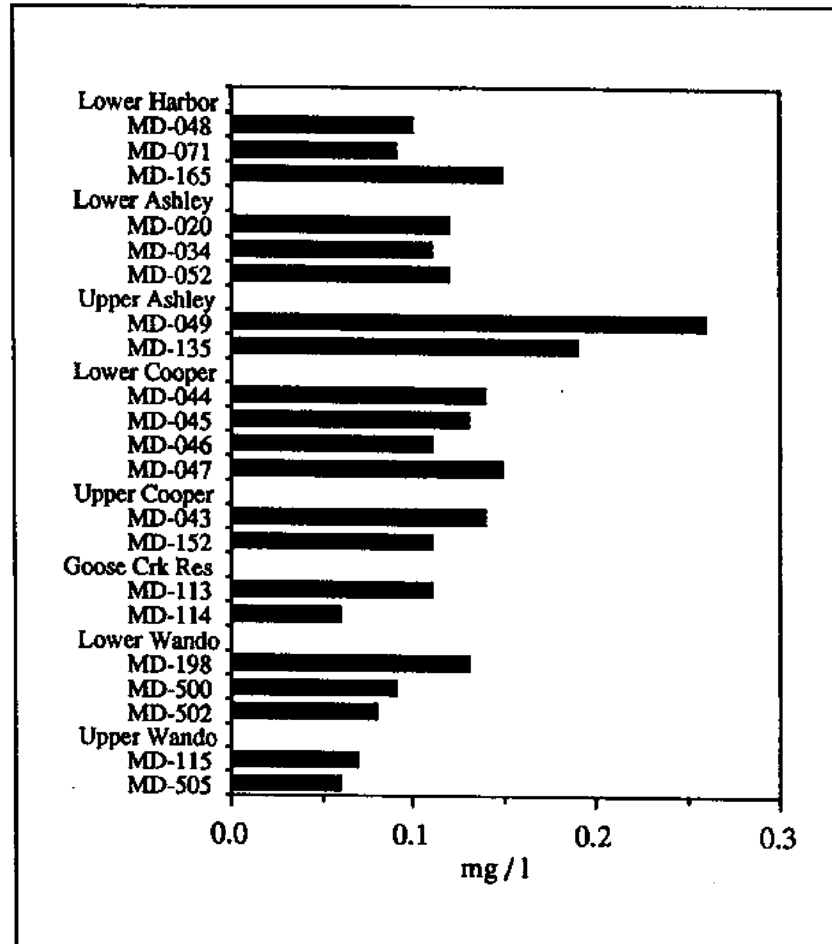


Fig. II-39. Mean total nitrite-nitrate values for SCDHEC stations sampled during 1970-1985. Means are for all dates and all depths combined.

upper Cooper River when compared with the rest of the estuary (Fig. II-40).

Plots for total surface nitrite-nitrate do not demonstrate trends by season, time, or geographic location, and demonstrate the high variability and spottiness of the data (Fig. II-41). Plots of total surface ammonia do not indicate seasonal, long-term, or geographic trends either, but indicate that higher concentrations occurred throughout the estuary between 1981 and 1983 (Fig. II-42). Surface orthophosphate measurements were not taken at a large number of stations during the review period, and the stations that were sampled do not indicate seasonal, long-term or geographic trends (Fig. II-43).

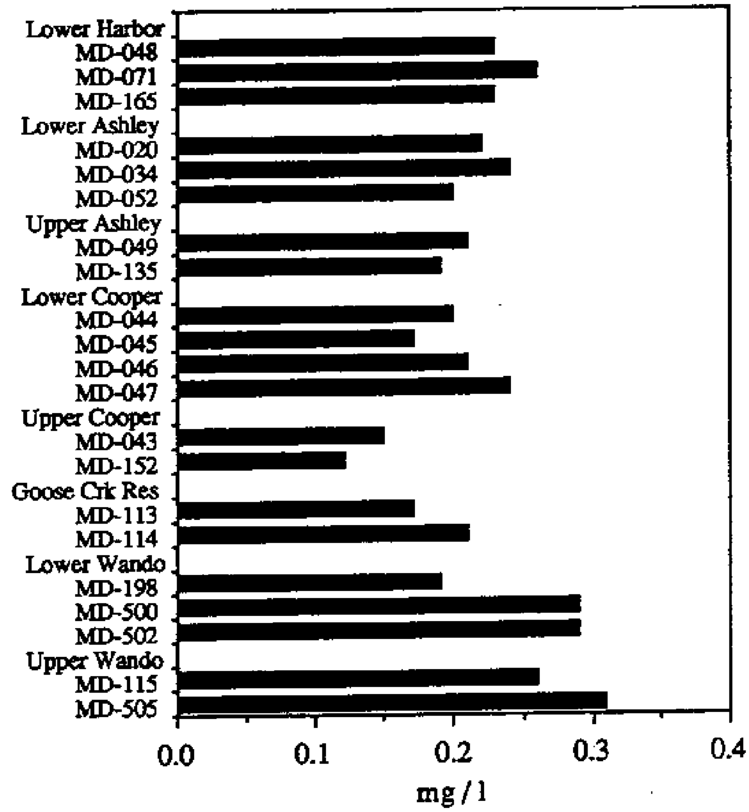


Fig. II-40. Mean total ammonia values for SCDHEC stations sampled during 1970-1985. Means are for all dates and all depths combined.

Fig. II-41. Total nitrite-nitrate (mg/l) from six SCDHEC stations in the Charleston Harbor Estuary between 1970 and 1985. Absence of vertical bars means no sample was taken. Station locations are shown in Fig. II-10. Data depicts surface values only.

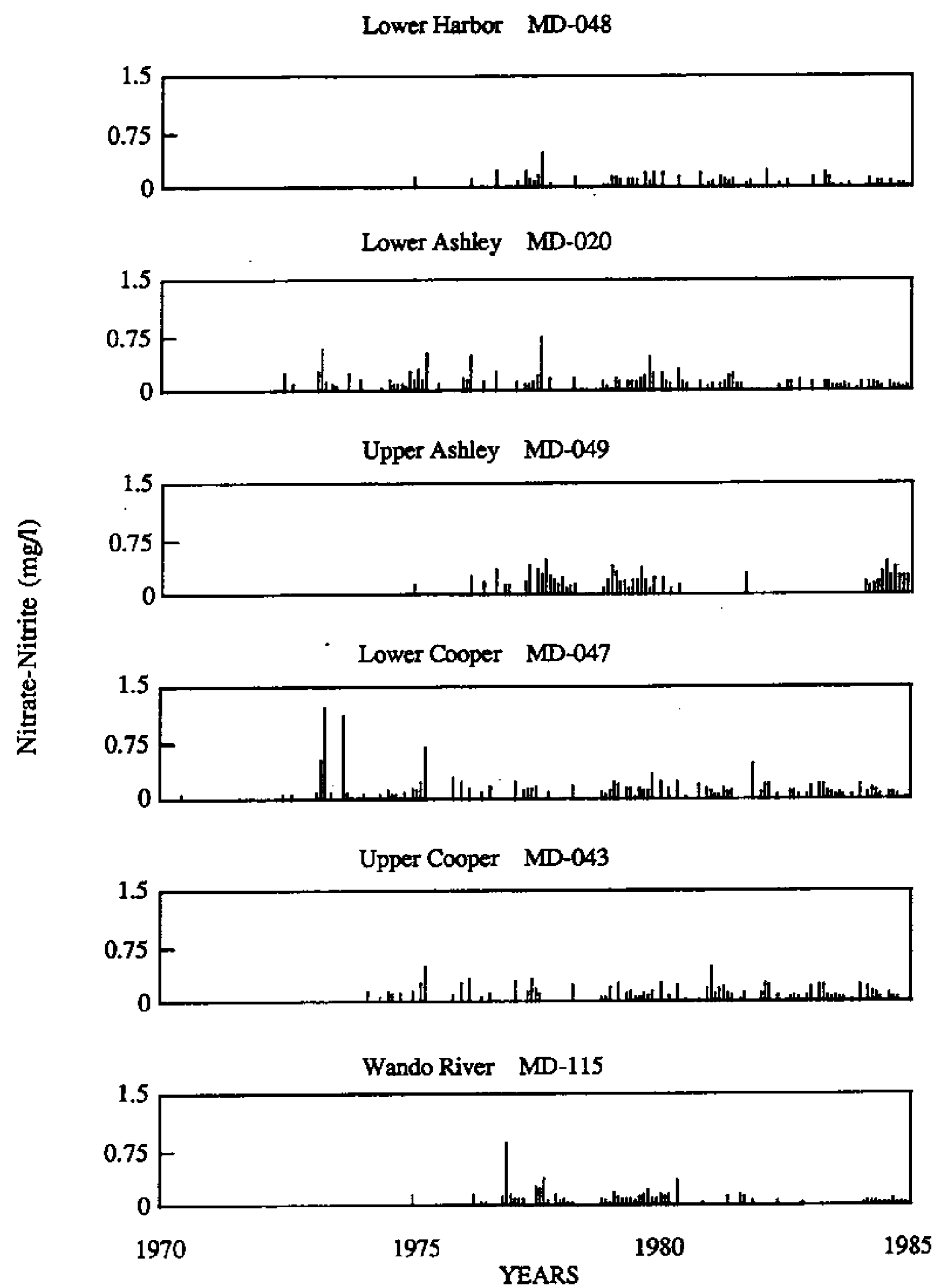


Fig. II-42. Total ammonia (mg/l) from six SCDHEC stations in the Charleston Harbor Estuary between 1970 and 1985. Absence of vertical bars means no sample was taken. Station locations are shown in Fig. II-10. Data depicts surface values only.

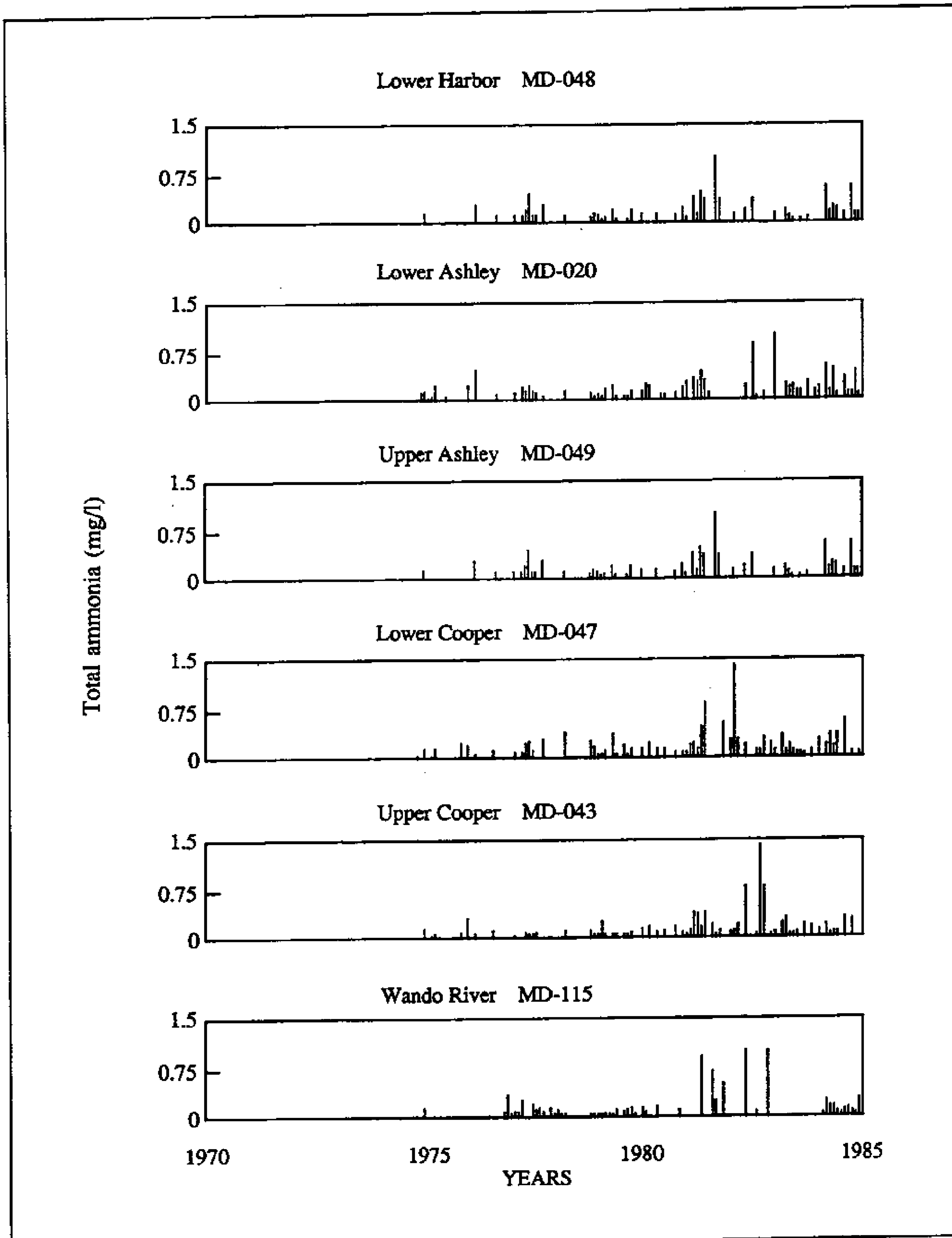
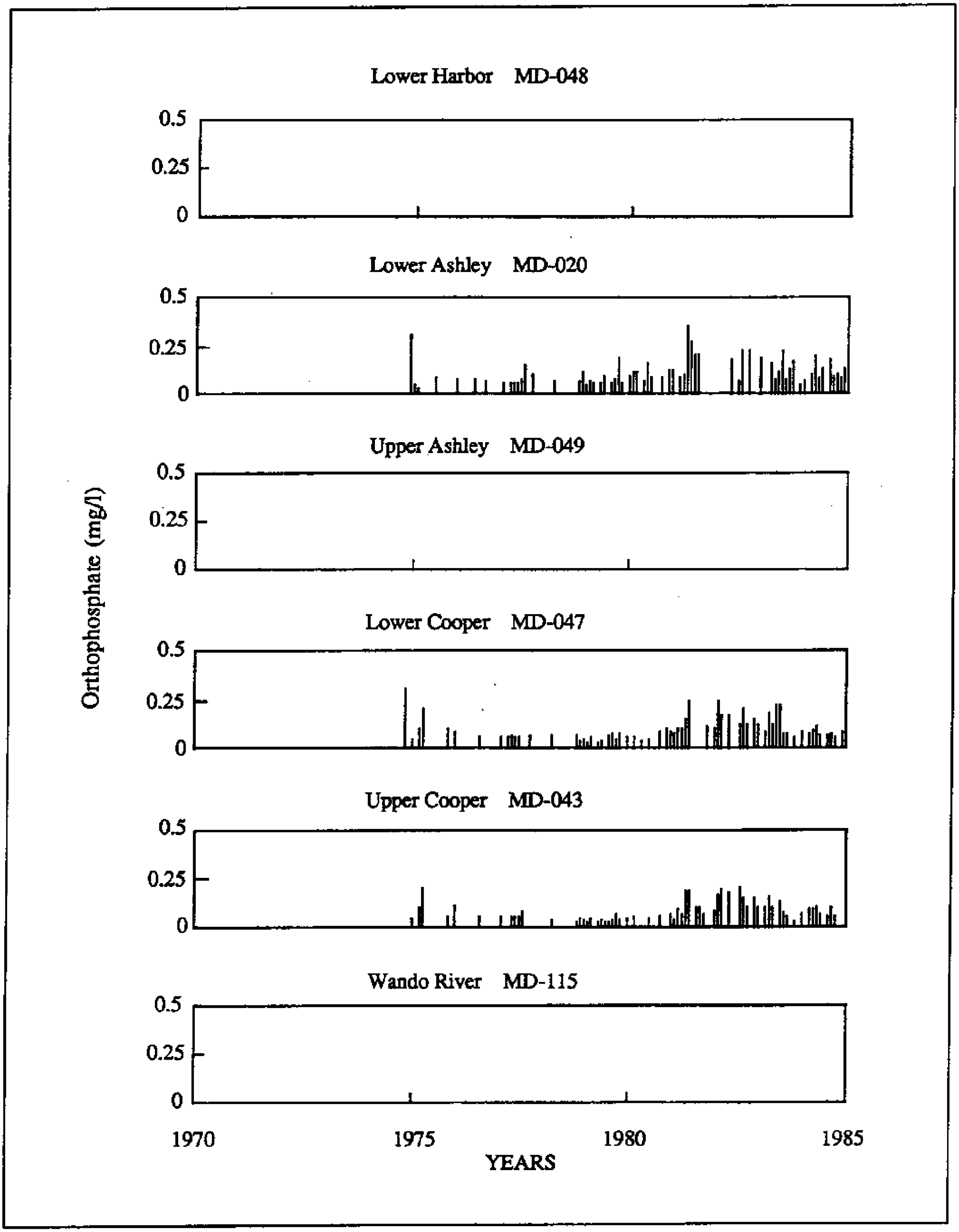


Fig. II-43. Orthophosphate from six SCDHEC stations in the Charleston Harbor Estuary between 1970 and 1985. Absence of vertical bars means no sample was taken. Station locations are shown in Fig. II-10. Data depicts surface values only.



TRENDS IN POLLUTANT LOADINGS

The SCDHEC STORET database contains annual measurements for metals and organic pollutants in sediments and quarterly measurements for dissolved organics and metals. Values reported for the dissolved pollutants rarely exceeded the detection limit, and were not useful for analysis in this review. Chestnut (1989) found decreasing trends for many dissolved contaminants between 1974 and 1987, but concluded that these trends were actually the result of decreasing detection limits over time through the use of better analytical techniques.

The contaminant data for sediments provide another indication of changes in pollutant loadings throughout the estuary over time. These data are less subject to short-term variability resulting from the large daily changes that occur in water quality parameters of estuarine systems. Therefore, only the sediment data were utilized for these analyses. Three separate stations (MD-048, MD-052, and MD-115) and three sets of combined SCDHEC stations (MD-049 and MD-135; MD-045 and MD-046; and MD-043 and MD-152) were selected for analysis of trends in sediment concentrations. These stations had the largest amount of data for the lower harbor, lower Ashley River, upper Ashley River, lower Cooper River, upper Cooper River, and Wando River areas.

Average values for the periods 1975-1979 and 1980-1985 were calculated for concentrations of mercury, copper, chromium, lead, PCBs, and total DDT from sediments in the six areas, and are presented in Figures II-44 through II-50. Other parameters were measured in these areas, but levels were generally undetectable. The range and average values for all sediment parameters in each area are presented in Appendix A, as are the minimum, maximum, and average values for major parameters sampled at all SCDHEC stations during the review period.

Inorganics

Average concentrations of mercury in sediments were not widely different throughout the estuary nor over the two time periods (Fig. II-44). The average concentrations of mercury in sediments ranged from 0.11 µg/g in the lower harbor during the 1975-1979 period to 0.40 µg/g in the upper Ashley River during the 1975-1979 period (Fig. II-44). Individual values for mercury ranged from below the detection limit to 0.56 µg/g during the review period. Both the average and maximum values for mercury in sediments are comparable with mid-range values for mercury in sediments obtained from other estuaries throughout the United States by the National Status and Trends Program (NSTP) (NOAA 1988).

Average concentrations of copper in sediments ranged from 6.75 µg/g in the upper Ashley River during the 1975-1979 period to 34.40 µg/g in the Wando River during the 1980-1985 period (Fig. II-45). Levels of copper were somewhat elevated in the Wando and Ashley rivers during the 1980-1985 period as compared with the other areas of the estuary. Individual values for copper in sediments ranged from 5.0 µg/g to 149.0 µg/g during the review period (Appendix A). The average concentrations of copper found in the Charleston Harbor Estuary were low in comparison with other estuaries, but individual measurements ranged into the higher levels found in some of the nation's more polluted estuaries (NOAA 1988).

The 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 (Fig. II-46) as compared with the rest of the estuary, particularly during the 1980-1985 period. The range of

Fig. II-44. Mean values for mercury in sediments in six areas of the estuary during the periods 1975-1979 and 1980-1985. The N value is the number of SCDHEC samples averaged over each period. Station locations are beneath graphs or denoted with lines.

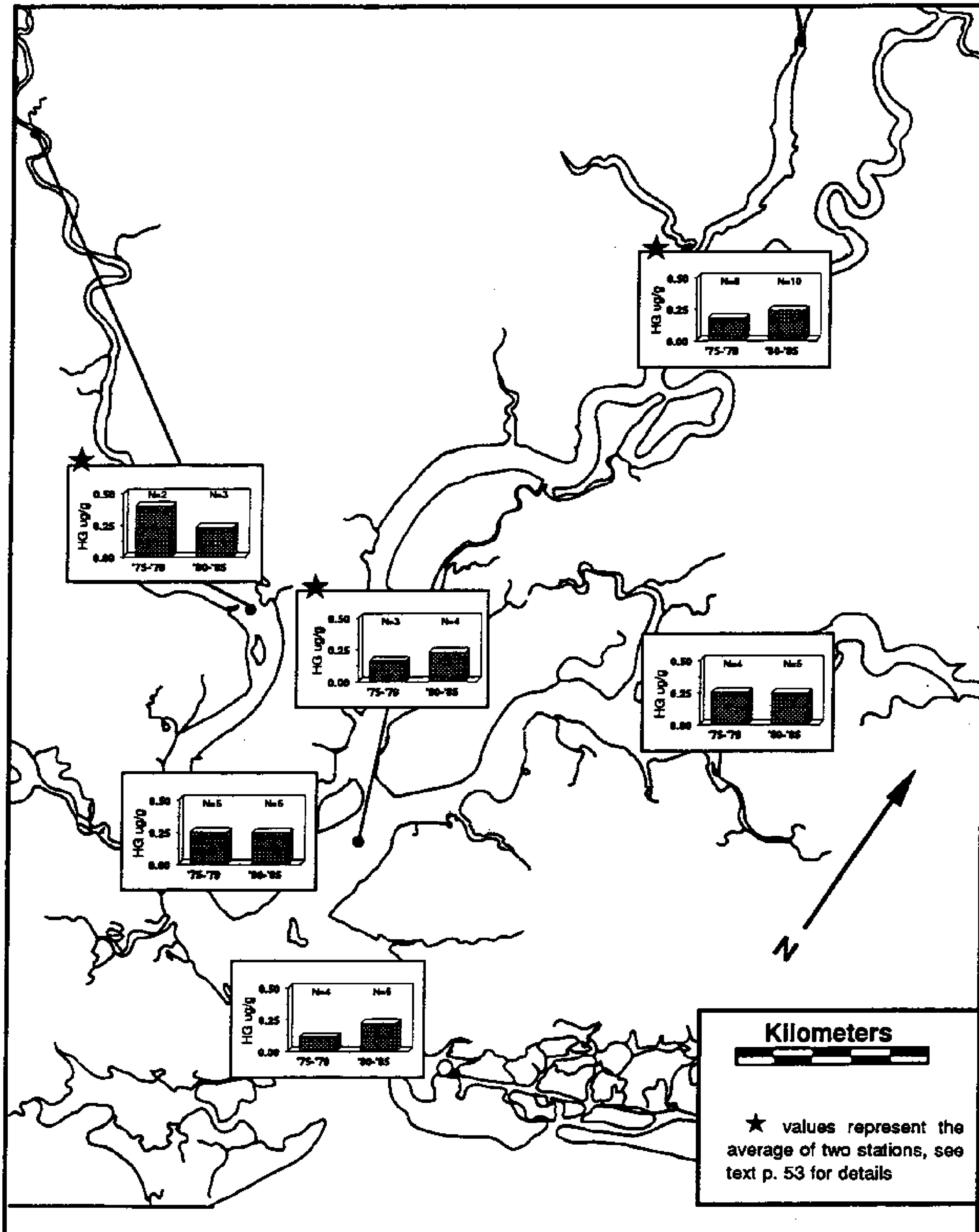


Fig. II-45. Mean values for copper in sediments in six areas of the estuary during the periods 1975-1979 and 1980-1985. The N value is the number of SCDHEC samples averaged over each period. Station locations are beneath graphs or denoted with lines.

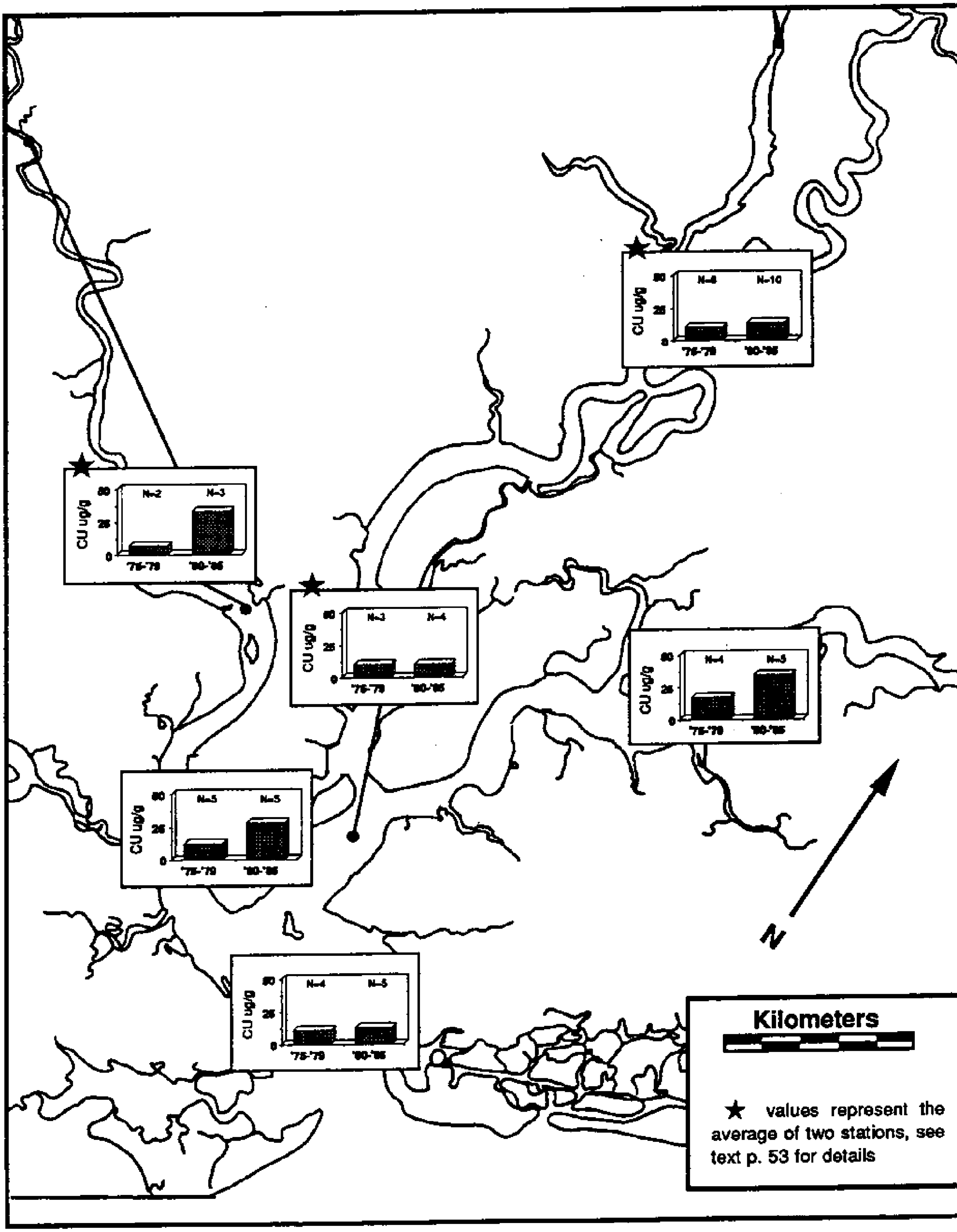
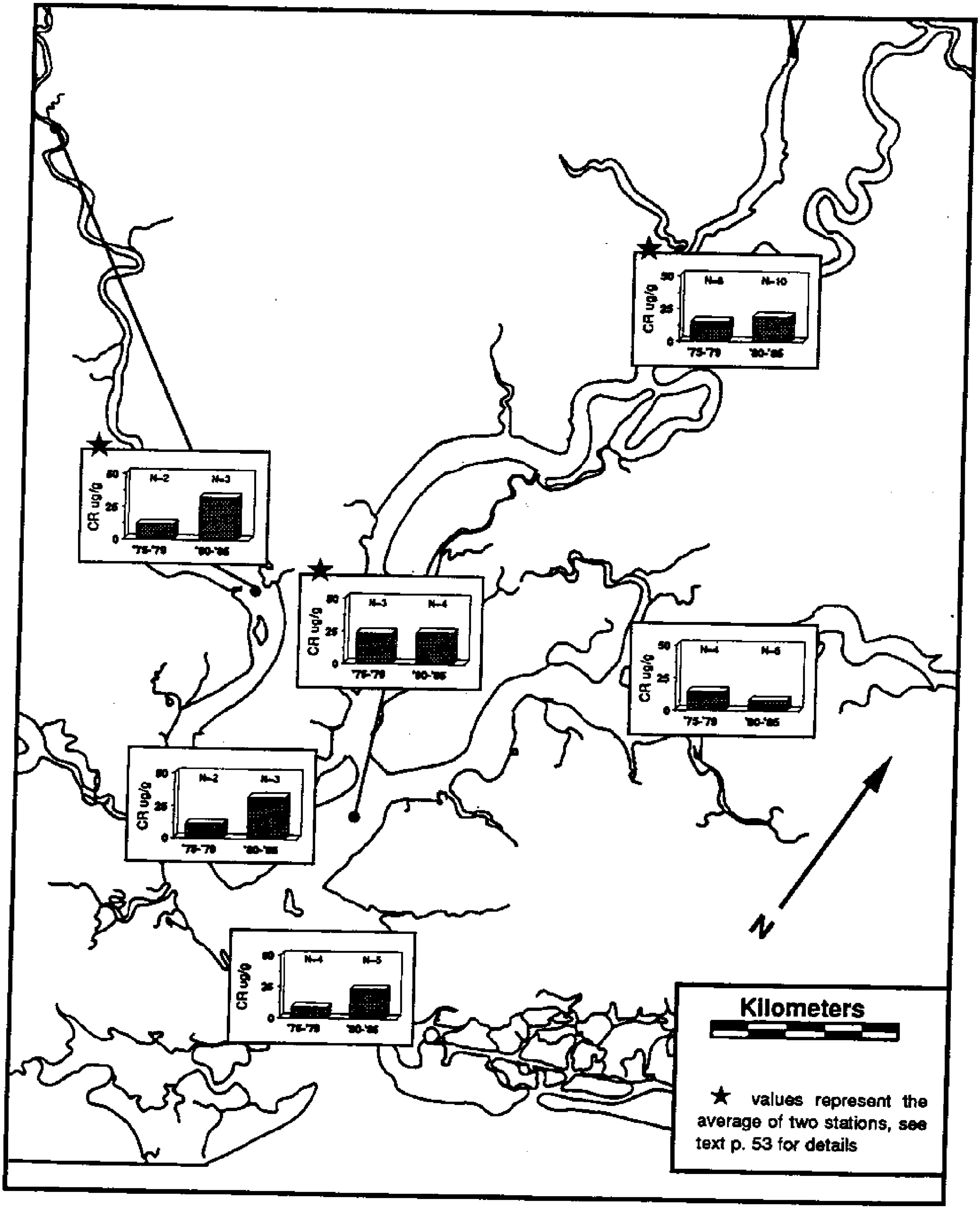


Fig. II-46. Mean values for chromium in sediments in six areas of the estuary during the periods 1975-1979 and 1980-1985. The N value is the number of SCDHEC samples averaged over each period. Station locations are beneath graphs or denoted with lines.



individual chromium values extended from 4.0 μg/g to 50.0 μg/g during the review period, and are low in comparison with concentrations found in other estuaries (NOAA 1988).

Average concentrations of cadmium in sediments ranged from 0.68 μg/g to 5.09 μg/g throughout the estuary during the review period. Concentrations of cadmium in the lower Ashley River sediments were quite a bit higher than other parts of the estuary during the 1975-1979 period (Fig. II-47). Individual values for cadmium ranged from less than 0.50 μg/g to 22.20 μg/g during the review period. Average values for cadmium in sediments in the Charleston Harbor Estuary are comparable with mid and high values obtained from other estuaries, while the maximum individual values exceed the highest levels reported by the NSTP (NOAA 1988).

The average concentrations of lead in sediments ranged from 18.40 μg/g to 96.65 μg/g in the estuary during the review period, and higher levels were found in the upper Ashley area during the 1975-1979 period than in other areas (Fig. II-48). Individual values for lead ranged from 3.0 μg/g to 531.90 μg/g during the survey period. The maximum values measured by SCDHEC exceed those reported for other estuaries (NOAA 1988) and the average values are comparable to mid-range values.

Organics

Concentrations of PCBs in the sediments were a great deal higher in the Wando River and somewhat higher in the Cooper River than in other areas of the estuary during the 1975-1979 period (Fig. II-49). The average values for PCBs ranged from below the detection limit to 47.9 μg/g. The highest PCB concentrations found in the Charleston Harbor Estuary exceeded the maximum values reported for other estuaries throughout the country (NOAA 1988).

The concentrations of most pesticides in sediments were too low to be detected during the review period. Higher levels of DDT and its degradation products were found in the lower Cooper River and lower Ashley River during the two time periods, as well as in the upper Cooper river during the 1975-1979 period (Fig. II-50). Average concentrations of total DDT ranged from below the detection limit to 1.93 μg/g, which is high in comparison with data from other estuaries (NOAA 1988).

Coliform Bacteria

The fecal coliform data contained a great deal of variability, largely due to the infrequent occurrence of extremely high values. For this reason, the median and mean coliform values by station are presented in addition to the mean coliform values in Figure II-51. The mean coliform values ranged from 15 colonies/100 ml to 410 colonies/100 ml during the survey period, and median values ranged from 7 colonies/100 ml to 143 colonies/100 ml. The median values are lower than the corresponding mean values, but the pattern of ranking among stations is very similar for the two plots. 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.

Time series plots of surface fecal coliform show distinct geographic trends, and suggest seasonal trends for this parameter at some stations (Fig. II-52), but no long-term trends are evident. Almost the entire Charleston Harbor Estuary was designated as SC waters by the SCDHEC (SCDHEC 1985a,b,c; Chestnut 1989), and values for most parameters rarely exceeded values for SC waters as water bodies were designated during the review period. The upper Cooper and Wando river stations demonstrated consistently lower concentrations of fecal coliform than

Fig. II-47. Mean values for cadmium in sediments in six areas of the estuary during the periods 1975-1979 and 1980-1985. The N value is the number of SCDHEC samples averaged over each period. Station locations are beneath graphs or denoted with lines.

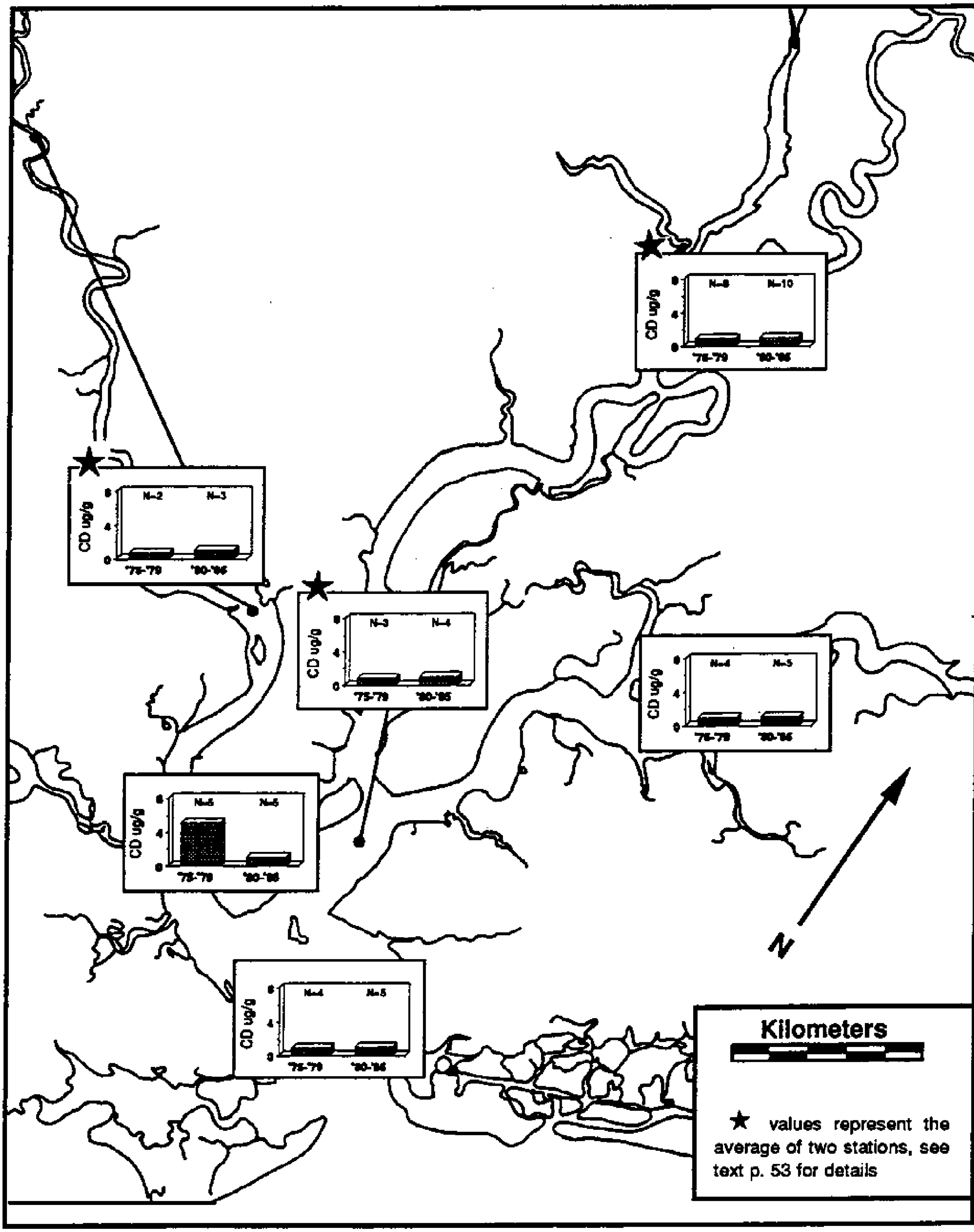


Fig. II-48. Mean values for lead in sediments in six areas of the estuary during the periods 1975-1979 and 1980-1985. The N value is the number of SCDHEC samples averaged over each period. Station locations are beneath graphs or denoted with lines.

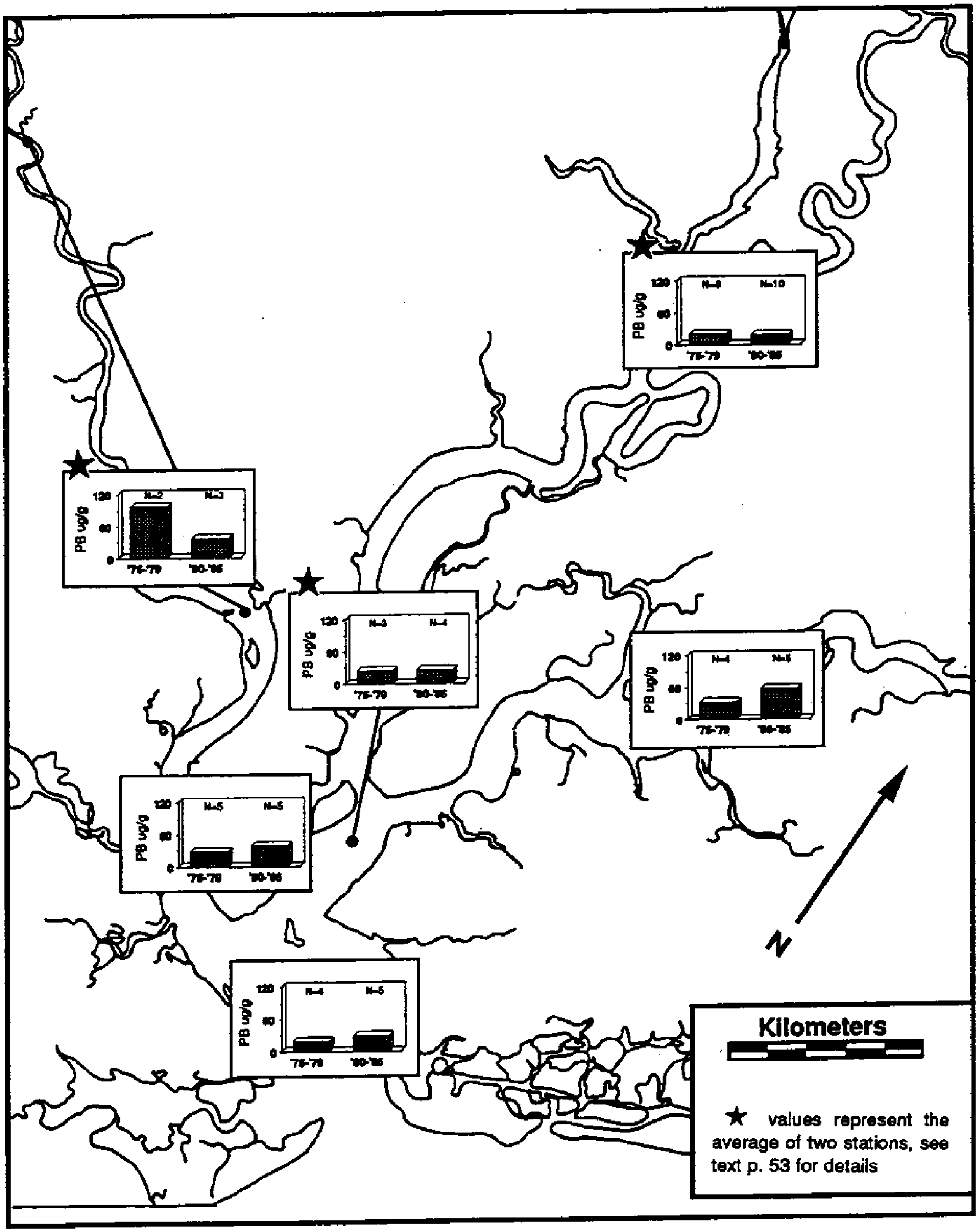


Fig. II-49. Mean values for PCBs in sediments in six areas of the estuary during the periods 1975-1979 and 1980-1985. The N value is the number of SCDHEC samples averaged over each period. Station locations are beneath graphs or denoted with lines. Time periods with no vertical bars indicate that concentrations were below detection limits.

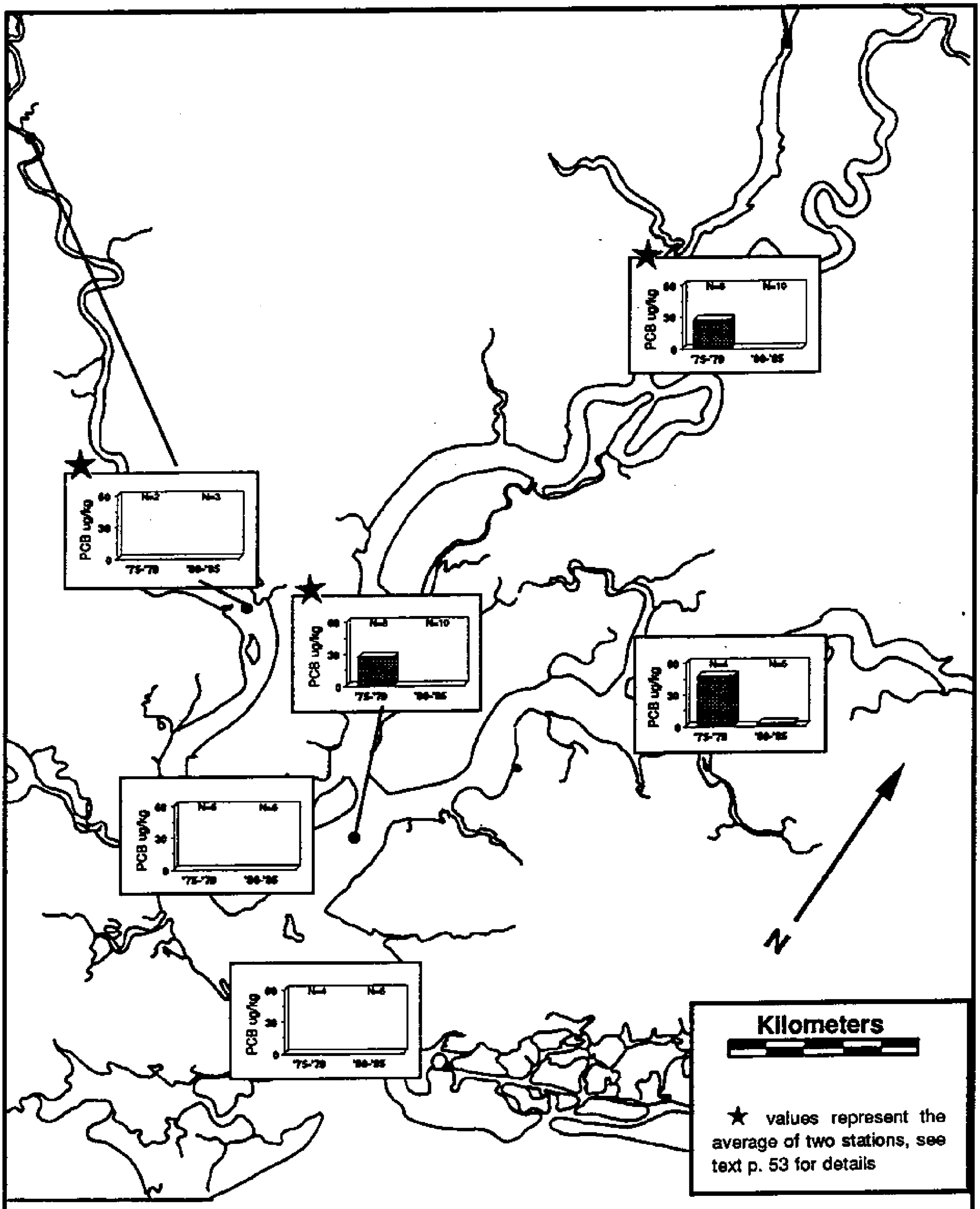
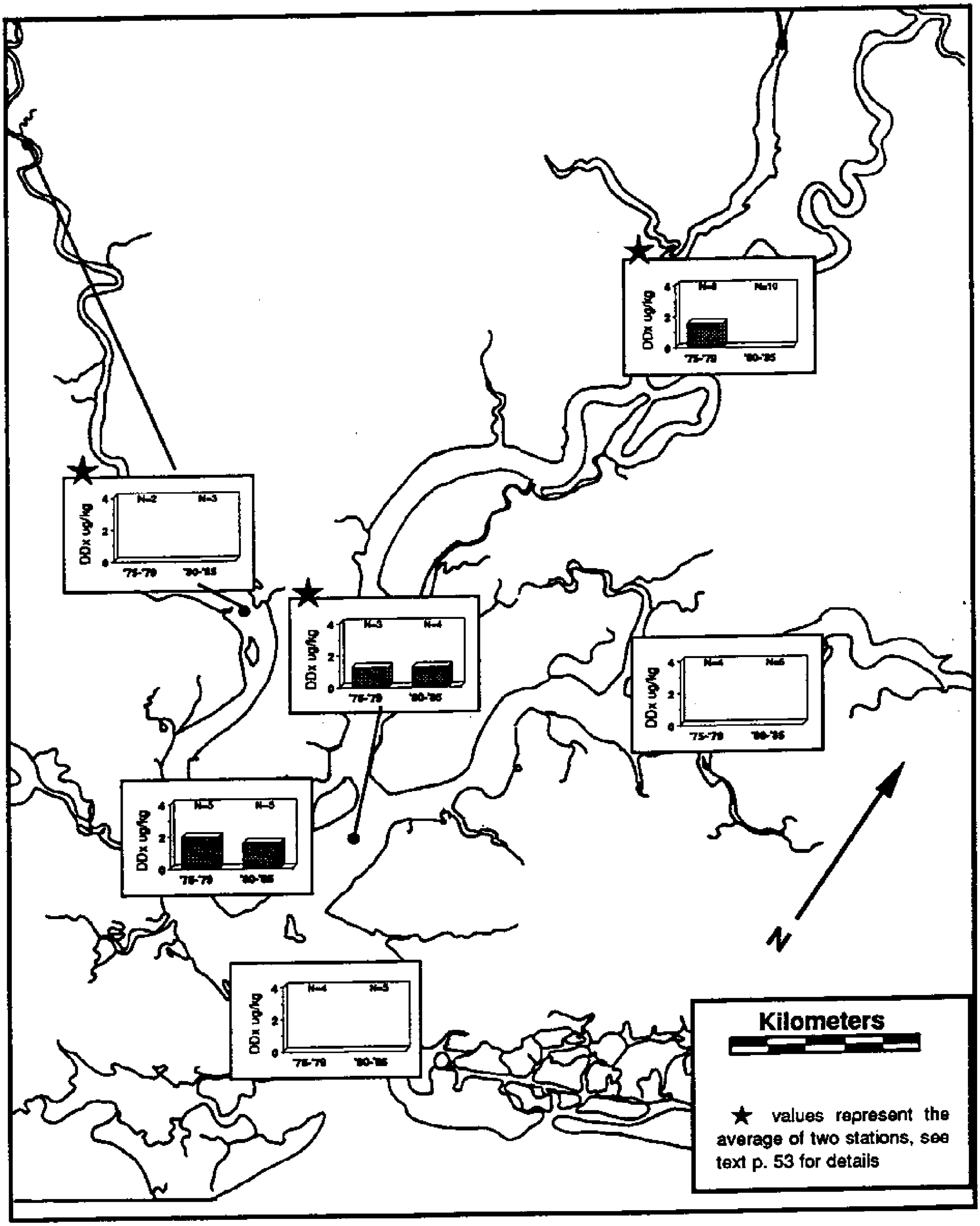


Fig. II-50. Mean values for DDT and its degradation products in sediments in six areas of the estuary during the periods 1975-1979 and 1980-1985. The N value is the number of SCDHEC samples averaged over each period. Station locations are beneath graphs or denoted with lines. Time periods with no vertical bars indicate that concentrations were below detection limits.



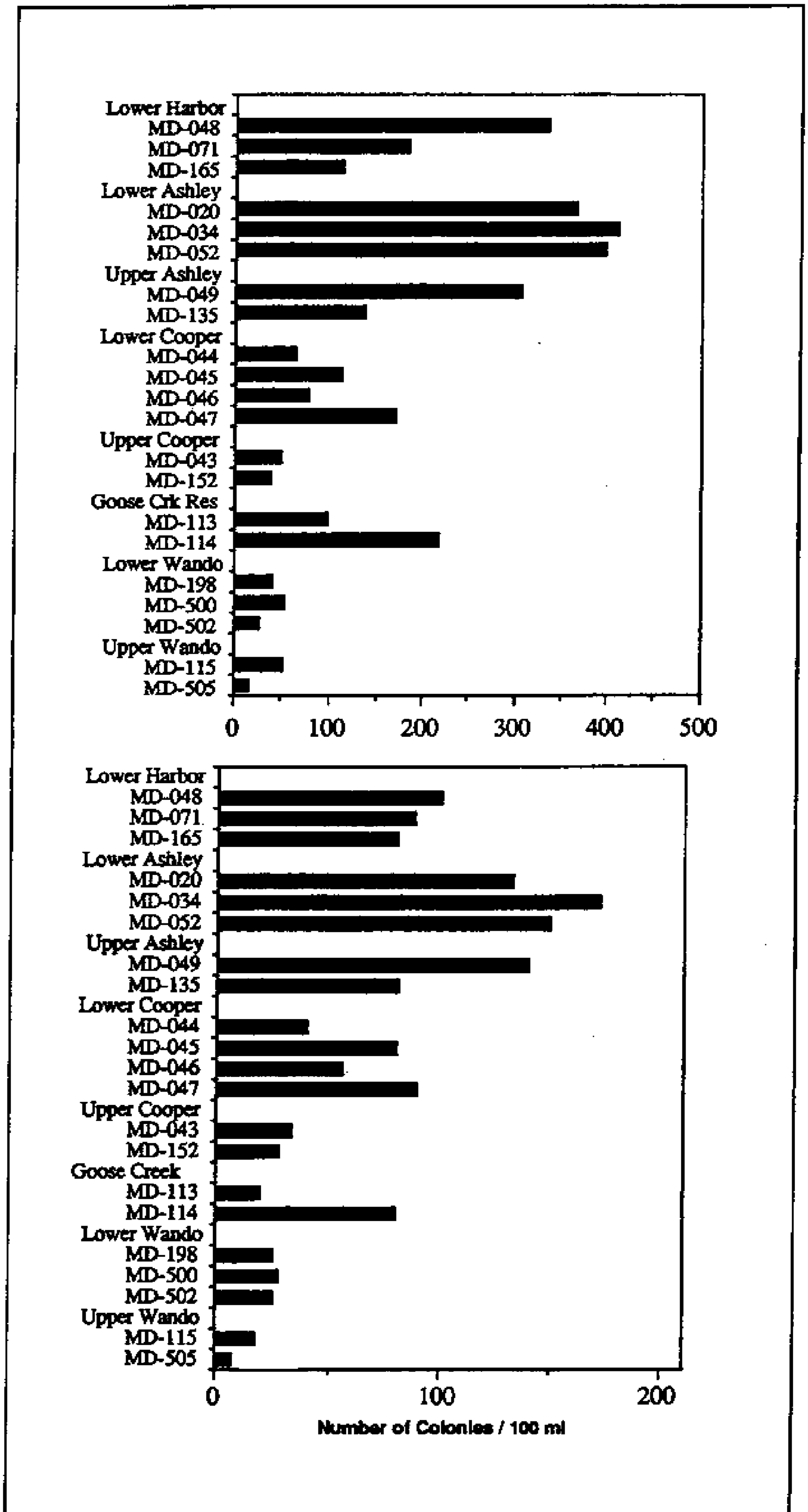
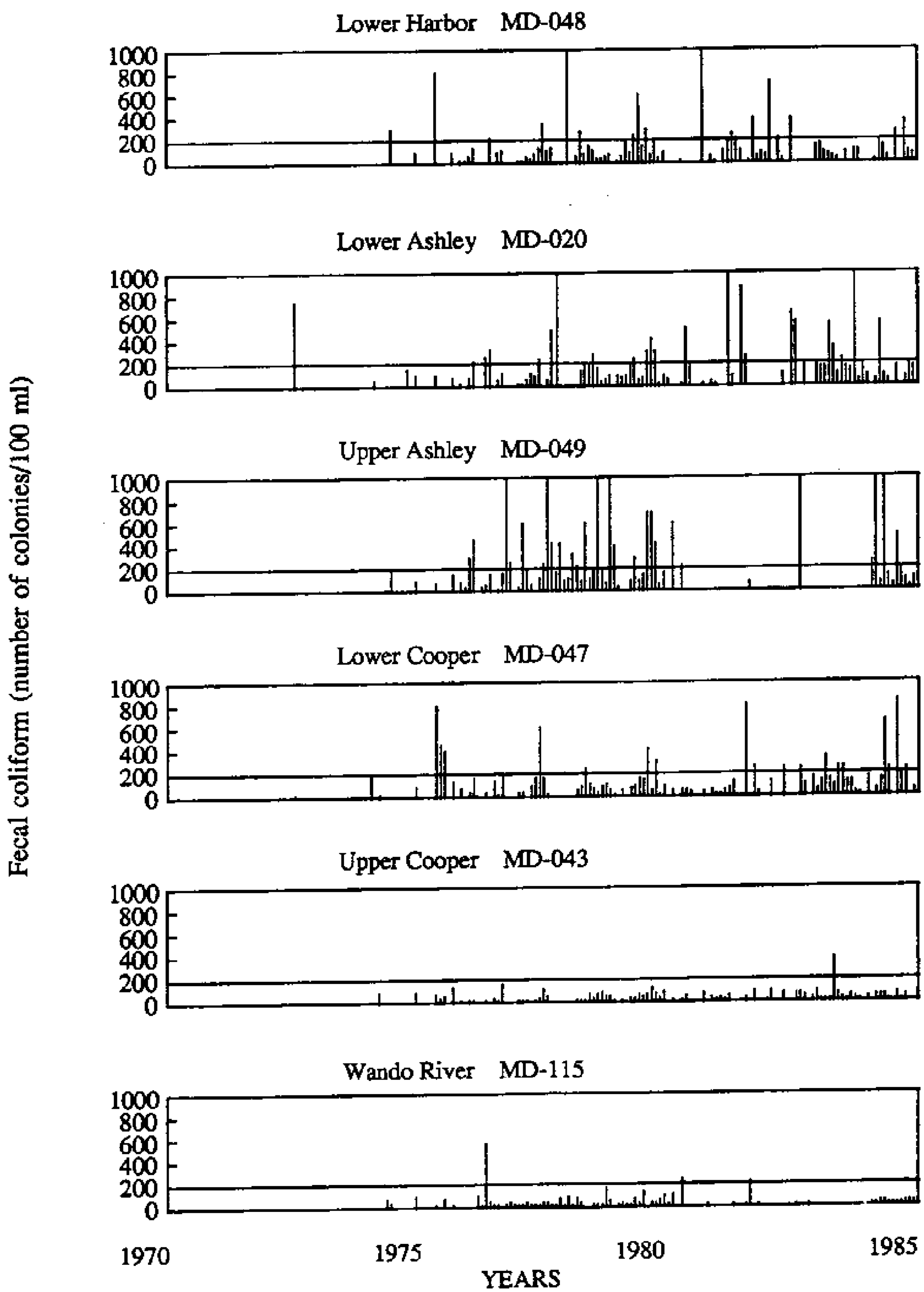


Fig. II-51. Mean (top) and median (bottom) coliform values for SCDHEC stations during 1970-1985. Means and medians are for all dates and all depths combined.

other areas of the estuary. The fecal coliform plots at these stations indicate the number of times that the values exceeded the SCDHEC designation limits of SA waters (200 colonies/100 ml) and SB waters (1,000 colonies/100 ml) using the SCDHEC designations in use during the review period. The Wando River station (MD-115) exceeded SA limits three times (out of 78 measurements) during the 15-year survey period, while the upper Cooper River station (MD-043) exceeded SA limits only once (out of 77 measurements). The lower Cooper River station (MD-047) exceeded SA limits 20 times (out of 81 measurements) during the survey period. The upper Ashley River station (MD-049), however, exceeded SA limits 28 times and SB limits eight times (out of 63 measurements), while the lower Ashley station (MD-020) exceeded SA limits 27 times and SB limits three times (out of 78 measurements) between 1970 and 1985. Finally, the lower harbor station (MD-048) exceeded SA limits 19 times and SB limits twice (out of 77 measurements) during the survey period. It should be noted that these six stations are representative of each area of the estuary, but do not indicate the number of times limits were exceeded by other stations.

Trend analysis for changes in basic water quality and pollutant loadings yielded some seasonal trends, but we did not observe long-term trends in the Charleston Harbor

Fig. II-52. Fecal coliform from the surface waters of six SCDHEC stations in the Charleston Harbor Estuary sampled between 1970 and 1985. Absence of vertical bars means no sample was taken. Values which touch the top axis exceed 1,000 colonies/100 ml. Station locations are shown in Fig. II-10. The horizontal line at 200 colonies/100 ml presents the distinction between SA and SB waters under SCDHEC's old desination of water quality.



Estuary based on our review of the SCDHEC STORET database. Trends may have been masked by the lack of sampling during a standardized tidal stage which undoubtedly contributed to the massive variances noted in the data set. In addition, the majority of stations were not sampled continuously during the review period, which also contributed to the large variances. Chestnut (1989) reported significant decreases in some water quality parameters using the same data set, although extended through 1987. The additional three years of data extend through the period of rediversion, and may be responsible for these discrepancies. It should be noted, however, that the inferential techniques employed by Chestnut (1989) were designed to be utilized in river systems that experience a relatively constant flow, and the observed trends may be due to variations in freshwater flow, tidal stage, and tidal amplitude in the system between sampling periods.

There are only two biological data sources available for the Charleston Harbor system that provide more than five years of data for biological resources. These include commercial landings data for blue crab and penaeid shrimp species (SCWMRD unpublished data), and fishery independent sampling for penaeid shrimp populations collected at several sites in the harbor basin (Whitaker unpublished SCWMRD data).

The commercial landings data provide estimates of catches for all commercially harvested species in South Carolina throughout most of the review period. Estimates are also available by fishing region within the state beginning in 1979 (SCWMRD, Office of Fisheries Management). Landings estimates for three species, the white shrimp *Penaeus setiferus*, the brown shrimp *P. aztecus*, and the blue crab *C. sapidus*, which are very abundant in Charleston Harbor, are plotted in Figure II-53. Because the penaeid shrimps are only commercially harvested offshore in the Charleston area, we considered landings from 0 miles to 12 miles offshore and from Capers Island to Kiawah Island as the best estimate of shrimp that were likely to be produced from the Charleston Harbor drainage system. A comparison of the landings estimates showed large fluctuations during the survey period, but there were no clear trends over time for any of these species. Estimates of the landings from Charleston

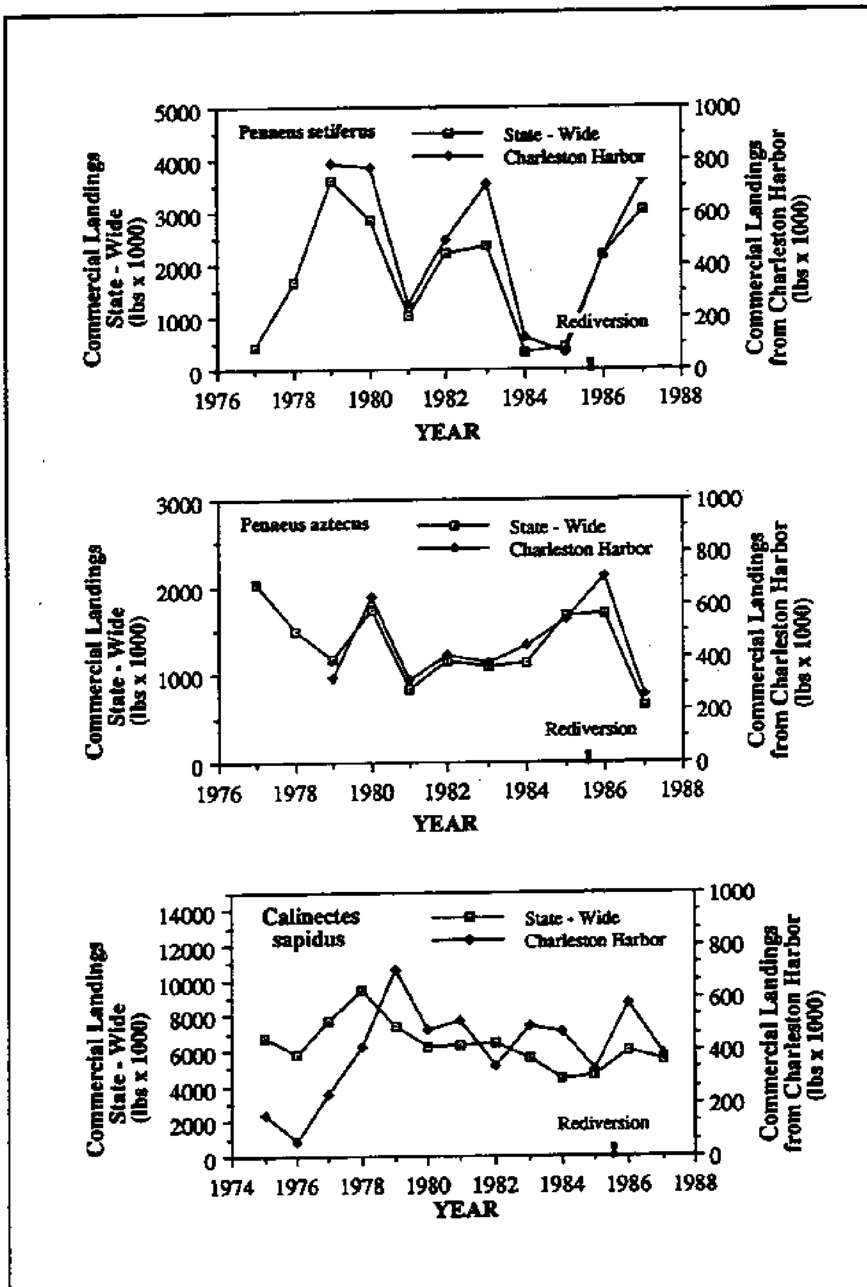


Fig. II-53. Comparison of estimated landings of white shrimp (*P. setiferus*), brown shrimp (*P. aztecus*), and blue crab (*C. sapidus*) produced from Charleston Harbor versus statewide landings estimates (SCWMRD unpublished data). Commercial landings estimates represent catches from Capers Inlet to Kiawah Island from 0 miles to 12 miles offshore.

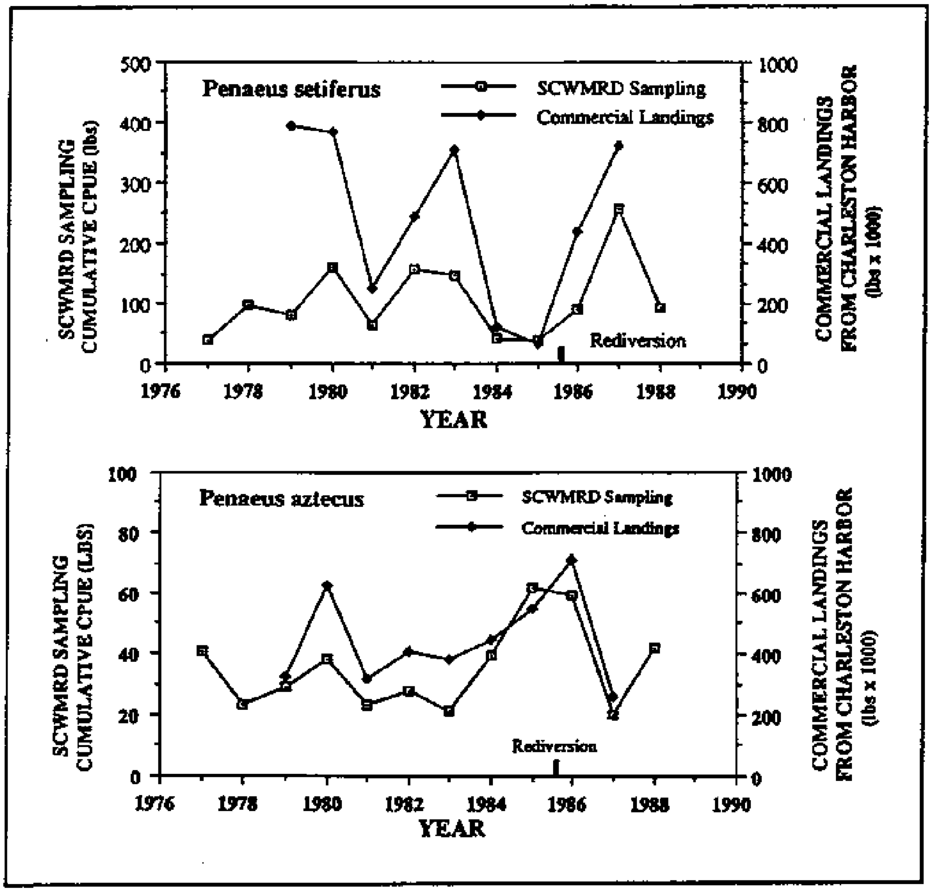


Fig. II-54. Comparison of estimated landings and SCWMRD sampling from Charleston Harbor of white shrimp (*P. setiferus*) and brown shrimp (*P. aztecus*). Commercial landings estimates represent catches from Capers Inlet to Kiawah Island from 0 miles to 12 miles offshore. SCWMRD sampling data represents the annual sum of monthly catches averaged from two index stations in the lower harbor.

Harbor generally showed patterns similar to those observed statewide, which suggests that the production of shrimp and crabs from this estuary is typical compared to other South Carolina estuaries.

Reduced landings of white shrimp were observed in 1977, 1978, 1981, 1984, 1985, and 1986 (Fig. II-53). These were years in which spring spawner abundance was reduced because of unusually cold winter temperatures (Whitaker, personal communication). Brown shrimp landings were less variable during the survey period, with highest landings noted in 1980, 1981, and 1987. Blue crab landings estimated for Charleston Harbor were relatively low from 1975 to 1977 compared with later years, a pattern not observed in the state-wide landings. This discrepancy is most likely the result of poor landings estimates available for that time period.

Fishery independent data collected by Whitaker (unpublished data, SCWMRD) provides a second long-term database for penaeid shrimp at several locations in the harbor system. Two stations located in the lower harbor basin which have been continuously sampled since the mid-1970's were evaluated for trends in abundance over time. These stations include one off the Fort Johnson Marine Resources Center and one located in the lower harbor anchorage basin. Monthly sums of trawl catches averaged among these two stations are plotted by year in Figure II-54 and compared with the fishery-dependent landing estimates for Charleston Harbor described above. These data also show fluctuations in the yearly abundance of *P. setiferus* and *P. aztecus* corresponding roughly to the changes noted in the commercial landings, with no consistent long-term declines or increases in abundance.

Two other data sets of shorter duration provide some additional information on demersal finfish and decapod crustacean assemblages. Wenner et al. (1984) described these assemblages at several sites in the harbor basin and Cooper River which were sampled over the five-year period 1973-1977 (see previous section for details). Several of these stations were

Table II-16. Rank of numerically dominant finfish species captured by trawl at five sites in the harbor basin and Cooper River during 1984-1988 (SCWMRD unpublished data) and 1973-1977 (Wenner et al. 1984).

Rank by abundance	1984-88	1973-77
Anchoa mitchilli (bay anchovy)	1	2
Stellifer lanceolatus (star drum)	2	1
Leiostomus xanthurus (spot)	3	5
Micropogonias undulatus (Atlantic croaker)	4	3
Cynoscion regalis (weakfish)	5	8
Bairdiella chrysoura (silver perch)	6	7
Urophycis regius (spotted hake)	7	9
Ictalurus catus (white catfish)	8	11
Brevoortia tyrannus (Atlantic menhaden)	9	4
Symphurus plagiusa (blackcheek tonguefish)	10	6
% of total number	95.4	90.0

Table II-17. Rank by abundance of numerically dominant decapods collected by trawl at five index sites in the harbor basin and Cooper River during the periods 1980-1985 (SCWMRD unpublished data) and 1973-1977 (Wenner et al 1984).

Rank by abundance	1984-88	1973-77
Penaeus setiferus (white shrimp)	1	1
Penaeus aztecus (brown shrimp)	2	2
Trachypenaeus constrictus (roughneck)	3	6
Palaemonetes vulgaris (grass shrimp)	4	7
Callinectes sapidus (blue crab)	5	4
Callinectes similis (lesser blue crab)	6	5
Penaeus duorarum (pink shrimp)	7	12
Rhithropanopeus harrisii (mud crab)	8	14
% of total number	92.5	95.7

revisited from 1984 to 1988 using similar, although not identical, sampling techniques (Van Dolah et al. 1989). Comparisons of the numerically dominant finfish species (Table II-16) and decapod crustaceans (Table II-17) collected in 1984 versus 1973-1977 indicate very little change in the species composition at these stations. Even after rediversion, the composition of numerically dominant species in the samples collected at these sites was not markedly different (Van Dolah et al. 1989).

LITERATURE CITED

Academy of Natural Sciences of Philadelphia. 1974. Cooper River Survey 1973. Report for E.I. duPont de Numours and Company, Charleston, SC.

Archambault, J.A., E.L. Wenner, and J.D. Whitaker. 1990. Life history and abundance of blue crab, *Callinectes sapidus* Rathburn at Charleston Harbor, South Carolina. *Bulletin of Marine Science* 46:145-158.

Arthur D. Little, Inc. 1974. A summary - Analysis of Environmental Impact of Port Development. Arthur D. Little, Inc., 98 p.

Batson, W.T. 1974. Vascular plant survey of marsh and adjacent highland in selected portions of Cooper River and Wando River. p. 36-40. In F.P. Nelson (ed.), The Cooper River Environmental Study. South Carolina Water Resources Commission Report Number 117, Columbia, SC.

Batson, W.T., and B.C. Blackwelder. 1974. Vertical distribution of epiphytic algae on Spartina alterniflora from transects along the Cooper and Wando rivers. p. 22-35 In F.P. Nelson (ed.), The Cooper River Environmental Study. South Carolina Water Resources Commission Report Number 117, Columbia, SC.

Bears Bluff Laboratories, Inc. 1964. Biological studies of Cooper River system. Bureau of Sports Fisheries and Wildlife, Fish and Wildlife Service, Contract # 14-16-0004-1024.

Bears Bluff Laboratories, Inc., 1965. Biological studies of Price Inlet area from Charleston Harbor to Bulls Bay, South Carolina. Bears Bluff Laboratories, Inc., Wadmalaw Island, SC. 54 p.

Benson, H.A., 1976. Effects of 40-foot Charleston Harbor project on tides, currents, and salinities - Hydraulic model investigation - Final report. Miscellaneous Paper # H-76-9. United States Army Corps of Engineers, Charleston District, Charleston.

Benson, H.A. 1977. Charleston Harbor navigation study, South Carolina verification tests. 119 p. Miscellaneous Paper H-77-4, United States Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Berkeley-Charleston-Dorchester Council of Governments. 1987. Housing market analysis and forecasting. 1985-2005. BCDCOG, Charleston, SC. 28 p.

Berkeley-Charleston-Dorchester Council of Governments, 1988. Water quality management plan. Draft update 2. BCDCOG, Charleston, SC. 104 p.

Bidleman, T.F., W.T. Foreman, M.T. Zaranski, and D.W. Wall. 1984. Baseline studies of petroleum hydrocarbons in Charleston Harbor. Final report to NOAA, Coastal Energy Impact Program, Grant No. CEIP-83-04, Rockville, MD. 30 p.

Bishop, J.M., and M.H. Shealy, Jr. 1977. Biological observations on commercial Penaeid shrimps caught by bottom trawl in South Carolina estuaries, February 1973 - January 1975. South Carolina Marine Wildlife and Marine Resources, Charleston, SC.

Bollinger, G.A. 1975. A catalog of southeastern United States earthquakes 1754 through 1974.Bulletin 101. Department of Geological Sciences, Virginia Polytechnical Institute and State University, Blacksburg, VA. 68 p.

Box, G.E.P. and G.M. Jenkins. 1976. Time Series Analysis: Forecasting and Control. Holden-Day, Inc., Oakland, CA.

Calder, D.R. and B.B. Boothe, Jr. 1977a. Data from some subtidal quantitative benthic samples taken in estuaries of South Carolina. South Carolina Marine Resources Center, Data Report Number 3, Charleston, SC. 35 p.

Calder, D.R. and B.B. Boothe, Jr. 1977b. Some subtidal epifaunal assemblages in South Carolina estuaries. South Carolina Marine Resources Center Data Report Number 4, Charleston, SC. 54 p.

Carter, H.S. 1970. Georgia Temperatures. Georgia Agricultural Experimental Station, Research Report Number 69, Athens, GA. 53 p.

Chestnut, D. 1989. A Review of Charleston Harbor Water Quality Data 1974-1987. South Carolina Department of Health and Environmental Control Technical Report Number 002-89, Columbia, SC. 46 p.

Cleveland, W.S. 1979. Robust locally weighted regression and smoothing scatterplots. *Journal of the American Statistical Association* 74:829-836.

Colquhoun, D.J. and H.S. Johnson, Jr. 1968. Tertiary sea-level fluctuation in South Carolina. *Palaeogeography, Palaeoclimatology and Palaeoecology* 5:105-126.

Colquhoun, D.J. 1969. Geomorphology of the lower Coastal Plain of South Carolina. MS-15. Division of Geology. South Carolina State Development Board, Columbia, SC. 36 p.

Colquhoun, D.J. 1972. Charleston Harbor, South Carolina, estuarine values study. United States Army Corps of Engineers, Charleston District, Contract No. DACW 60-71-C-007, Charleston, SC. 51 p.

Cooke, C.W. 1936. Geology of the Coastal Plain of South Carolina. 196 p. U.S. Geological Survey Bulletin 867. United States Government Printing Office, Washington, DC.

Cooke, W.C. and F.S. MacNeil. 1952. Tertiary stratigraphy of South Carolina. p. 19-29. *In* Geological Survey Paper 243-B, U.S. Government Printing Office, Washington, DC.

Curtis, T.A. 1976. Anadromous fish survey of the Santee and Cooper rivers. Annual Progress Report. South Carolina Wildlife and Marine Resources Department, Division of Game and Freshwater Fisheries, Columbia, SC. 27 p.

Dames and Moore Company. 1975. Environmental assessment report proposed chemical plant Berkeley County, South Carolina. Prepared for Amoco Chemicals Corporation, Charleston, SC.

Davis, J.S., M.D. McKenzie, J.V. Miglarese, R.H. Dunlap, J.J. Manzi, and L.A. Barclay. 1980. Ecological Characterization of the Sea Island Coastal Region of South Carolina and Georgia: Resource Atlas. United States Fish and Wildlife Service, Washington, D.C.

Duncan, R.E., 1975. Wando River aerial imagery and marsh productivity study. South Carolina Water Resources Commission Report Number 120, Columbi, SC.

Dunn, G.E. and B.I. Miller. 1960. Atlantic hurricanes. Louisiana State University Press, Baton Rouge, LA. p. 326

Enwright Laboratories, Inc. 1977. Arthur Williams station 316(a) and (b). Demonstration Project. Report to South Carolina Electric and Gas, Columbia, SC. 184 p.

Enwright Laboratories, Inc. 1984. South Carolina State Ports Authority Wando River Terminal Environmental Monitoring. South Carolina State Ports Authority, Charleston, SC. 47 p.

Federal Water Pollution Control Administration. 1966. A report on the water quality of Charleston Harbor and the effects thereon of the proposed Cooper River rediversion. United States Army Corps of Engineers, Charleston District, Charleston, SC. 80 p.

Gallagher, J.J. 1963. Field Report, Cooper River, Charleston, S.C., Dye Dispersal Tests. . Marine Sciences Department, U.S. Naval Oceanographic Office, Washington, DC. 52 p

Gibson, H.E., 1974. Charleston Area Sediment Samples, January 2, 1973.p. 105-118. In F.P. Nelson, (ed.), The Cooper River Environmental Study. South Carolina Water Resources Commission Report, Number 117, Columbia, SC.

Goodwin, M.H. 1989. The Charleston Harbor Estuary: Historic, geographic and socio-economic setting. p. 7-12. NOAA Estuary of the Month Seminar Series No. 16, Charleston Harbor: Issues, Resources, Status, and Management.

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

Hicks, S.D. 1978. An average geopotential sea level series for the United States. *Journal of Geophysical Research* 85:1377-1379.

Ho, F.P. 1974. Storm Tide Frequency Analysis for the Coast of Georgia. National Weather Service, Office of Hydrology, Silver Spring, MD. 28 p.

Hoffman, J.S., D. Keyes, and J.G. Titus, 1983. Projecting future sea level rise: Methodology, estimates to the year 2100 and research needs. Environmental Protection Agency Document #23-09-007, Washington, DC. 121 p.

Hoffman, J.S., J.R. Wells, and J.G. Titus. 1985. Future global warming and sea level rise. In Sigbjarnarson, (ed.), Iceland Coastal and River Symposium, Proceedings. Library of National Energy Authority, Reykjavik, Iceland. p. 245-266.

Hoss, D.E., L.C. Coston, and W.E. Schaaf. 1973. Effectes of dredged harbor sediments on larval estuarine fish common to Charleston Harbor, South Carolina.United States Army Corps of Engineers, Charleston, SC. 31 p.

Jensen, J.R., and B. Davis. 1986. Remote sensing of aquatic macrophyte distribution in selected South Carolina reservoirs. Department of Geography, University of South Carolina, Columbia, SC. 27 p.

Jones, Edmunds and Associates. 1983. South Carolina State Ports Authority Wando River Terminal Environmental Monitoring. South Carolina State Ports Authority, Charleston, SC. 57 p.

Kana, T.W., J. Michel, M.O. Hayes, and J.R. Jensen. 1984. The physical impact of sea level rise in the area of Charleston, South Carolina. In M. Barth and J. Titus, eds., Greenhouse Effect and Sea Level Rise: A Challenge for this Generation, Van Nostrand Reinhold Company, NY. p. 105-150.

Kana, T.W., B.J. Baca, and M.L. Williams,.1986. Potential impacts of sea level rise on wetlands around Charleston, South Carolina. United States Environmental Protection Agency, Document # 203-10-85-014, Washington, DC. 65 p.

Kelly, B.J. Jr., R.D. Porcher, and Y. Michel. 1990. Chapter X: Macrophyte vegetation of freshwater tidal marsh in the Cooper River. p 384-402. In R.F. Van Dolah, P.H. Wendt, and E. L. Wenner (eds.), A Physical and Ecological Characterization of the Charleston Harbor Estuarine System. Final report submitted to the South Carolina Coastal Council under grant No. NA87AA-D-CZ068. 634 p.

Kjerfve, B. 1976. The Santee-Cooper: A study of estuarine manipulations. P. 44-56. In M. Wiley (ed.), Estuarine Processes, Vol. 1. Academic Press, New York.

Kjerfve, B., and K. E. Magill. 1990. Salinity changes in Charleston Harbor 1922-1987. *Journal of Waterway, Port, Coastal and Ocean Engineering*. 616(2): 153-168.

Ludlum, D.M.. 1963. Early American hurricanes. American Meteorological Society, Boston, MA. 198 p.
Malde, H.E. 1959. Geology of the Charleston Phosphate Area, South Carolina. Geological Survey Bulletin 1079, U.S. Government Printing Office, Washington, D.C.

Mathews, T.D., and M.H. Shealy. 1978. Hydrography of South Carolina estuaries, with an emphasis on the North and South Edisto and Cooper Rivers. South Carolina Marine Resources Research Instituts, Technical Report No. 30, Charleston, SC.

Mathews, T.D., F.W. Stapor, C.R. Richter, J.V. Miglarese, M.D. McKenzie, and L.A. Barclay. 1980. Ecological Characterization of the Sea Island Coastal Region of South Carolina and Georgia: Volume I: Physical Features of the Characterization Area. United States Fish and Wildlife Service, Washington, DC. 212 p.

Mathews, T.D., and M.H. Shealy. 1982. A description of the salinity regimes of major South Carolina estuaries. South Carolina Marine Resources Research Center, Technical Report No. 54, Charleston, SC.

National Oceanic and Atmospheric Administration. 1972. Tide tables, high and low water predictions, 1973, east coast of North and South America including Greenland. National Ocean Survey, United States Department of Commerce, Rockville, MD.

National Oceanic and Atmospheric Administration, 1978. Tide tables, high and low water predictions, 1979, east coast of North and South America including Greenland. National Ocean Survey, United States Department of Commerce, Rockville, MD.

National Oceanic and Atmospheric Administration. 1983. Tide tables, high and low water predictions, 1984, east coast of North and South America including Greenland. National Ocean Survey, United States Department of Commerce, Rockville, MD.

National Oceanic and Atmospheric Administration. 1984. Baseline studies of petroleum hydrocarbons in Charleston Harbor.Final report to NOAA, Coastal Energy Impact Program, Grant No. CEIP-83-04, Rockville, MD. 30 p.

National Oceanic and Atmospheric Administration. 1985. National estuarine inventory - Data atlas - Volume I - Physical and Hydrologic Characteristics. United States Department of Commerce, NOAA, Washington, DC.

National Oceanic and Atmospheric Administration. 1986. Marine Environmental Assessment, Southeastern United States. NOAA, Marine Assessment Branch, Marine Environmental Assessment Division, Rockville, MD. 134 p.

National Oceanic and Atmospheric Administration. 1988. National Status and Trends Program for Marine Environmental Quality. Progress Report. A Summary of Selected Data on Chemical Contaminants in Sediments Collected During 1984, 1985, 1986, 1987. NOAA Technical Memorandum NOS OMA44, Rockville, MD. 15 p.

Neiheisel, J. 1959. Littoral drift in vicinity of Charleston Harbor. *American Society of Chemical Engineers Proceedings* 85:99-113.

Neiheisel, J., and C.E. Weaver. 1967. Transport and deposition of clay minerals in southeastern United States. *Journal of Sedimantary Petrology* 37:1084-1116.

Nelson, F.P. 1974. Cooper River Environmental Study. South Carolina Water Resources Commission Report Number 117, Columbia, SC. 164 p.

Project Eutro. 1974. Report on "in situ" Benthic Respiration and Vertical Oxygen:Temperature Profiles. In F.P. Nelson, (ed.), The Cooper River Environmental Study.South Carolina Water Resources Commission Report Number 117, Columbia, SC. p. 52-61.

Purvis, J.C., and H. Landers. 1973. South Carolina Hurricanes: or a Descriptive Listing of Tropical Cyclones that have affected South Carolina. South Carolina Disaster Preparedness Agency, Columbia, SC. 52 p.

Purvis, J.C., and E. Rampey. 1975. Weather Extremes in South Carolina. South Carolina Disaster Preparedness Agency, Columbia, SC. 5 p.

Rankin, D.W. 1977. Studies related to the Charleston, South Carolina, earthquake of 1886 - a preliminary report. Geological Survey Professional Paper 1028. United States Government Printing Office, Washington. 204 p.

Ringold, P.L., and J. Clark, 1980. The Coastal Almanac. W.H. Freeman and Company, San Francisco, CA. 172 p.

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. Volume III. Biological features of the characterization area. United States Fish and Wildlife Service, Charleston, SC. 620 p.

Settlemyre, J.L., and L.R. Gardner. 1975. Chemical and sediment budgets for a small tidal creek, Charleston Harbor, South Carolina. Water Resources Research Institute, Clemson University, Report Number 57, Clemson, SC. 56 p.

Shealy, M.H., J.V. Miglarese, and E.B. Joseph. 1974. Bottom fishes of South Carolina estuaries relative abundance, seasonal distribution, and length-frequency relationships. South Carloina Marine Resources Center Technical Report Number 6, Charleston, SC. 189 p.

Shealy, M.H., and J.M. Bishop. 1977. Environmental baseline study of South Carolina estuaries. South Carolina Marine Resources Center, Annual report to Coastal Plains Contract 10340031, Charleston, SC. 8 p.

Simmons, H.B. 1965. Tidal and salinity model practice. In A.T. Ippen, (ed.), Estuarine and coastal hydrodynamics, p. 711-731. McGraw Hill, New York.

Sokal, R.R., and F.J. Rohlf. 1981. Biometry. W.H. Freeman and Compahy, New York. 859 p.

South Carolina Budget and Control Board. 1984. South Carolina Statistical Abstract. South Carolina Division of Research and Statistical Services, Columbia, SC. 371 p.

South Carolina Department of Health and Environmental Control. 1970. Environmental quality control and coastal zone management. SCDHEC, Columbia, SC. 36 p.

South Carolina Department of Health and Environmental Control. 1975. Santee-Cooper River Basin water quality management plan. SCDHEC, Columbia, SC. 469 p.

South Carolina Department of Health and Environmental Control. 1976. South Carolina State Monitoring Strategy FY1977. SCDHEC Technical Report Number 002-76, Columbia, SC. 88 p.

South Carolina Department of Health and Environmental Control. 1985a. Prohibited areas for the taking of shellfish January, 1985.SCDHEC, Columbia, SC. 25 p.

South Carolina Department of Health and Environmental Control. 1985b. Water classifications and standards. Classified waters. State of South Carolina. SCDHEC, Columbia, SC. 58 p.

South Carolina Water Resources Commission. 1973. Wando River environmental quality studies, An interim report. SCWRC, Columbia, SC. 115 p.

South Carolina Water Resources Commission. 1975. Population inventory by counties, river basins and sub-basins in South Carolina. SCWRC, Report No. 121, Columbia., SC. 69 p.

South Carolina Water Resources Commission. 1979. Cooper River controlled low-flow study. SCWRC Technical Report Number 131, Columbia, SC. 353 p.

South Carolina Water Resources Commission, 1980. Water quality and aquatic vegetation in the Back River Reservoir, Berkeley County, South Carolina. SCWRC Technical Report Number 130, Columbia, SC. 62 p.

South Carolina Wildlife and Marine Resources Department. 1972. A study of the Charleston Harbor estuary with special reference to deposition of dredged sediments. United States Army Corps of Engineers, Charleston District, Contract No. DACW 60-71-C-0014, Charleston, SC.

Stalter, R. 1974. The Vegetation of the Cooper River Estuary. In F.P. Nelson, (ed.), The Cooper River Environmental.Study. South Carolina Water Resources Commission Report Number 117, Columbia, SC. p. 41-45.

Stender, B.W. and R.M. Matore. 1990. Chapter VIII: Finfish and invertebrate communities. p. 241-287. In: R.F. Van Dolah, P.H. Wendt, and E. L. Wenner (eds.), A Physical and Ecological Characterization of the Charleston Harbor Estuarine System. Final report submitted to the South Carolina Coastal Council under grant No. NA87AA-D-CZ068. 634 p.

Sugg, A.L., and R.L. Carrodus. 1969. Memorable Hurricanes of the United States Since 1873. National Weather Bureau, Scientific Services Division, Southeastern Region Headquarters, Fort Worth, TX. 50 p.

Taber, S. 1939. Geology of the Santee-Cooper Project. South Carolina Public Service Authority, Columbia, SC. 21 p.

Tiner, R W.,1977. An inventory of South Carolina's coastal marshes. South Carolina Wildlife and Marine Resources Department, Technical Report Number 23, Charleston, SC. 33 p.

Titus, J.G. 1986. Greenhouse effect, sea level rise, and coastal zone management. *Coastal Zone Management Journal* 14:147-171.

Turner, W.R., and G.N. Johnson. 1974. Standing crops of aquatic organisms in tidal streams of the lower Cooper River system, South Carolina. In: F.P. Nelson, (ed.), The Cooper River environmental study. South Carolina Water Resources Commission Report Number 1137 Columbia, SC. p. 13-20.

United States Department of the Interior. 1966. A report on the water quality of Charleston Harbor and the effects of the proposed Cooper River rediversion. Federal Water Pollution Control Administration, USDOI, Washington, DC. 90 p.

United States Army Corps of Engineers. 1954. Investigation for reduction of maintenance dredging in Charleston Harbor, S.C. Prototype Investigation. Part 2: Materials testing laboratory investigation of properties of shoals and materials in motion. USACOE, Charleston District, Charleston, SC. 22 p.

United States Army Corps of Engineers. 1957a. Investigation for reduction of maintenance dredging in Charleston Harbor, South Carolina, Summary report of model investigation, Appendix 1 - Subsidiary Model Tests. Technical Report # 2-444 - Volume III-1, USACOE, Waterways Experiment Station, Vicksburg, MS.

United States Army Corps of Engineers. 1957b. Investigation for reduction of maintenance dredging in Charleston Harbor, South Carolina. Appendix 2. Technical Report 2-444, Volume III-2-1. USACOE, Waterways Experiment Station, Vicksburg, MS.

United States Army Corps of Engineers. 1957c. Investigation for reduction of maintenance dredging in Charleston Harbor, South Carolina. Appendix 3 - Flow pattern photographs. Technical Report 2-444, Volume III-3. USACOE, Waterways Experiment Station, Vicksburg, MS.

United States Army Corps of Engineers. 1957d. Investigation for reduction of maintenance dredging in Charleston Harbor, South Carolina. Technical Report 2-444, USACOE, Waterways Experiment Station, Vicksburg, MS.

United States Army Corps of Engineers. 1958. Prototype confirmation of model investigation, Charleston Harbor, South Carolina - First interim report. Miscellaneous Paper # 2-299, USACOE, Waterways Experiment Station, Vicksbur, MS.

United States Army Corps of Engineers. 1966a. Charleston Harbor, South Carolina: A review of certain aspects of plans for rediverting Santee-Cooper power plant discharges from Cooper River. Committee on Tidal Hydraulics, USACOE, Washington, DC. 30 p.

United States Army Corps of Engineers. 1966b. Survey Report on Cooper River, S. C. (Shoaling in Charleston Harbor). Appendix A. Special geologic investigations utilizing diagnostic minerals.USACOE, Charleston. 30 p.

United States Army Corps of Engineers. 1966c. Survey report on the Cooper River, S. C. (Shoaling in Charleston Harbor). Appendix B. Spoil Disposal. USACOE, Charleston District, Charleston, SC.

United States Army Corps of Engineers. 1972. Charleston Harbor, South Carolina Estuarine values study. USACOE, Charleston District, Charleston, SC. 53 p.

United States Army Corps of Engineers. 1975. Final environmental impact statement, Cooper River rediversion project, Charleston Harbor, South Carolina. USACOE, Charleston District, Charleston, SC.

United States Army Corps of Engineers. 1976. Maintenance Dredging of Atlantic Intracoastal Waterway, South Carolina. Final Environmental Statement. USACOE, Charleston District, Charleston, SC. 94 p.

United States Army Corps of Engineers. 1977. Water Resources Development by the U.S. Army Corps of Engineers in Georgia. USACOE, South Atlantic Division, Atlanta, GA. 111 p.

United States Department of Commerce,.1967. Tidal Current Charts: Charleston Harbor, SC. Environmental Sciences Service Administration, Coastal and Geodetic Survey, Rockville, MD. 25 p.

United States Environmental Protection Agency. 1974. Water Quality Portion of the Cooper River Environmental Study. In F.P. Nelson, (ed.), The Cooper River Environmental Study. South Carolina Water Resources Commission Report Number 117, Columbia, SC. p. 64-103.

Van Dolah, R.F., R.M. Martore, and K.B. Davis. 1989. Charleston Harbor's Living Resources: A Review of Conditions Following Rediversion.Proceedings of Sixth Symposium on Coastal and Ocean Management, ASCE, July 11-14, 1989, Charleston, SC.. p 2628-2639.

Van Dolah, R.F., P.H. Wendt, and E.L. Wenner. (eds.) 1990. A Physical and Ecological Characterization of the Charleston Harbor Estuarine System. Final report submitted to the South Carolina Coastal Council under grant no. NA87AA-D-CZ068. 634 p.

Van Nieuwenhuise, D.S., J.M. Yarus, R.S. Przygocki, and R. Ehrlich. 1978. Sources of shoaling in Charleston Harbor, Fourier grain shape analysis. *Journal of Sedimentary Petrology* 48:373-383.

Velleman, P.F., and D.C. Hoaglin. 1981. Applications, Basics, and Computing of Exploratory Data Analysis. Duxburg Press, Belmont, CA.

Wendt, P.H. and R.F. Van Dolah. 1990. Chapter VII: Benthic macrofaunal communities. p 149-239. In R.F. Van Dolah, P.H. Wendt, and E. L. Wenner (eds.), A Physical and Ecological Characterization of the Charleston Harbor Estuarine System. Final report submitted to the South Carolina Coastal Council under grant No. NA87AA-D-CZ068. 634 p.

Wenner, E.L., W.P. Coon, M.H. Shealy Jr., and P.A. Sandifer. 1984. A five-year study of seasonal distribution and abundance of fishes and decapod crustaceans in the Cooper River and Charleston Harbor, South Carolina, prior to diversion. NOAA Technical Report, NMFS SSRF-782, Washington, DC. 16 p.

Wenner, E.L., J. Archambault, and J. Boylan. 1990. Chapter IX: Recruitment of fishes and decapod crustaceans into nursery habitats. p. 289-383. In R.F. Van Dolah, P.H. Wendt, and E. L. Wenner (eds.), A Physical and Ecological Characterization of the Charleston Harbor Estuarine System. Final report submitted to the South Carolina Coastal Council under grant No. NA87AA-D-CZ068. 634 p.

Westvaco. 1971. A summary of biological studies of the Cooper River and adjacent waters in the vicinity of Charleston, South Carolina, 1967-1971. Westvaco Corporation, Charleston, SC. 72 p.

Williams, J.B. 1984. Final Report. An ecological study of the Cooper River prior to rediversion for Cooper River Water Users Association Charleston, South Carolina. Department of Environmental Health Sciences, University of South Carolina, Columbia, SC. 243 p.

Wilmont, W.L., and R.G. Williams. 1987. Charleston Harbor Oceanography Project. Phase I: Quality Assurance of NOS Tide and Tidal Current Predictions. NOAA, National Ocean Survey, Office of Oceanography and Marine Assessment, Rockville, MD. 70 p.

Wilmont, W.L. 1988. Charleston Harbor Oceanography Project. Phase 2: Plan. NOAA, National Ocean Survey, Office of Oceanography and Marine Assessment, Rockville, MD. 15 p.

Additional References

Abernathy, A.R. 1979. Heavy metal contamination of surface waters and fish flesh in South Carolina. Water Resources Research Institute, Clemson University, Report Number 74, Clemson. 119 p.

Armentano, T.V., R.A. Park, and C.L. Cloonan. 1986. Draft Report. The effect of future sea level rise on U.S. coastal wetland areas. United States Environmental Protection Agency, Contract # 68-01-6614, Subcontract # EPA29-54(A), Washington, D.C. 100 p.

Aull, J.L., and D.A. Duncan. 1967. South Carolina supplemental interim report on water resources for designated SC Appalachia area. South Carolina Water Resources Commission, Columbia, SC. 105 p.

Bearden, C.M. 1961. Notes on postlarvae of commercial shrimp (*Penaeus*) in South Carolina.Contributions of Bears Bluff Laboratory Number 33, Wadmalaw Island, SC. 8 p.

Bearden, C.M. 1963. A contribution to the biology of king whitings, genus *Menticirrhus*, of South Carolina. Contributions of Bears Bluff Laboratory Number 38, Wadmalaw Island, SC. 27 p.

Bearden, C.M. 1964. Distribution and abundance of Atlantic croaker, *Micropogonias undulatus*, in South Carolina. Contributions of Bears Bluff Laboratory Number 40, Wadmalaw Island, SC. 23 p.

Bearden, C.M., and D.M. McKenzie, no date. A guide to saltwater sport fishing in South Carolina. South Carolina Wildlife and Marine Resources Department, Charleston, SC. 118 p.

Belle W. Baruch Coastal Research Institute. 1973. Bioassay studies, Charleston Harbor, South Carolina: The effects of dredging harbor sediments on plankton. United States Army Corps of Engineers, Charleston District, Contract No. DACW 60071-C-0009.

Bennett, C.S., R.D. Hayes, J.W. Gissendanner, and K.H. Jones. 1984. Water resources data, South Carolina, Water year 1984. United States Geological Survey water-data report, SC-84-1, Columbia, SC. 392 p.

Berkely-Charleston-Dorchester Regional Planning Council. 1975. A study of the population and economy of the Berkely-Charleston-Dorchester Region. National Technical Information Service, Springfield, VA. 93 p.

Bloxham, W.M. 1981. Low-flow characteristics of ungaged streams in the Piedmont and Lower Coastal Plain of South Carolina. South Carolina Water Resources Commission, Report No. 14, Columbia, SC. 48 p.

Bloxham, W.M. 1976. Low-flow characteristics of streams in the Inner Coastal Plain of South Carolina. South Carolina Water Resources Commission, Report No. 5, Columbia, SC. 31 p.

Bloxham, W.M. 1979. Low-flow frequency and flow duration of South Carolina streams. South Carolina Water Resources Commission, Report No. 11, Columbia, SC. 90 p.

Board of Engineers for Rivers and Harbors, War Department. 1940. The Port of Charleston, South Carolina. Port Series No. 9, United States Government Printing Office, Washington, D.C. 163 p.

Burrell, V.G., Jr. 1977. Mortalities of oysters and hard clams associated with heavy runoff in the Santee River system, South Carolina, in the spring of 1975. *Proceedings of the National Shellfish Association* 67: 35-43.

Calder, D.R. 1976. The zonation of hydroids along salinity gradients in South Carolina estuaries. In G.O. Mackie, (ed.), Coelenterate ecology and behavior. Plenum Press, New York, NY. p. 165-174

Calder, D.R., B.B. Boothe, Jr., and M.S. Maclin. 1977. A preliminary report on estuarine macrobenthos of the Edisto and Santee River systems, South Carolina. South Carolina Marine Resources Center Technical Report Number 22, Charlesto, SC. 50 p..

CH2M Hill and Betz Environmental Engineers, Inc. 1978. Berkeley - Charleston, Dorchester Council of Governments 208 Areawide Waste Treatment Management Plan. BCDCOG, Charleston, SC.

Chesley, S.C. 1982. Coastal summaries: A SCWRC source book. South Carolina Water Resources Commission Report Number 135, Columbia, SC. 194 p.

Chigges, J.A., and M.G. Taylor. 1981. Low flow verification of the Charleston Harbor Dynamic Estuary Model: salinity simulation following the Cooper River Rediversion Project. South Carolina Department of Health and Environmental Control, Environmental Analysis Division, Report Number EA81-01, Columbia, SC.

Coleman, F.D., and J.A. Dennis. 1974. Inventory of lakes in South Carolina ten acres or more in surface area. South Carolina Water Resources Commission Report Number 119, Columbia, SC. 221 p.

Crabtree, R.E., J.M. Bishop, and M.H. Shealy, Jr. 1976. Abundance of the white shrimp, *Penaeus setiferus* (Linnaeus), in relation to bottom salinity and temperature in South Carolina estuaries. *Bulletin of the South Carolina Academy of Science* 38:104, Abstract.

Curtis, T.A. 1971. Anadromous fish survey of the Santee and Cooper Riverrs. Job Progress Report. South Carolina Wildlife and Marine Resources Department, Columbia, SC. 57 p.

Curtis, T.A. 1972. Anadromous fish survey of the Santee and Cooper Riverrs. Job Progress Report. South Carolina Wildlife and Marine Resources Department, Columbia, SC. 40 p.

Curtis, T.A. 1973. Anadromous fish survey of the Santee and Cooper Riverrs. Annual Progress Report.South Carolina Wildlife and Marine Resources Department, Division of Game and Freshwater Fisheries, Columbia, SC. 44 p.

Curtis, T.A. 1974. Anadromous fish survey of the Santee and Cooper Riverrs. Job Progress Report. South Carolina Wildlife and Marine Resources Department, Columbia, SC 54 p.

Curtis, T.A. 1975. Anadromous fish survey of the Santee and Cooper Riverrs. Annual Progress Report. South Carolina Wildlife and Marine Resources Department, Division of Game and Freshwater Fisheries, Columbia, SC. 31 p.

Dowgiallo, J.M., I.C. Sheifer, F.G. Everdale, K.B. Pechman, M.C. Predoehl, and T.W. Waltz. 1987. Marine environmental assessment, Southeastern United States: Annual summary. United States Department of Commerce, NOAA, Washington, D.C. 134 p.

Eldridge, P.J., W. Waltz, and H. Mills. 1976. Relative abundance of *Mercenaria mercenaria notata* in estuaries in South Carolina. *Veliger* 18: 396-397.

Enwright Laboratories, Inc. 1980. A ten day solid phase bioassay test of Wando River sediments with polychaete worms (*Neries virens*). Report to the South Carolina State Ports Authority, Charleston, SC. 8 p.

Goldstein, A.K., and J.J. Manzi. 1976. Additions to the freshwater algae of South Carolina. *Journal of the Elisha Mitchell Scientific Society* 92: 9-13.

Gornitz, V., S. Lebedeff, and J. Hansen. 1982. Global sea level trend in the past century. *Science* 215:1611-1614.

Gresham, C.A., and D.D. Hook. 1982. Rice fields of South Carolina: A resource inventory and management policy evaluation. *Coastal Zone Management Journal* 9:183-203.

Hammond, D.L., and D.M. Cupka. 1977. An economic and biological evaluation of the South Carolina pier fishery. South Carolina Marine Resources Center Technical Report Number 20, Charleston, SC. 14 p.

Harder, H.,1977. Distribution and ecology of polychaetous annelids in estuaries of South Carolina. M.S. Thesis, College of Charleston, Charleston, SC

Harris, K.F. 1962. Chemical character of surface waters of South Carolina, 1945-60. South Carolina State Development Board, Bulletin Number 16C, Columbia, SC. 123 p.

Hester, B.S. 1976. Distribution and seasonality of hydromedusae in South Carolina estuaries. M.S. Thesis, College of Charleston, Charleston, SC.

Hite, J.C., and J.M. Stepp. 1969. Economic analysis of the development potential of the commercial fisheries of the coastal plains region. Clemson University Economics of Marine Resources Bulletin Number 1, Clemson, SC. 78 p.

Interstate Electronics Corporation. 1969. Case study report, Charleston Harbor, South Carolina. Interstate Electronics Corporation, Oceanics Division, Anaheim.

Jones, Edmunds and Associates. 1979. Results of bioassay evaluations of sediments from the Wando River. South Carolina State Ports Authority, Charleston, SC. 10 p.

Kelly, S.T. 1973. Coastal Zone Water Quality Monitoring: Charleston Harbor. Interstate Electronics Corporation, Anaheim, CA.

Kimsey, C.P., Jr., L.E. Turner, and J.N. Knox. 1982. The Environmental Status of South Carolina's Barrier Islands. South Carolina Department of Health and Environmental Control Publication Number 020-82, Columbia, SC. 130 p.

Lagman, L.H., F.P. Nelson, and G.E. Richardson. 1980. Water quality and aquatic vegetation in the Back River Reservoir, Berkely County, South Carolina.Report Number 130, South Carolina Water Resources Commission, Columbia, SC. 62 p.

Lonon, G.E. 1983. Water Use in South Carolina. 1980. South Carolina Water Resources Commission, Columbia, SC. 20 p.

Lovingood, P.E., and J.C. Purvis. 1972. The nature of precipitation, South Carolina, 1941-1970.University of South Carolina, Columbia, SC. 45 p.

Lunz, G.R., J.T. Penney, and T.P. Lesesne. 1944. Special study of the marine fishery resources in South Carolina.. South Carolina State Planning Board bulletin number 14, Columbia, SC. 61 p

Lunz, G.R.,1964. Biological studies of Cooper River system.Bears Bluff Laboratory Report, Contract Number 14-16-0004-1024 to United States Fish and Wildlife Service, Washington, D.C. 18 p.

Lunz, G.R., and F.J. Schwartz. 1970. Analysis of eighteen year trawl captures of seatrout (*Cynoscion* sp: Sciaenidae) from South Carolina. Contributions of Bears Bluff Laboratory Number 53, Wadmalaw Island, SC. 29 p.

Martin, D.P. 1970. Santee-Cooper comprehensive development plan. Technical Report # 248, Wilbur Smith and Associates, Inc., Columbia, SC. 115 p.

Mathews, T.D., M.H. Shealy, Jr., and N. Cummings. 1981. Hydrography of South Carolina estuaries, with an emphasis on the North and South Santee and Charleston Harbor Cooper River estuaries. South Carolina Marine Resources Center Technical Report Number 47, Charleston, SC. 128 p.

McCloskey, L.R. 1970. The dynamics of the community associated with a marine scleractinian coral. *Int. Rev. Gesamten Hydrobiol.* 55:13-81.

McDonald, J.E. 1963. Soil resources for an expanding population: James Island, Charleston County, South Carolina. United States Department of Agriculture, Soil Conservation Service, Columbia, SC. 37 p.

McKellar, H.N., M. Homer, L. Pearstine, and W. Kitchens. 1981. Preliminary analysis of energy flow impacts of a river rediversion. In W.J. Mitsch and R.W. Bosserman, (eds.), Energey and ecological modeling. Elseiver, Amsterdam.

McMillan, C.W., M.H. Shealy, Jr., and J.V. Miglarese. 1975. Occurrence of Atlantic croaker (*Micropogonias undulatus*) in relation to bottom salinity and temperature in South Carolina estuaries. *Bulletin of the South Carolina Academy of Sciences*, 37: 84, Abstract.

Meade, R.H. 1969. Landward transport of bottom sediments in estuaries of the Atlantic Coastal Plain. *Journal of Sedimentary Petrology* 39:222-234.

Miglarese, J.V., B.S. Anderson, and W.D. Chamberlain. 1979. Ecological characterization of the sea island coastal region of South Carolina and Georgia. Directory of information sources. United States Fish and Wildlife Service, Charleston Office, Charleston, SC. 35 p.

Miglarese, J.V., and P. S. Sandifer. 1982. An ecological characterization of South Carolina wetland impoundments. South Carolina Marine Resources Research Institute, Technical Report Number 51.

Moore. C.J. no date. A recreational guide to oystering, clamming, shrimping and crabbing in South Carolina. South Carolina Wildlife and Marine Resources Department, Charleston, SC. 60 p.

Moore, C.J., H. Mills, and D. Cupka. 1984. Recreational shellfish gathering in South Carolina 1980-81. South Carolina Marine Resources Center Technical Report Number 37, Charleston, SC. 8 p.

National Oceanic and Atmospheric Administration. 1986. Marine Environmental Assessment, Southeastern United States. NOAA, Marine Assessment Branch, Marine Environmental Assessment Division, Rockville, MD. 134 p.

Olmi, E.J., III, J.M. Bishop, and M.H. Shealy, Jr. 1977. Abundance and distribution of adult blue crabs, *Callinectes sapidus* Rathbun, in relation to bottom salinity and water temperature. *Bulletin of the South Carolina Academy of Sciences* 39:58, Abstract.

Park, R.A., M.S. Trehan, P.W. Mausel, and R.C. Howe. 1988. The Effects of Sea Level Rise on U.S. Coastal Wetlands. Holcomb Research Institute, Butler University, Indianapolis, IN. 60 p.

Patterson, G.G. 1983. Effect of the proposed Cooper River rediversion on sedimentation in Charleston Harbor, South Carolina. USGS Water Resources Investigations Report 83/4198, Columbia, SC. 65 p.

Pearlstine, L.G. 1983. An energy analysis of environmental and economic impacts of a river rediversion: a case study of the Santee-Cooper Rediversion Project. M.S. Thesis, University of South Carolina, Columbia, SC. 163 p.

Pender, D.R., and R.P. Wilder. 1974. Impact of the State Ports Authority upon the economy of South Carolina. Occasional Studies #6, College of Business Administration, University of South Carolina, Columbia, SC. 120 p.

Purvis, J.C., G. Lonon, M. Perry, and T.R. White. 1983. Monthly rainfall probabilities in South Carolina. South Carolina Water Resources Commission, Climate Report Number G1, Columbia, SC. 31 p.

Reimold, R.J. and M.H. Shealy, Jr., 1976. Chlorinated hydrocarbon pesticides and mercury in coastal finfish from Georgia and South Carolina, 1972-1974. Pesticide Monitoring Journal 9:170-175.

Robinson, S.L., and L.K. Himelright. 1963. An investigation of the pollution into Charleston Harbor. Department of Civil Engineering, The Citadel, Charleston, SC. 34 p.

Rutz, S.B. 1987. Post-rediversion longitudinal water elevation and salinity variability in the Cooper River, SC. Master's Thesis, University of South Carolina, Columbia, SC. 58 p.

Sharp, W.E. 1974. The dilution capacity of small streams in South Carolina. Water Resources Research Institue, Clemson University, Report Number 48, Clemson, SC. 70 p.

Shealy, M.H., Jr. 1974. Bottom trawl data from South Carolina Estuarine Survey Cruises, 1973. South Carolina Marine Resources Center, Data Report Number 1, Charleston, SC.

Shealy, M.H., Jr. 1975. Midwater trawl data from South Carolina Estuarine Survey Cruises (North Edisto, South Edisto, and Cooper rivers), 1973 and 1974. South Carolina Marine Resources Center, Data Report Number 2, Charleston, SC. 64 p.

Simmons, H.B., and F.A. Hermann, Jr. 1972. Effects of man-made works on the hydraulic, salinity, and shoaling regimes of estuaries. *Geological Society of America*, Memoirs 133:555-570.

South Carolina Budget and Control Board. 1984. South Carolina Statistical Abstract. South Carolina Division of Research and Statistical Services, Columbia, SC. 371 p.

South Carolina Department of Health and Environmental Control. 1978. Prohibited areas for the taking of shellfish September, 1978. SCDHEC, Columbia, SC. 25 p.

South Carolina Pollution Control Authority. 1972. South Carolina water pollution control state program plan.South Carolina Pollution Control Authority, Columbia, SC. 156 p.

South Carolina State Climate Office. 1982-1986. Palmetto State Climate Summarys. South Carolina State Climate Office, Columbia, SC.

South Carolina Water Resources Research Commission. 1970. South Carolina Tidelands Report. SCWRC, Columbia, SC. 178 p.

South Carolina Water Resources Commission. 1971. Water use in South Carolina, 1970. SCWRC, Columbia, SC. 113 p.

South Carolina Water Resources Commissio., 1972. "ACE" framework study, Ashley-Combahee-Edisto river basin. SCWRC, Columbia, SC. 265 p.

South Carolina Water Resources Commission. 1983. South Carolina State Water Assessment. SCWRC Report Number 140, Columbia, SC. 367 p.

South Carolina Water Resources Commission. 1983. Monthly Rainfall Probabilities in S.C. SCWRC, Columbia, SC. 31 p.

Stamey, B.B., Jr., M.H. Shealy, Jr., and C.R. Richter. 1975. Length-weight relationship for star drum, *Stellifer lanceolatus*, in South Carolina estuaries. *Bulletin of the South Carolina Academy of Sciences* 37:85, Abstract.

Stanley, D.W.,1985. Nationwide review of oxygen depletion and eutrophication in estuarine and coastal waters. Report submitted to Brookhaven National Laboratory, New York.

Steele, W.J., D.H. Higgins, and W.C. Moser. 1973. The Cooper River, Santee-Cooper lakes navigation system. Second interim report. South Carolina Water Resources Commission Technical Report Number 116, Columbia, SC. 66 p.

Sutterfield, S.T., S.R. Pettigrew, and L.H. Lagman. 1977. Volumetric and related characteristics of the Back River Reservoir near Charleston, South Carolina. Report # 124. South Carolina Water Resources Commission, Columbia, SC. 52 p.

Theiling, D. 1978. Catch and effort data for commercial fisheries in South Carolina. Report for NOAA-NMFS for period July 1, 1974 September 30, 1977. Prepared by the South Carolina Wildlife and Marine Resources Department, Charleston, SC. 15 p.

United States Army Corps of Engineers. 1960. The port of Charleston, S.C. USACOE, Port Series Number 13, Part 2, Charleston District, Charleston, SC. 44 p.

United States Army Corps of Engineers. 1962. Survey Report on Cooper River, South Carolina (Rediversion). USACOE, Charleston District, Charleston, SC.

United States Army Corps of Engineers. 1966. Survey report on Cooper River, S. C. (Shoaling in Charleston Harbor). Appendix G. Coordination with other agencies.USACOE, Charleston District, Charleston, SC. 47 p.

United States Army Corps of Engineers. 1974. Draft Environmental Statement. Charleston Harbor Deepening Project. Charleston Harbor and Shipyard River, South Carolina. USACOE, Charleston District, Charleston, SC. 146 p.

United States Army Corps of Engineers. 1983. Cooper River rediversion project. St. Stephens hydroelectric palnt, South Carolina. USACOE, Charleston District, Charleston, SC. 10 p.

United States Department of Health, Education and Welfare. 1965. Ashley River pollution study, Charleston, South Carolina, June-July, 1965. United States Department of Health, Education and Welfare, Public Health Services, Division of Water Supply and Pollution Control, Southeast Water Laboratory, Athens, GA. 18 p.

United States Navy. 1952. A preliminary report on Charleston Harbor and its approaches. U.S. Navy, Hydrographic Office, Inshore Survey Project, Washington, D.C. 9 p.

United States Soil Conservation Service. 1971. Soil survey, Charleston County, South Carolina. United States Department of Agriculture, Soil Conservation Service, Columbia, SC. 77 p.

United States Soil Conservation Service. 1973. Santee River basin water and land resources. United States Department of Agriculture, Economic Research Service, Forest Service, SCS, Washington.

Van Dolah, R.F. 1986. A salinity profile study of the Cooper River at the Naval Weapons Station, Pier X-Ray. Prepared by the South Carolina Marine Resources Center for the Department of the Navy, Charleston Naval Base, Charleston, SC 21 p.

Verona. 1972. Cooper River biological survey. Unpublished report to South Carolina Electric and Gas. SCE&G, Columbia.

Verona. 1973. Cooper River biological survey. Unpublished report to South Carolina Electric and Gas. SCE&G, Columbia.

Verona. 1974. Cooper River biological survey. Unpublished report to South Carolina Electric and Gas. SCE&G, Columbia.

Verona. 1975. Cooper River biological survey. Unpublished report to South Carolina Electric and Gas. SCE&G, Columbia.

Verona. 1976. Cooper River biological survey. Unpublished report to South Carolina Electric and Gas. SCE&G, Columbia.

Whitaker, J.D., and C.F. Lam. 1987. A white shrimp prediction model for South Carolina. Presentation made at the 11th annual meeting of the South Carolina Fisheries Workers Association, Charleston, South Carolina, February 5-6, 1987.

Wilbur Smith and Associates. 1970. Santee Cooper. Comprehensive development plan. Wilbur Smith and Associates Technical Report for Santee-Cooper, Moncks Corner, SC. 115 p.

Zingmark, R.G. 1978. An Annotated Checklist of the Biota of the Coastal Zone of South Carolina. University of South Carolina Press, Columbia, SC. 364 p.

Appendix A. Minimum, maximum and average values for parameters at all SCDHEC stations in the Charleston Harbor Estuary from 1970-1985 (t = total, o = ortho, d = dissolved, s = sediments). Values were derived from all depths sampled during each year, excluding data tagged as suspect by SCDHEC.

	Temp	pH	DO	Sal	Turb	k-N	N-N	o-PO4	t-PO4	t-NH	BOD	COD
MD-020												
MIN:	6.00	6.40	2.00	0.00	1.00	0.04	0.02	0.00	0.02	0.02	0.60	24.00
MAX:	35.00	8.80	12.40	33.00	34.00	3.50	1.06	0.51	0.42	1.80	8.00	739.00
AVG:	19.55	7.64	7.34	20.47	8.07	0.67	0.12	0.18	0.11	0.22	1.83	325.25
MD-034												
MIN:	6.20	6.20	2.20	7.80	0.80	0.05	0.02	0.00	0.03	0.02	0.30	88.00
MAX:	33.00	8.60	12.20	36.00	80.00	4.00	1.29	0.48	0.48	2.00	6.60	400.00
AVG:	19.58	7.70	7.19	21.27	7.99	0.69	0.11	0.24	0.10	0.24	1.85	230.34
MD-043												
MIN:	5.00	6.00	2.80	0.00	0.80	0.05	0.00	0.00	0.02	0.02	0.20	6.00
MAX:	34.00	8.80	13.80	20.50	32.50	3.40	1.52	0.09	4.60	2.20	5.75	27.00
AVG:	20.47	7.54	7.15	7.36	6.90	0.61	0.14	0.04	0.11	0.15	1.46	17.75
MD-044												
MIN:	2.60	4.10	2.80	0.00	0.80	0.05	0.01	0.00	0.02	0.02	0.40	28.00
MAX:	33.00	8.50	13.80	24.00	70.00	5.40	0.67	0.87	0.46	2.50	6.75	98.00
AVG:	19.61	7.53	7.21	8.94	7.48	0.71	0.14	0.12	0.09	0.20	1.63	51.00
MD-045												
MIN:	5.00	6.50	2.90	1.00	0.30	0.05	0.02	0.00	0.02	0.02	0.50	19.00
MAX:	33.00	9.00	16.60	30.00	140.00	2.06	1.89	0.18	0.34	0.70	8.20	140.00
AVG:	20.18	7.70	7.07	16.64	8.80	0.60	0.13	0.08	0.08	0.17	1.52	81.83
MD-046												
MIN:	6.50	6.50	2.50	0.00	0.40	0.05	0.02	0.06	0.02	0.02	0.40	110.00
MAX:	32.00	9.10	17.00	35.00	100.00	3.60	0.53	0.39	4.60	1.20	8.15	410.00
AVG:	20.36	7.80	7.15	20.61	8.82	0.66	0.11	0.20	0.11	0.21	1.80	190.00
MD-047												
MIN:	5.00	4.20	3.10	1.50	0.50	0.05	0.01	0.00	0.02	0.02	0.10	80.00
MAX:	32.00	9.10	14.20	32.50	22.00	4.60	3.76	1.56	0.30	2.90	7.00	772.00
AVG:	20.60	7.61	7.14	19.57	6.31	0.68	0.15	0.18	0.08	0.24	1.76	224.15

	Temp	pH	DO	Sal	Turb	k-N	N-N	o-PO4	t-PO4	t-NH	BOD	COD
MD-048												
MIN:	7.00	5.60	2.40	0.50	1.40	0.05	0.02	0.12	0.03	0.02	0.60	100.00
MAX:	33.00	10.00	14.60	40.00	44.00	3.40	1.38	0.33	0.36	2.00	4.95	580.00
AVG:	19.93	7.80	7.27	23.56	6.73	0.66	0.10	0.19	0.09	0.23	1.77	245.50
MD-049												
MIN:	4.00	4.80	2.30	0.00	0.16	0.10	0.02	0.00	0.05	0.02	1.00	44.00
MAX:	33.00	8.50	28.00	18.00	75.00	7.80	3.24	1.14	1.40	4.00	7.20	600.00
AVG:	22.43	7.14	5.55	5.52	20.67	1.26	0.26	0.41	0.43	0.21	2.72	139.79
MD-052												
MIN:	2.50	5.90	3.30	6.80	1.10	0.04	0.02	0.00	0.02	0.02	0.30	68.00
MAX:	34.00	8.60	14.50	31.00	130.00	3.30	0.66	0.57	1.73	1.00	6.65	398.00
AVG:	20.61	7.64	6.95	19.27	9.25	0.69	0.12	0.26	0.15	0.20	2.02	221.38
MD-060												
MIN:	17.00	—	—	—	—	—	—	—	—	—	—	—
MAX:	30.00	—	—	—	—	—	—	—	—	—	—	—
AVG:	26.33	—	—	—	—	—	—	—	—	—	—	—
MD-070												
MIN:	2.60	6.30	3.00	9.00	1.10	0.10	0.00	0.02	0.02	0.04	0.50	52.00
MAX:	32.00	8.90	14.00	36.00	29.00	3.80	0.81	0.75	0.54	2.20	6.60	616.00
AVG:	20.14	7.74	7.00	24.68	7.19	0.61	0.09	0.22	0.10	0.22	1.78	276.00
MD-071												
MIN:	1.50	6.00	2.40	1.00	1.10	0.10	0.01	0.04	0.04	0.02	0.20	63.00
MAX:	32.00	8.70	15.80	32.50	29.00	5.28	1.30	0.81	0.56	2.60	7.30	912.00
AVG:	20.45	7.58	6.52	22.57	8.69	0.83	0.09	0.25	0.12	0.26	2.31	264.71
MD-113												
MIN:	4.00	4.80	0.00	0.00	1.30	0.05	0.00	0.00	0.05	0.02	0.15	8.00
MAX:	32.00	9.30	11.90	71.00	830.00	12.40	3.84	0.81	1.80	3.00	8.20	661.00
AVG:	19.16	6.98	4.81	0.98	13.46	1.05	0.11	0.30	0.24	0.17	3.16	83.27
MD-114												
MIN:	2.70	3.10	0.00	0.00	0.74	0.05	0.00	0.00	0.05	0.02	0.15	0.00
MAX:	32.00	8.40	8.80	1.00	56.00	19.90	0.80	1.32	1.90	1.40	11.00	171.20
AVG:	18.17	6.42	1.40	0.18	8.33	1.38	0.06	0.38	0.42	0.21	3.74	55.71

	Temp	pH	DO	Sal	Turb	k-N	N-N	o-PO4	t-PO4	t-NH	BOD	COD
MD-115												
MIN:	6.00	5.90	2.60	0.00	0.25	0.10	0.00	0.00	0.02	0.02	0.25	31.00
MAX:	32.00	8.20	13.80	24.00	69.00	4.40	1.27	0.68	0.44	13.00	7.10	930.00
AVG:	21.21	7.23	6.76	14.35	9.96	0.78	0.07	0.16	0.09	0.26	2.57	247.64
MD-135												
MIN:	7.00	6.60	2.75	1.50	2.00	0.12	0.02	0.04	0.05	0.02	1.10	88.00
MAX:	31.00	8.50	28.00	27.00	50.00	3.20	1.56	0.85	0.76	1.20	8.80	300.00
AVG:	26.01	7.46	5.34	18.41	11.43	0.71	0.19	0.46	0.21	0.19	2.39	200.43
MD-152												
MIN:	5.00	4.20	3.60	0.00	0.40	0.05	0.00	0.00	0.02	0.02	0.20	2.00
MAX:	34.00	9.00	13.00	14.00	110.00	1.65	0.66	0.24	0.32	0.90	4.60	25.00
AVG:	20.77	7.54	7.43	3.76	7.57	0.57	0.11	0.04	0.08	0.12	1.53	11.40
MD-165												
MIN:	2.40	6.60	3.00	7.50	0.50	0.04	0.02	0.00	0.02	0.02	0.10	95.00
MAX:	31.00	8.70	12.00	39.50	60.00	4.40	6.65	0.53	1.49	2.70	7.15	874.20
AVG:	19.59	7.79	7.25	24.01	6.79	0.64	0.15	0.21	0.09	0.23	1.80	329.31
MD-198												
MIN:	5.50	6.20	4.00	1.50	0.50	0.05	0.02	0.06	0.02	0.02	0.20	100.00
MAX:	32.00	8.90	18.00	32.00	100.00	13.00	2.52	0.24	2.60	1.50	5.20	280.00
AVG:	20.38	7.71	7.17	18.91	8.66	0.82	0.13	0.14	0.11	0.19	1.82	184.00
MD-204												
MIN:	9.00	6.60	4.40	10.90	2.30	0.05	0.04	—	0.03	0.05	1.00	—
MAX:	31.00	8.40	10.25	27.50	15.00	1.66	0.14	—	0.08	0.36	4.20	—
AVG:	20.10	7.71	6.74	18.70	6.40	0.51	0.09	—	0.05	0.12	2.02	—
MD-205												
MIN:	9.00	6.90	2.30	11.00	2.00	0.05	0.02	—	0.02	0.05	1.00	—
MAX:	31.00	8.35	10.40	38.50	25.00	1.16	0.21	—	0.06	0.15	4.60	—
AVG:	20.77	7.79	6.75	21.74	10.58	0.40	0.09	—	0.04	0.07	1.92	—
MD-214												
MIN:	15.50	7.85	5.70	17.50	—	—	—	—	—	—	—	—
MAX:	26.00	8.00	9.35	20.50	—	—	—	—	—	—	—	—
AVG:	20.75	7.92	7.53	19.00	—	—	—	—	—	—	—	—

	Temp	pH	DO	Sal	Turb	k-N	N-N	o-PO4	t-PO4	t-NH	BOD	COD
MD-217												
MIN:	8.00	6.25	4.10	0.00	2.50	0.30	0.02	—	0.05	0.02	0.80	—
MAX:	30.00	8.05	11.90	10.00	21.00	2.70	0.20	—	0.08	0.21	8.40	—
AVG:	19.95	6.96	7.45	0.82	5.94	0.73	0.06	—	0.05	0.08	2.24	—
MD-500												
MIN:	7.00	—	3.95	4.50	2.40	0.10	0.02	—	0.03	0.05	—	—
MAX:	30.50	—	11.00	25.00	32.00	1.72	0.48	—	0.20	1.00	—	—
AVG:	20.23	—	6.90	13.49	9.06	0.71	0.09	—	0.10	0.29	—	—
MD-501												
MIN:	7.00	—	2.90	7.00	2.40	0.10	0.02	—	0.03	0.05	—	—
MAX:	30.00	—	10.90	29.00	42.00	1.80	0.37	—	0.34	1.50	—	—
AVG:	20.54	—	6.53	16.34	11.47	0.76	0.10	—	0.13	0.33	—	—
MD-502												
MIN:	7.00	—	3.60	7.70	2.70	0.10	0.02	—	0.03	0.05	—	—
MAX:	31.00	—	10.90	29.00	26.00	1.18	0.21	—	0.52	1.10	—	—
AVG:	20.83	—	6.63	16.15	9.07	0.62	0.08	—	0.12	0.29	—	—
MD-503												
MIN:	7.00	—	3.90	2.30	2.10	0.10	0.02	—	0.04	0.05	3.00	—
MAX:	30.00	—	12.20	24.20	28.00	1.50	0.26	—	0.30	0.63	3.00	—
AVG:	20.95	—	6.88	15.48	8.26	0.54	0.09	—	0.12	0.17	3.00	—
MD-504												
MIN:	7.50	—	3.90	8.50	2.10	0.10	0.02	—	0.03	0.05	2.60	—
MAX:	31.00	—	11.20	25.60	17.00	1.96	0.16	—	0.32	0.92	2.60	—
AVG:	21.14	—	6.55	15.70	7.24	0.64	0.06	—	0.12	0.26	2.60	—
MD-505												
MIN:	7.00	—	2.90	7.00	1.70	0.10	0.02	—	0.02	0.05	3.10	—
MAX:	31.00	—	11.50	22.00	17.00	4.00	0.17	—	0.18	1.20	3.10	—
AVG:	20.99	—	6.14	13.46	6.91	0.83	0.06	—	0.09	0.31	3.10	—
MD-530												
MIN:	23.00	6.60	4.30	0.00	6.60	0.30	0.02	—	0.09	0.05	2.00	—
MAX:	31.00	7.85	7.20	0.50	42.00	1.14	0.17	—	0.28	0.53	3.70	—
AVG:	26.46	7.22	6.04	0.07	28.80	0.75	0.06	—	0.17	0.25	2.94	—
MD-531												
MIN:	22.50	6.30	3.20	0.00	12.00	0.82	0.02	—	0.34	0.05	1.40	—
MAX:	28.50	7.60	4.40	20.00	45.00	1.88	0.51	—	1.40	0.91	3.40	—
AVG:	26.55	6.87	3.78	2.87	26.50	1.14	0.30	—	0.69	0.21	1.97	—

	Temp	pH	DO	Sal	Turb	k-N	N-N	o-PO4	t-PO4	t-NH	BOD	COD
MD-532												
MIN:	22.50	5.60	2.92	0.00	6.20	0.78	0.02	—	0.34	0.05	1.70	—
MAX:	29.20	7.45	5.90	5.00	110.00	1.86	1.13	—	2.00	0.66	3.60	—
AVG:	26.62	6.85	4.25	1.48	34.05	1.28	0.58	—	0.96	0.18	2.42	—
MD-533												
MIN:	23.00	1.60	3.00	0.00	4.60	0.69	0.02	—	0.30	0.05	1.40	—
MAX:	29.00	7.45	6.32	3.50	100.00	1.70	1.29	—	1.80	0.91	3.70	—
AVG:	26.67	6.35	4.38	0.74	35.62	1.31	0.64	—	1.00	0.25	2.58	—
MD-534												
MIN:	22.50	5.60	2.70	0.00	3.90	1.19	0.02	—	0.32	0.05	1.60	—
MAX:	28.80	7.40	6.43	2.00	95.00	3.20	1.11	—	1.70	1.50	3.40	—
AVG:	26.46	6.71	4.30	0.72	37.38	1.52	0.52	—	0.95	0.28	2.55	—
MD-620												
MIN:	10.00	7.10	4.20	8.50	5.60	0.94	0.09	—	0.14	0.10	2.70	—
MAX:	31.50	7.90	11.20	31.50	5.60	0.94	0.09	—	0.14	0.10	2.70	—
AVG:	21.80	7.49	6.76	18.46	5.60	0.94	0.09	—	0.14	0.10	2.70	—
MD-621												
MIN:	27.90	7.70	3.96	22.30	6.60	0.56	0.03	—	0.08	0.14	2.10	—
MAX:	29.40	8.25	7.82	25.40	13.00	0.85	0.03	—	0.15	0.25	2.70	—
AVG:	28.53	8.09	6.24	23.69	10.20	0.68	0.03	—	0.10	0.19	2.40	—
MD-641												
MIN:	26.50	6.80	3.48	0.50	48.00	0.98	0.51	—	0.83	0.09	2.00	—
MAX:	28.20	7.20	4.20	1.00	56.00	1.66	0.60	—	1.70	0.70	3.40	—
AVG:	27.07	7.00	3.77	0.63	52.00	1.32	0.56	—	1.26	0.39	2.70	—
MD-642												
MIN:	27.20	6.80	3.04	0.50	25.00	0.91	0.40	—	0.70	0.06	1.60	—
MAX:	29.70	7.45	4.71	5.80	65.00	3.60	1.87	—	2.30	0.74	3.70	—
AVG:	27.84	7.14	3.62	2.65	46.40	1.65	0.79	—	1.30	0.24	2.16	—
MD-657												
MIN:	27.80	7.70	5.18	21.40	7.00	0.62	0.03	—	0.12	0.12	1.80	—
MAX:	29.50	8.15	7.95	24.30	11.00	0.85	0.05	—	0.23	0.17	4.10	—
AVG:	28.39	7.96	5.83	22.80	9.10	0.74	0.04	—	0.16	0.14	2.90	—
MD-658												
MIN:	28.00	7.70	5.10	21.30	5.50	0.51	0.02	—	0.09	0.12	2.00	—
MAX:	29.10	8.20	7.32	24.70	10.00	0.69	0.05	—	0.22	0.24	2.80	—
AVG:	28.33	7.99	5.91	22.86	7.20	0.59	0.04	—	0.13	0.17	2.43	—

	Temp	pH	DO	Sal	Turb	k-N	N-N	o-PO4	t-PO4	t-NH	BOD	COD
MD-659												
MIN:	28.00	7.80	5.20	21.20	3.50	0.46	0.03	—	0.06	0.13	1.90	—
MAX:	29.50	8.40	7.60	25.80	10.00	0.60	0.04	—	0.18	0.26	2.40	—
AVG:	28.25	8.12	5.90	22.72	5.90	0.54	0.03	—	0.13	0.18	2.13	—
MD-660												
MIN:	27.50	7.80	5.10	20.60	3.50	0.58	0.03	—	0.07	0.14	1.60	—
MAX:	29.00	8.30	7.10	26.90	9.90	0.90	0.23	—	0.19	0.31	2.50	—
AVG:	28.13	8.08	5.92	24.08	6.07	0.70	0.10	—	0.13	0.20	1.97	—
MD-663												
MIN:	28.00	7.80	5.10	20.10	3.10	0.39	0.03	—	0.06	0.15	1.60	—
MAX:	29.00	8.40	7.40	27.20	11.00	0.67	0.07	—	0.16	0.34	2.40	—
AVG:	28.19	8.05	5.93	23.88	5.83	0.56	0.04	—	0.10	0.23	2.00	—
MD-662												
MIN:	27.50	7.90	5.31	21.70	3.40	0.45	0.03	—	0.06	0.20	1.60	—
MAX:	28.80	8.20	7.23	29.50	9.60	0.73	0.05	—	0.14	0.25	2.40	—
AVG:	28.07	8.07	5.88	25.62	5.50	0.57	0.04	—	0.09	0.22	1.93	—
MD-663												
MIN:	28.00	7.70	4.90	21.00	6.20	0.49	0.03	—	0.07	0.13	1.60	—
MAX:	29.00	8.30	7.70	26.50	16.00	0.73	0.04	—	0.13	0.26	2.40	—
AVG:	28.26	7.99	5.95	24.14	9.70	0.58	0.03	—	0.10	0.19	2.07	—

	COD-s	TOC	Cl	Alk	Cu-d	Cu-s	Fe-d	Cd-d	Cd-s	Cr-d	Cr-s
MD-020											
MIN:	25000.00	2.20	33.00	0.00	50.00	10.04	100.00	10.00	11.05	50.00	6.03
MAX:	25000.00	22.10	33.00	142.00	1100.00	10.04	2900.00	100.00	11.05	100.00	6.03
AVG:	25000.00	6.21	33.00	76.73	132.50	10.04	659.52	26.52	11.05	58.40	6.03
MD-034											
MIN:	16000.00	1.00	—	30.00	50.00	4.86	180.00	10.00	11.18	50.00	3.89
MAX:	16000.00	18.10	—	130.00	265.00	4.86	2550.00	260.00	11.18	100.00	3.89
AVG:	16000.00	5.69	—	79.27	104.60	4.86	638.42	38.25	11.18	57.50	3.89
MD-043											
MIN:	4400.00	1.70	8.00	12.00	10.00	5.00	100.00	10.00	0.50	50.00	6.00
MAX:	117000.00	11.40	8.00	96.00	100.00	29.00	1810.00	100.00	1.50	910.00	46.00
AVG:	56500.00	4.66	8.00	35.88	94.40	14.68	427.52	15.50	0.99	98.50	24.81
MD-044											
MIN:	127000.00	1.00	—	6.00	50.00	24.50	100.00	10.00	0.50	50.00	27.00
MAX:	127000.00	11.80	—	82.00	100.00	24.50	1500.00	100.00	0.50	310.00	27.00
AVG:	127000.00	4.85	—	35.78	98.00	24.50	365.12	15.50	0.50	71.50	27.00
MD-055											
MIN:	6500.00	1.00	1500.00	10.00	50.00	5.00	100.00	10.00	0.50	50.00	5.00
MAX:	150000.00	36.00	20000.00	180.00	160.00	26.00	1700.00	100.00	1.10	100.00	50.00
AVG:	66690.91	4.60	7980.00	58.65	100.40	14.61	374.08	15.79	0.97	52.63	26.52
MD-046											
MIN:	80000.00	1.70	3.00	17.00	50.00	5.50	100.00	10.00	0.50	50.00	13.00
MAX:	80000.00	21.60	22500.00	178.00	150.00	10.00	2030.00	100.00	1.00	100.00	28.00
AVG:	80000.00	4.98	9508.84	72.71	98.15	8.38	334.48	18.10	0.88	55.24	19.13
MD-047											
MIN:	122000.00	2.10	17500.00	6.00	50.00	15.00	100.00	10.00	0.50	50.00	26.00
MAX:	122000.00	11.60	25940.00	180.00	140.00	15.00	1485.00	105.00	0.50	100.00	26.00
AVG:	122000.00	4.90	21131.11	64.39	93.23	15.00	467.46	33.40	0.50	62.00	26.00
MD-048											
MIN:	7600.00	1.50	—	40.00	50.00	5.00	59.00	10.00	0.50	50.00	4.80
MAX:	135000.00	16.50	—	130.00	1111.00	17.00	1000.00	100.00	1.00	217.00	34.00
AVG:	46550.00	4.71	—	82.73	170.05	9.75	347.23	24.71	0.96	65.71	15.49
MD-049											
MIN:	4900.00	3.40	14.00	8.00	50.00	6.30	220.00	10.00	0.63	50.00	9.47
MAX:	4930.00	37.40	13000.00	140.00	1000.00	49.00	3500.00	100.00	1.00	110.00	40.00
AVG:	4915.00	15.14	2582.84	60.33	129.63	26.07	910.84	20.09	0.91	59.09	26.37

	COD-s	TOC	Cl	Alk	Cu-d	Cu-s	Fe-d	Cd-d	Cd-s	Cr-d	Cr-s
MD-052											
MIN:	34000.00	0.59	——	8.00	50.00	6.60	180.00	10.00	0.50	50.00	4.80
MAX:	130000.00	17.60	——	129.00	180.00	60.00	2220.00	100.00	22.20	100.00	39.00
AVG:	71833.33	6.84	——	79.39	96.96	18.00	587.22	26.32	2.49	60.00	22.34
MD-060											
MIN:	——	——	——	——	——	——	——	——	——	——	——
MAX:	——	——	——	——	——	——	——	——	——	——	——
AVG:	——	——	——	——	——	——	——	——	——	——	——
MD-070											
MIN:	——	1.10	——	24.00	50.00	——	100.00	10.00	——	50.00	——
MAX:	——	18.90	——	170.00	314.00	——	1330.00	100.00	——	100.00	——
AVG:	——	4.35	——	89.96	99.92	——	492.26	33.16	——	66.84	——
MD-071											
MIN:	——	1.90	0.51	1.40	50.00	——	100.00	10.00	——	50.00	——
MAX:	——	19.00	0.51	332.00	290.00	——	3363.00	100.00	——	103.00	——
AVG:	——	5.71	0.51	93.19	99.79	——	610.67	30.31	——	61.65	——
MD-113											
MIN:	20000.00	1.00	——	0.30	50.00	17.40	219.00	10.00	0.73	50.00	5.09
MAX:	20000.00	19.30	——	92.00	100.00	17.40	8762.00	100.00	0.73	410.00	5.09
AVG:	20000.00	10.33	——	32.23	89.47	17.40	1036.94	30.72	0.73	79.06	5.09
MD-114											
MIN:	55000.00	6.20	——	1.20	10.00	38.17	100.00	10.00	0.63	50.00	11.26
MAX:	55000.00	28.00	——	92.00	100.00	38.17	10310.00	100.00	0.63	110.0	11.26
AVG:	55000.00	13.83	——	33.83	88.05	38.17	1231.42	29.59	0.63	66.47	11.26
MD-115											
MIN:	1700.00	2.80	3000.00	4.50	50.00	5.00	100.00	5.00	0.92	50.00	6.00
MAX:	86000.00	33.20	17000.00	130.00	15970.00	149.00	1451.00	20.00	1.00	670.00	30.00
AVG:	30220.00	8.45	7209.52	74.22	1410.00	27.95	559.00	12.14	0.99	133.75	13.22
MD-135											
MIN:	50000.00	6.00	——	20.00	26.50	7.20	290.00	10.00	0.72	50.00	13.70
MAX:	50000.00	14.90	——	130.00	2000.00	7.20	2000.00	100.00	0.72	100.00	13.70
AVG:	50000.00	10.01	——	75.88	197.18	7.20	756.70	18.62	0.72	53.85	13.70
MD-152											
MIN:	1400.00	1.50	0.06	16.00	50.00	5.00	100.00	10.00	0.80	50.00	4.00
MAX:	110000.00	41.30	0.06	90.00	100.00	10.00	1714.00	100.00	1.30	1080.00	44.00
AVG:	39645.45	5.82	0.06	31.00	94.83	6.81	452.09	22.61	1.00	135.26	15.60

	COD-s	TOC	Cl	Alk	Cu-d	Cu-s	Fe-d	Cd-d	Cd-s	Cr-d	Cr-s
MD-165											
MIN:	96000.00	1.80	—	3.40	50.00	8.20	160.00	10.00	0.90	50.00	24.50
MAX:	96000.00	9.80	—	150.00	1550.00	8.20	3434.00	100.00	0.90	153.00	24.50
AVG:	96000.00	4.86	—	77.28	155.29	8.20	560.40	36.84	0.90	70.16	24.50
MD-198											
MIN:	—	1.00	4400.00	20.00	50.00	10.00	100.00	10.00	1.00	50.00	27.00
MAX:	—	175.00	21000.00	820.00	160.00	17.00	1942.00	100.00	1.00	131.00	33.00
AVG:	—	9.90	9400.00	78.47	101.30	12.67	512.70	22.65	1.00	55.35	30.00
MD-204											
MIN:	—	3.60	—	53.00	—	—	—	—	—	—	—
MAX:	—	21.90	—	130.00	—	—	—	—	—	—	—
AVG:	—	10.17	—	84.43	—	—	—	—	—	—	—
MD-205											
MIN:	—	4.70	—	59.00	—	—	—	—	—	—	—
MAX:	—	6.90	—	150.00	—	—	—	—	—	—	—
AVG:	—	5.53	—	93.76	—	—	—	—	—	—	—
MD-214											
MIN:	—	—	—	—	—	5.00	—	—	1.00	—	8.80
MAX:	—	—	—	—	—	5.00	—	—	1.00	—	17.00
AVG:	—	—	—	—	—	5.00	—	—	1.00	—	12.93
MD-217											
MIN:	—	2.70	5.50	2.20	—	—	—	—	—	—	—
MAX:	—	42.00	140.00	31.00	—	—	—	—	—	—	—
AVG:	—	8.93	20.15	24.45	—	—	—	—	—	—	—
MD-500											
MIN:	—	1.50	3600.00	45.00	—	7.00	—	—	1.00	—	11.00
MAX:	—	25.20	13500.00	96.00	—	11.00	—	—	1.00	—	19.00
AVG:	—	5.72	6888.89	71.91	—	9.33	—	—	1.00	—	15.33
MD-501											
MIN:	—	1.70	3800.00	55.00	—	18.00	—	—	1.00	—	20.00
MAX:	—	25.00	19000.00	110.00	—	24.00	—	—	1.00	—	27.00
AVG:	—	5.68	8300.00	81.82	—	20.67	—	—	1.00	—	22.67M
D-502											
MIN:	—	1.50	4200.00	51.00	—	8.00	—	—	1.00	—	12.00
MAX:	—	13.90	14500.00	160.00	—	19.00	—	—	1.00	—	25.00
AVG:	—	5.32	7419.44	78.91	—	12.33	—	—	1.00	—	17.00

	COD-s	TOC	Cl	Alk	Cu-d	Cu-s	Fe-d	Cd-d	Cd-s	Cr-d	Cr-s
MD-503											
MIN:	—	2.10	4000.00	48.00	—	5.00	—	—	1.00	—	5.00
MAX:	—	12.50	15000.00	96.00	—	10.00	—	—	5.00	—	8.00
AVG:	—	5.30	7811.11	78.00	—	6.67	—	—	2.33	—	6.67
MD-504											
MIN:	—	2.80	4000.00	55.00	—	5.00	—	—	1.00	—	5.00
MAX:	—	17.80	14500.00	120.00	—	20.00	—	—	1.00	—	15.00
AVG:	—	6.55	7366.67	80.65	—	11.03	—	—	1.00	—	8.67
MD-505											
MIN:	—	2.80	14.50	54.00	—	5.00	—	—	1.00	—	5.00
MAX:	—	18.30	9500.00	100.00	—	15.00	—	—	1.00	—	11.00
AVG:	—	7.28	5927.08	81.52	—	10.00	—	—	1.00	—	8.00
MD-530											
MIN:	—	—	—	39.00	—	—	—	—	—	—	—
MAX:	—	—	—	72.00	—	—	—	—	—	—	—
AVG:	—	—	—	58.71	—	—	—	—	—	—	—
MD-531											
MIN:	—	—	—	17.00	—	5.00	—	—	1.00	—	5.00
MAX:	—	—	—	72.00	—	41.00	—	—	1.00	—	36.00
AVG:	—	—	—	51.13	—	18.00	—	—	1.00	—	17.00
MD-532											
MIN:	—	—	—	15.00	—	5.00	—	—	1.00	—	6.00
MAX:	—	—	—	68.00	—	5.00	—	—	1.00	—	11.00
AVG:	—	—	—	48.50	—	5.00	—	—	1.00	—	7.67
MD-533											
MIN:	—	—	—	10.00	—	5.00	—	—	1.00	—	12.00
MAX:	—	—	—	64.00	—	7.40	—	—	1.00	—	24.00
AVG:	—	—	—	45.25	—	5.80	—	—	1.00	—	16.67
MD-534											
MIN:	—	—	—	14.00	—	5.00	—	—	1.00	—	22.00
MAX:	—	—	—	60.00	—	11.00	—	—	1.00	—	36.00
AVG:	—	—	—	41.13	—	7.93	—	—	1.00	—	30.67
MD-620											
MIN:	—	—	—	72.00	—	—	—	—	—	—	—
MAX:	—	—	—	72.00	—	—	—	—	—	—	—
AVG:	—	—	—	72.00	—	—	—	—	—	—	—

	COD-s	TOC	Cl	Alk	Cu-d	Cu-s	Fe-d	Cd-d	Cd-s	Cr-d	Cr-s
MD-621											
MIN:	—	—	—	88.00	—	—	—	—	—	—	—
MAX:	—	—	—	110.00	—	—	—	—	—	—	—
AVG:	—	—	—	95.67	—	—	—	—	—	—	—
MD-641											
MIN:	—	—	—	67.00	—	5.00	—	—	1.00	—	26.00
MAX:	—	—	—	117.00	—	5.00	—	—	1.00	—	26.00
AVG:	—	—	—	92.00	—	5.00	—	—	1.00	—	26.00
MD-642											
MIN:	—	—	—	66.00	—	15.00	—	—	1.00	—	17.00
MAX:	—	—	—	95.00	—	15.00	—	—	1.00	—	17.00
AVG:	—	—	—	76.00	—	15.00	—	—	1.00	—	17.00
MD-657											
MIN:	—	—	—	92.00	—	—	—	—	—	—	—
MAX:	—	—	—	96.00	—	—	—	—	—	—	—
AVG:	—	—	—	94.00	—	—	—	—	—	—	—
MD-658											
MIN:	—	—	—	89.00	—	—	—	—	—	—	—
MAX:	—	—	—	96.00	—	—	—	—	—	—	—
AVG:	—	—	—	91.67	—	—	—	—	—	—	—
MD-659											
MIN:	—	—	—	90.00	—	—	—	—	—	—	—
MAX:	—	—	—	95.00	—	—	—	—	—	—	—
AVG:	—	—	—	92.00	—	—	—	—	—	—	—
MD-660											
MIN:	—	—	—	90.00	—	—	—	—	—	—	—
MAX:	—	—	—	96.00	—	—	—	—	—	—	—
AVG:	—	—	—	93.00	—	—	—	—	—	—	—
MD-661											
MIN:	—	—	—	90.00	—	—	—	—	—	—	—
MAX:	—	—	—	96.00	—	—	—	—	—	—	—
AVG:	—	—	—	92.33	—	—	—	—	—	—	—
MD-662											
MIN:	—	—	—	93.00	—	—	—	—	—	—	—
MAX:	—	—	—	93.00	—	—	—	—	—	—	—
AVG:	—	—	—	93.00	—	—	—	—	—	—	—

	COD-s	TOC	Cl	Alk	Cu-d	Cu-s	Fe-d	Cd-d	Cd-s	Cr-d	Cr-s
MD-663											
MIN:	—	—	—	88.00	—	—	—	—	—	—	—
MAX:	—	—	—	100.00	—	—	—	—	—	—	—
AVG:	—	—	—	92.67	—	—	—	—	—	—	—

	Pb-d	Pb-s	Hg-d	Hg-s	Mn-d	Mn-s	Ni-d	Ni-s	Zn-d	Zn-s	Mg-d	Coli
MD-020												
MIN:	50.00	40.18	0.20	0.11	50.00	59.26	100.00	10.04	100.00	37.16	11.30	——
MAX:	300.00	40.18	5.30	0.11	950.00	59.26	290.00	10.04	570.00	37.16	664.00	29700.00
AVG:	129.03	40.18	0.73	0.11	132.65	59.26	124.50	10.04	133.33	37.16	329.80	366.82
MD-O34												
MIN:	50.00	2.92	0.01	0.08	50.00	27.70	100.00	4.86	100.00	13.61	270.00	2.00
MAX:	250.00	2.92	7.30	0.08	100.00	27.70	270.00	4.86	250.00	13.61	2970.00	30500.00
AVG:	147.36	2.92	0.73	0.08	58.67	27.70	123.33	4.86	109.38	13.61	703.11	410.40
MD-043												
MIN:	50.00	5.00	0.02	0.03	50.00	59.00	100.00	5.00	100.00	11.00	1.50	1.00
MAX:	200.00	64.00	3.23	0.35	4800.00	355.00	100.00	22.00	670.00	80.00	461.00	1000.00
AVG:	59.20	25.27	0.43	0.23	316.11	207.00	100.00	14.25	131.67	48.92	51.72	49.78
MD-044												
MIN:	50.00	34.50	0.02	0.40	50.00	442.50	100.00	11.00	100.00	70.00	4.40	2.00
MAX:	200.00	34.50	2.46	0.40	370.00	442.50	100.00	11.00	120.00	70.00	959.00	800.00
AVG:	56.80	34.50	0.46	0.40	69.17	442.50	100.00	11.00	101.11	70.00	119.50	63.49
MD-045												
MIN:	50.00	5.00	0.10	0.20	50.00	100.00	100.00	5.00	100.00	10.00	67.00	2.00
MAX:	270.00	46.00	8.53	29.00	140.00	990.00	100.00	20.00	100.00	80.00	187.50	1700.00
AVG:	95.20	26.50	0.60	2.04	57.06	545.00	100.00	12.08	100.00	50.07	134.01	114.06
MD-046												
MIN:	50.00	17.00	0.05	0.08	50.00	226.00	100.00	15.00	100.00	23.00	0.36	1.00
MAX:	260.00	34.00	9.88	0.25	470.00	226.00	170.00	15.00	100.00	41.50	596.00	860.00
AVG:	122.07	23.50	0.70	0.18	75.00	226.00	112.78	15.00	100.00	34.13	303.17	78.47
MD-047												
MIN:	50.00	3.00	0.10	0.03	50.00	483.00	100.00	20.00	100.00	60.00	0.26	——
MAX:	380.00	3.00	4.15	0.03	630.00	483.00	120.00	20.00	100.00	60.00	450.00	4000.00
AVG:	127.10	3.00	0.63	0.03	82.78	483.00	101.11	20.00	100.00	60.00	208.24	171.97
MD-048												
MIN:	1.58	5.00	0.20	0.05	50.00	81.00	100.00	5.00	100.00	9.10	244.00	1.00
MAX:	320.00	50.00	5.60	0.25	80.00	155.00	170.00	16.00	280.00	70.00	506.00	31500.00
AVG:	142.00	19.08	0.69	0.21	56.15	118.00	120.00	9.55	112.86	34.47	373.78	334.61
MD-049												
MIN:	50.00	13.30	0.10	0.20	50.00	23.40	100.00	6.30	100.00	17.10	2.80	8.00
MAX:	280.00	49.00	4.70	0.50	170.00	23.40	110.00	23.00	150.00	180.00	330.00	2800.00
AVG:	87.52	30.82	0.43	0.30	76.67	23.40	100.56	16.43	106.32	114.27	85.28	307.56

	Pb-d	Pb-s	Hg-d	Hg-s	Mn-d	Mn-s	Ni-d	Ni-s	Zn-d	Zn-s	Mg-d	Coli
MD-052												
MIN:	50.00	4.00	0.20	0.20	50.00	210.00	100.00	5.90	100.00	34.00	250.00	2.00
MAX:	350.00	54.00	6.30	0.56	110.00	928.00	140.00	16.00	170.00	160.00	543.00	26300.00
AVG:	156.25	29.99	0.66	0.26	57.86	471.33	106.43	9.98	104.67	70.11	408.11	398.17
MD-060												
MIN:	—	—	—	—	—	—	—	—	—	—	—	—
MAX:	—	—	—	—	—	—	—	—	—	—	—	—
AVG:	—	—	—	—	—	—	—	—	—	—	—	—
MD-070												
MIN:	50.00	—	0.20	—	50.00	—	100.00	—	100.00	—	184.00	1.00
MAX:	380.00	—	6.90	—	550.00	—	260.00	—	100.00	—	623.00	420.00
AVG:	195.13	—	0.79	—	106.15	—	156.15	—	100.00	—	485.44	53.89
MD-071												
MIN:	50.00	—	0.10	—	50.00	—	100.00	—	100.00	—	0.39	4.00
MAX:	420.00	—	4.00	—	140.00	—	380.00	—	150.00	—	800.00	2500.00
AVG:	201.34	—	0.65	—	73.68	—	177.22	—	104.50	—	486.88	184.40
MD-113												
MIN:	30.00	54.50	0.01	0.56	50.00	21.80	100.00	7.30	100.00	69.00	0.70	—
MAX:	200.00	54.50	2.15	0.56	420.00	21.80	100.00	7.30	100.00	69.00	2.40	3320.00
AVG:	81.05	54.50	0.45	0.56	80.42	21.80	100.00	7.30	100.00	69.00	1.32	97.48
MD-114												
MIN:	30.00	531.90	0.05	0.50	50.00	13.80	70.00	6.30	100.00	158.30	0.60	—
MAX:	200.00	531.90	3.00	0.50	700.00	13.80	100.00	6.30	150.00	158.30	3.60	2650.00
AVG:	78.78	531.90	0.51	0.50	206.67	13.80	98.89	6.30	102.40	158.30	1.30	216.89
MD-115												
MIN:	14.00	6.90	0.01	0.10	50.00	140.00	100.00	5.00	100.00	10.00	356.00	—
MAX:	200.00	245.00	2.30	0.40	150.00	140.00	310.00	15.00	100.00	390.00	356.00	800.00
AVG:	95.40	38.95	0.39	0.25	68.33	140.00	145.00	8.23	100.00	71.30	356.00	50.31
MD-135												
MIN:	50.00	180.00	0.20	0.30	50.00	108.00	100.00	7.20	100.00	150.00	149.00	—
MAX:	290.00	180.00	80.00	0.30	120.00	108.00	120.00	7.20	180.00	150.00	488.00	990.00
AVG:	122.78	180.00	4.30	0.30	69.00	108.00	103.00	7.20	107.27	150.00	343.11	138.22
MD-152												
MIN:	50.00	4.00	0.00	0.10	50.00	35.30	100.00	5.00	100.00	5.00	2.00	2.00
MAX:	200.00	55.00	1.77	0.50	100.00	160.00	230.00	15.00	100.00	48.00	485.00	260.00
AVG:	65.86	13.34	0.43	0.24	54.74	97.65	106.84	9.34	100.00	22.99	45.87	37.47

	Pb-d	Pb-s	Hg-d	Hg-s	Mn-d	Mn-s	Ni-d	Ni-s	Zn-d	Zn-s	Mg-d	Coli
MD-165												
MIN:	50.00	34.20	0.20	—	50.00	612.00	100.00	9.80	100.00	72.50	218.00	2.00
MAX:	290.00	34.20	7.30	—	1200.00	612.00	180.00	9.80	350.00	72.50	601.00	1240.00
AVG:	158.33	34.20	0.83	—	149.17	612.00	123.33	9.80	119.23	72.50	374.56	114.00
MD-198												
MIN:	50.00	18.00	0.02	0.20	50.00	—	100.00	—	100.00	30.00	131.00	1.00
MAX:	420.00	29.00	5.24	0.25	220.00	—	120.00	—	200.00	54.00	411.00	620.00
AVG:	148.51	24.00	0.59	0.22	67.33	—	104.00	—	106.25	41.67	282.89	40.60
MD-204												
MIN:	—	—	0.20	—	—	—	—	—	—	—	—	6.00
MAX:	—	—	3.40	—	—	—	—	—	—	—	—	270.00
AVG:	—	—	1.20	—	—	—	—	—	—	—	—	83.48
MD-205												
MIN:	—	—	0.20	—	—	—	—	—	—	—	—	2.00
MAX:	—	—	4.60	—	—	—	—	—	—	—	—	500.00
AVG:	—	—	1.20	—	—	—	—	—	—	—	—	99.11
MD-214												
MIN:	—	5.00	—	0.25	—	88.00	—	5.00	—	17.00	—	—
MAX:	—	12.00	—	0.25	—	130.00	—	6.00	—	34.00	—	—
AVG:	—	7.67	—	0.25	—	109.00	—	5.33	—	25.67	—	—
MD-217												
MIN:	—	—	0.20	—	—	—	—	—	—	—	—	2.00
MAX:	—	—	0.20	—	—	—	—	—	—	—	—	448.00
AVG:	—	—	0.20	—	—	—	—	—	—	—	—	71.29
MD-500												
MIN:	—	16.00	0.20	0.20	—	—	—	—	—	27.00	—	8.00
MAX:	—	20.00	0.90	0.25	—	—	—	—	—	43.00	—	190.00
AVG:	—	18.67	0.28	0.22	—	—	—	—	—	36.67	—	54.14
MD-501												
MIN:	—	30.00	0.20	0.20	—	—	—	—	—	60.00	—	6.00
MAX:	—	36.00	1.00	0.25	—	—	—	—	—	76.00	—	80.00
AVG:	—	32.00	0.33	0.22	—	—	—	—	—	65.33	—	31.67
MD-502												
MAX:	—	17.00	0.20	0.20	—	—	—	—	—	30.00	—	4.00
MAX:	—	28.00	0.60	0.25	—	—	—	—	—	63.00	—	86.00
AVG:	—	20.67	0.25	0.22	—	—	—	—	—	43.00	—	26.68

	Pb-d	Pb-s	Hg-d	Hg-s	Mn-d	Mn-s	Ni-d	Ni-s	Zn-d	Zn-s	Mg-d	Coli
MD-503												
MIN:	—	8.00	0.20	0.20	—	—	—	—	—	10.00	—	2.00
MAX:	—	17.00	1.20	0.30	—	—	—	—	—	34.00	—	63.00
AVG:	—	11.33	0.42	0.25	—	—	—	—	—	18.00	—	20.24
MD-504												
MIN:	—	8.00	0.20	0.20	—	—	—	—	—	22.00	—	1.00
MAX:	—	20.00	0.80	0.25	—	—	—	—	—	40.00	—	110.00
AVG:	—	13.33	0.33	0.22	—	—	—	—	—	30.67	—	24.05
MD-505												
MIN:	—	9.00	0.20	0.20	—	—	—	—	—	19.00	—	1.00
MAX:	—	26.00	0.70	0.25	—	—	—	—	—	47.00	—	85.00
AVG:	—	15.00	0.30	0.22	—	—	—	—	—	28.67	—	15.82
MD-530												
MIN:	—	—	0.20	—	—	—	—	—	—	—	—	340.00
MAX:	—	—	0.30	—	—	—	—	—	—	—	—	500.00
AVG:	—	—	0.24	—	—	—	—	—	—	—	—	420.00
MD-531												
MIN:	—	11.00	0.20	0.20	—	—	—	5.00	—	36.00	—	2200.00
MAX:	—	59.00	0.20	0.25	—	—	—	22.00	—	180.00	—	3100.00
AVG:	—	28.33	0.20	0.23	—	—	—	13.50	—	85.00	—	2650.00
MD-532												
MIN:	—	6.00	0.20	0.20	—	—	—	5.00	—	8.00	—	600.00
MAX:	—	10.00	0.20	0.25	—	—	—	5.00	—	12.00	—	3300.00
AVG:	—	7.67	0.20	0.23	—	—	—	5.00	—	9.67	—	1950.00
MD-533												
MIN:	—	11.00	0.20	0.20	—	—	—	6.00	—	20.00	—	320.00
MAX:	—	25.00	0.30	0.25	—	—	—	10.00	—	48.00	—	460.00
AVG:	—	16.33	0.21	0.23	—	—	—	8.00	—	30.00	—	390.00
MD-534												
MIN:	—	22.00	0.20	0.20	—	—	—	8.00	—	28.00	—	100.00
MAX:	—	34.00	0.30	0.25	—	—	—	17.00	—	50.00	—	240.00
AVG:	—	26.67	0.22	0.23	—	—	—	12.50	—	42.00	—	170.00
MD-620												
MIN:	—	—	—	—	—	—	—	—	—	—	—	1600.00
MAX:	—	—	—	—	—	—	—	—	—	—	—	1600.00
AVG:	—	—	—	—	—	—	—	—	—	—	—	1600.00

	Pb-d	Pb-s	Hg-d	Hg-s	Mn-d	Mn-s	Ni-d	Ni-s	Zn-d	Zn-s	Mg-d	Coli
MD-621												
MIN:	—	—	0.20	—	—	—	—	—	—	—	—	—
MAX:	—	—	0.20	—	—	—	—	—	—	—	—	—
AVG:	—	—	0.20	—	—	—	—	—	—	—	—	—
MD-641												
MIN:	—	19.00	0.20	0.25	—	—	—	10.00	—	26.00	—	—
MAX:	—	19.00	0.30	0.25	—	—	—	10.00	—	26.00	—	—
AVG:	—	19.00	0.25	0.25	—	—	—	10.00	—	26.00	—	—
MD-642												
MIN:	—	34.00	0.20	0.25	—	—	—	10.00	—	70.00	—	—
MAX:	—	34.00	0.20	0.25	—	—	—	10.00	—	70.00	—	—
AVG:	—	34.00	0.20	0.25	—	—	—	10.00	—	70.00	—	—
MD-657												
MIN:	—	—	0.20	—	—	—	—	—	—	—	—	—
MAX:	—	—	0.20	—	—	—	—	—	—	—	—	—
AVG:	—	—	0.20	—	—	—	—	—	—	—	—	—
MD-658												
MIN:	—	—	0.20	—	—	—	—	—	—	—	—	—
MAX:	—	—	0.30	—	—	—	—	—	—	—	—	—
AVG:	—	—	0.23	—	—	—	—	—	—	—	—	—
MD-659												
MIN:	—	—	0.20	—	—	—	—	—	—	—	—	—
MAX:	—	—	0.20	—	—	—	—	—	—	—	—	—
AVG:	—	—	0.20	—	—	—	—	—	—	—	—	—
MD-660												
MIN:	—	—	0.20	—	—	—	—	—	—	—	—	—
MAX:	—	—	0.20	—	—	—	—	—	—	—	—	—
AVG:	—	—	0.20	—	—	—	—	—	—	—	—	—
MD-661												
MIN:	—	—	0.20	—	—	—	—	—	—	—	—	—
MAX:	—	—	0.20	—	—	—	—	—	—	—	—	—
AVG:	—	—	0.20	—	—	—	—	—	—	—	—	—
MD-662												
MIN:	—	—	0.20	—	—	—	—	—	—	—	—	—
MAX:	—	—	0.20	—	—	—	—	—	—	—	—	—
AVG:	—	—	0.20	—	—	—	—	—	—	—	—	—

	Pb-d	Pb-s	Hg-d	Hg-s	Mn-d	Mn-s	Ni-d	Ni-s	Zn-d	Zn-s	Mg-d	Coli
MD-663												
MIN:	—	—	0.20	—	—	—	—	—	—	—	—	—
MAX:	—	—	0.20	—	—	—	—	—	—	—	—	—
AVG:	—	—	0.20	—	—	—	—	—	—	—	—	—

Appendix B. Species list of vegetation reported from the Charleston Harbor Estuary during the period 1970-1985.

Alisma plantago/—aquatica

Alternanthera philoreroides
Amaranthus cannibinus
Anacharis canadensis
Anarcharis densa
Aneilema keisak
Apios americana
Aster carolinianus
Bidens laevis
Cabomba caroliniana
Ceratophyllum demersum
Chara sp.
Cicuta maculata
Cladium jamaicensis
Cuscuta sp.
Cyperus sp.
Dracocephalum sp.
Egeria densa
Eleocharis sp.
Eryngium aqaticum
Eupatorium rotundifolium
Galium sp.
Hydrocotyle verticillata
Hydrotrida caroliniana
Hymenocallis sp.
Hypericum sp.
Impatiens capenses
Juncus biflows
Leersia hexandra
Leersia oryzoides
Lemna minor
Lobelia cardinalis
Ludwigia uruguayensis
Lycopus sp.
Lycopus sessilifolius
Mikania scandens
Myriophyllum heterophyllum
Nelumbo lutea
Nitella sp.
Nymphaea odorata
Orontium aquaticum
Oxypolis filiformis
Peltandra virginica
Pnicum sp.
Polygonum arifolium
Polygonum punctatum
Polygonum sagittatum
Polygonum sp.
Pontderia cordata
Potamogeton capillaceus
Potamogeton diversifolius
Potamogeton sp.
Ruppia maritima
Rynchospora careyana
Rynchospora macrostachya
Sacciolepis striata
Sagittaria graminea
Sagittaria latifolia
Samolus pauciflorus
Scirpus americanus
Scirpus cyperinus
Scirpus etuberculatus
Scirpus robustus
Scirpus validus
Sium suave
Spartina alterniflora
Spartina patens
Spartina cynosuroides
Spiranthes sp.
Typha angustifolia
Typha latifolia
Utricularia sp.
Xyris caroliniana
Zannichellia palustris
Zizania aquatica
Zizianiopsis miliacea
Zostera marina

Appendix C. Species list of benthic macroalgae reported from the Charleston Harbor Estuary during the period 1970-1985.

Bryopsis plumosa
Codium sp.
Enteromorpha lingulata
Halymenia sp.
Polysiphonia sp.
Porphyra sp.
Ulva lactuca

Appendix D. Species list of phytoplankton and periphyton reported from the Charleston Harbor Estuary during the period 1970-1985.

Achnanthes brevipes
Achnanthes exigua
Achnanthes lanceolata
Achnanthes longipes
Achnanthes manifera
Achnanthes microcephalum
Actinastrum hantzschii
Actinella punctata
Actinocyclus ehrenbergii
Actinoptychus splendens
Actinoptychus taeniatus
Actinoptychus undulatus
Agmenellum quadirduplicatum
Amphidinium fusiforme
Amphidinium klebsi
Amphiphora alata
Amphiphora gigantea
Amphiphora ornata
Amphiphora paludosa
Amphiphora sulcata
Amphiprora ornata
Amphora coffeaeformis
Amphora crassa
Amphora gigantea
Amphora lineolata
Amphora ostrearia
Amphora ovalis
Amphora proteoides
Anabaena inequalis
Anabaena variabilis
Anacystis aeruginosa
Anacystis cyanea
Anacystis thermalis
Ankistrodesmus convalutus
Ankistrodesmus falcatus
Ankistrodesmus nannoselene
Ankistrodesmus spiralis
Arthrodesmus convergens
Arthrodesmus phimus
Arthrospira jenneri
Asterionella formosa
Asterionella japonica
Aulosira laxa
Bacteriastrum delicatulum
Bacteriastrum elongatum
Bacteriastrum hyalinum
Bacteriastrum varians
Biddulphia alternans
Biddulphia aurita
Biddulphia dubia
Biddulphia laevis
Biddulphia longicruris
Biddulphia mobiliensis
Biddulphia pulchella
Biddulphia regia
Biddulphia rhombus
Biddulphia sinensis
Binuclearia tatrana
Botryococcus braunii
Bulbochaete sp.
Campylosira cymbelliforme
Ceartium incisum
Ceratium carolinianum
Ceratium contortium
Ceratium furca
Ceratium fusus
Ceratium macroceros
Ceratium massiliense
Ceratium reflexum
Ceratium teres
Ceratium tripos
Ceratulina bergonii
Ceratulina pelagica
Chaetoceros affinis
Chaetoceros atlanticus
Chaetoceros borgei
Chaetoceros brevis
Chaetoceros compressus
Chaetoceros constrictus
Chaetoceros convolutus
Chaetoceros crinitus
Chaetoceros curvisetus
Chaetoceros danicus
Chaetoceros debile

Chaetoceros decipiens
Chaetoceros didymus
Chaetoceros gracilis
Chaetoceros hispidum
Chaetoceros lacinosum
Chaetoceros lorenzianus
Chaetoceros mulleri
Chaetoceros pelagicus
Chaetoceros pendulus
Chaetoceros similis
Chaetoceros simplex
Chaetoceros subsecundus
Chaetoceros subtilis
Chaetoceros teres
Chaetoceros wighami
Chlamydomonas globosa
Chlamydomonas pseudoperty
Chlamydomonas sphagnicola
Chlorella sp.
Chotadella sp.
Chroococcus limneticus
Chroococcus turgidus
Chroomonas amphioxeia
Chroomonas caroliniana
Chroomonas minuta
Closterium abruptum
Closterium costatum
Closterium gracile
Closterium leibleinii
Closterium lineatum
Closterium lunula
Closterium navicula
Closterium pronum
Closterium toxon
Coccochloris stagnina
Coccolithus huxleyi
Cocconeis disculoides
Cocconeis placentula
Cocconeis scutellum
Cochlodinium heterolobatum
Coelastrum cambricum
Coelastrum morus
Coelosphaerium pallidum
Corethron criophilum
Coscinodiscus antiquus
Coscinodiscus asteromphalus
Coscinodiscus centralis
Coscinodiscus concinnus
Coscinodiscus excentricus
Coscinodiscus granii
Coscinodiscus gravidus
Coscinodiscus lineatus
Coscinodiscus perforatus
Coscinodiscus plicatus
Coscinodiscus radiatus
Coscinodiscus subtilis
Coscinosira polychorda
Cosmarium bioculatum
Cosmarium bipunctatum
Cosmarium biretum
Cosmarium blytii
Cosmarium circulare
Cosmarium cucumis
Cosmarium cucurbita
Cosmarium margaritiferum
Cosmarium margoritatum
Cosmarium obtusatum
Cosmarium portianum
Cosmarium quinarium
Cosmarium subcrenatum
Cosmarium subspeciosum
Cosmarium tenue
Crucigenia crucitera
Crucigenia fenestrata
Crucigenia irregularis
Crucigenia rectangularis
Crucigenia tetrapedia
Cryptomonas erosa
Cryptomonas ovata
Cryptomonas pseudobaltica
Cyclotella kutzingiana
Cyclotella meneghiniana
Cyclotella meneghininiana
Cyclotella striata
Cylindrotheca closterium
Cymatosira belgica
Cymbella affinis
Cymbella minuta
Cymbella tumida
Denticula sp.

Desmidium grevillii
Desmidium swartzii
Dictyocha fibula
Dictyosphaerium ehrenbergianum
Dictyosphaerium pulchellum
Dimeregramma minor
Dimeregramma rostratum
Dimorphococcus lunatus
Dinobryon sertularia
Dinoflagellate cyst
Dinophtsis hastata
Dinophysis acuminata
Dinophysis homunculus
Dinophysis ovum
Dinophysis schuetti
Dinophysis tripes
Diploneis bombus
Diploneis crabro
Diploneis didyma
Diploneis elliptica
Diploneis fusca
Diploneis obligua
Diploneis puella
Diploneis smithii
Ditylum brightwelli
Dunaliella sp.
Ebria tripartita
Epithemia sp.
Euastrum ansatum
Euastrum crassicolle
Euastrum denticulatum
Euastrum elegans
Euastrum oblongum
Eucampia zoodiacus
Eudorina sp.
Euglena acutissima
Euglena ascus
Euglena gracilis
Euglena minima
Euglena mutabilis
Euglena polymorpha
Euglena proxima
Euglena spirogyra
Eunotia curvata
Eunotia monodon
Eunotia robusta
Eunotogramma marinum
Eunotogramma rostratum
Eutrepia lanowii
Eutrepia viridis
Exuviaella compressa
Exuviaella marina
Fragilaria construens
Fragilaria crotonensis
Fragilaria investiens
Fragilaria virescens
Glenodinium rotundum
Gloeocystis ampla
Gloeocystis gigas
Gloeocystis vesiculosa
Gomphonema affine
Gomphonema augur
Gomphonema gracile
Gomphonema parvulum
Gomphonema spaerophorum
Gomphonema truncatum
Gomphosphaeria lacustris
Gonatozygon monotaenium
Goniaulax glyptorhynchus
Goniaulax spinifera
Gonium pectorale
Gonium sociale
Gopmphonema acuminatum
Grammayophora marina
Guinardia flaccida
Gymnodinium danicus
Gymnodinium galesianum
Gymnodinium lunula
Gymnodinium splendens
Gymnozyga moniliformis
Gyrodinium dominas
Gyrodinium estuariale
Gyrodinium glaebum
Gyrodinium metum
Gyrodinium pellucidum
Gyrosigma balticum
Gyrosigma fasciola
Gyrosigma febigerii
Gyrosigma obtusatum
Gyrosigma peisonis

Gyrosigma peisonis
Gyrosigma spencerii
Hantzschia virgata
Hemiaulus hauckii
Hemiaulus sinensis
Hemiselmis sp.
Heteromastix pyriformis
Hyalodiscus stelliger
Hyalotheca dissiliens
Hyalotheca mucosa
Isochrysis galbana
Katodinium rotundatum
Kirchneriella conloria
Kirchneriella lunaria
Kirchneriella obesa
Lauderia borealis
Leptocylindrus danicus
Leptocylindrus minimus
Licmophora lyngbyei
Lithodesmium undulater
Lyngbya digueti
Lyngbya langerheimii
Mallomonas caudata
Mastogloia gibbosa
Mastogloia minuta
Melosira distans
Melosira granulata
Melosira granulata
Melosira islandica
Melosira italica
Melosira jurgensii
Melosira moniliformis
Melosira nummuloides
Melosira sulcata
Melosira varians
Meridion circulare
Merismopedia elegans
Merismopedia glauca
Merismopedia punctata
Micractinium sp.
Micrasterias denticulata
Micrasterias laticeps
Micrasterias pinnatifida
Micrasterias radiata
Micrasterias radiosa
Micrasterias truncata
Microcoleus sp.
Microspora pachyderma
Monochrysis lutheri
Mougeotia recurva
Nannochloris sp.
Navicula abrupta
Navicula abunda
Navicula agnita
Navicula borealis
Navicula cancellata
Navicula cinta
Navicula dissipata
Navicula exigua
Navicula graciloides
Navicula granulata
Navicula lanceolata
Navicula lyra
Navicula meniscoides
Navicula minima
Navicula mutica
Navicula perigrina
Navicula salinarum
Navicula secura
Nephrocytium agardhianium
Nephrocytium obesum
Nitzschia acicularis
Nitzschia acuminata
Nitzschia adducta
Nitzschia circumsuta
Nitzschia closterium
Nitzschia compressa
Nitzschia delicatissima
Nitzschia dissipata
Nitzschia filiformis
Nitzschia hummi
Nitzschia laevis
Nitzschia levidensis
Nitzschia longa
Nitzschia longissima
Nitzschia obtusa
Nitzschia palea
Nitzschia panduriformis
Nitzschia paradoxa
Nitzschia paradoxa

Nitzschia pungens
Nitzschia reversa
Nitzschia seriata
Nitzschia sigma
Nitzschia sigmoidea
Nitzschia triblionella
Nitzschia vermicularis
Nostoc sp.
Ochromonas nannos
Oedogonium crassiusculum
Olisthodiscus carterae
Onchyonema filiforme
Oocystis elliptica
Oocystis lacustrus
Ornithoceros carolineae
Ornithoceros splendidus
Oscillatoria chlorina
Oscillatoria limosa
Oscillatoria princeps
Oscillatoria subuliformis
Oscillatoria tenuis
Oxyrrhis sp.
Palmyodictyon varium
Palmyodictyon viride
Pandorina morum
Pediastrum araneosum
Pediastrum biradiatum
Pediastrum duplex
Pediastrum simplex
Pediastrum tetras
Penium libellula
Penium spirostiolatum
Peridinium bervipes
Peridinium marielebourae
Peridinium oblungum
Peridinium oceanicum
Peridinium quarnerense
Peridinium quinquecorne
Peridinium triquetrum
Peridinium trochoideum
Phacus acuminatus
Phacus anacoelus
Phacus brevicaudatus
Phacus curvcavdata
Phacus lemmermannii
Phacus lismorensis
Phacus pyrum
Phacus svecicus
Phacus swirenkoi
Phacus tartus
Phalacroma acutum
Phalacroma hindmarchi
Phormidium fragile
Pinnularia mesolepta
Plagiogramma pygmaeum
Plagiogramma vanherckii
Pleurodiscus sp.
Pleurosigma aestaurii
Pleurosigma affine
Pleurosigma fasciola
Pleurotaenium coronatum
Pleurotaenium ehrenbergii
Pleurotaenium trabecula
Prorocentrum micans
Prorocentrum minimum
Pseudopedinella pyriforme
Pyramimonas amylifera
Pyramimonas grossi
Pyramimonas micron
Pyramimonas nanella
Pyramimonas obovata
Pyramimonas plurioculata
Radiofilium flavescens
Raphoneis amphiceros
Raphoneis belgica
Raphoneis surirella
Rhipodendron huxleyi
Rhizosolenia alata
Rhizosolenia calceravis
Rhizosolenia castracahei
Rhizosolenia fragilissima
Rhizosolenia hebetata
Rhizosolenia imbricata
Rhizosolenia robusta
Rhizosolenia setigera
Rhizosolenia stolterfothii
Rhodomonas minuta
Scenedesmus abundans
Scenedesmus abundans
Scenedesmus acuminata

Scenedesmus arcuatus
Scenedesmus armatus
Scenedesmus bijuga
Scenedesmus brasiliensis
Scenedesmus denticulatus
Scenedesmus dimorphus
Scenedesmus incrassulatus
Scenedesmus obliquus
Scenedesmus opoliensis
Scenedesmus perforatus
Scenedesmus producto-capitatus
Scenedesmus quadricauda
Selenastrum gracile
Selenastrum westii
Skeletonema costatum
Skeletonema tropicum
Spirogyra sp.
Spirulina laxissima
Spirulina major
Spirulina princeps
Spondylosium rectangulare
Staurastrum affine
Staurastrum alternans
Staurastrum breviaculatum
Staurastrum chaetoceras
Staurastrum dejectum
Staurastrum elongatum
Staurastrum granulosum
Staurastrum hexacerum
Staurastrum inconspicuum
Staurastrum johnsonii
Staurastrum margaritaceum
Staurastrum orbiculare
Staurastrum ornithopodum
Staurastrum pachyrhychum
Staurastrum paradoxum
Staurastrum polymorphum
Staurastrum seligerum
Staurastrum spiculiferum
Stauroneis anceps
Stephanopyxis turris
Stichococcus subtilis
Stigeoclonium subsecundum
Stigeoclonium tenue
Streptotheca thamensis
Surirella elegans
Surirella gemma
Surirella ovalis
Synecoccus aeruginosa
Synedra acus
Synedra delicatissima
Synedra fasiculata
Synedra gallionii
Synedra hennedyana
Synedra miniscula
Synedra parasitica
Synedra pulchella
Synedra rumpens
Synedra tabulata
Synedra ulna
Tabellaria fenestrata
Terpsinoe americana
Tetmemorus brebissonii
Tetmemorus granulatus
Tetradesmus wisconsinse
Tetraedon trigonum
Tetraedron limneticum
Tetraedron obesa
Tetraedron regulare
Tetraedron trigonum
Tetraselmis gracilis
Tetraselmis maculata
Tetrastrum staurogeniaeforme
Thalassionema nitzschoides
Thalassiosira decipiens
Thalassiosira fluviatilis
Thalassiosira pseudonana
Thalassiosira nordenskioldii
Thalassiosira rotula
Thalassiothrix delicatula
Thalassiothrix frauenfeldii
Thalassiothrix longissima
Thalassiothrix nitzschioides
Trachelomonas abrupta
Trachelomonas acuminata
Trachelomonas armata
Trachelomonas dybowskii
Trachelomonas ensifera
Trachelomonas hispida
Trachelomonas robusta

Triceratium americanum
Trichodesmium lacustre
Triplocerus gracile
Tropidoneis lepidoptera
Ulothrix tenerrima
Ulothrix variabilis
Vaucheria litorea
Xanthidium armatum
Zygnema sp.

Appendix E. Species list of zooplankton reported from the Charleston Harbor estuary during the period 1970-1985.

Copepods:

Acartia tonsa
Centropages hamatus
Centropages typicus
Corycaeus sp.
Eurytemora affines
Euterpina acutifrons
Labidocera aestiva
Microcyclops varicans
Oithona colcarua
Oithona nana
Pseudodiaptomous coronatus
Parvocalanus crassirostris
Temora turbidinata
Tortanus setacaudatus

Larval and Juvenile Finfish:

Alosa aestivalis
Alosa mediocris
Alosa sapidissima
Anchoa mitchilli
Anguilla rostrata
Brevoortia tyrannus
Cyprinus carpio
Dorosoma petenense
Enneacanthus chaetodon
Esox niger
Etheostoma sp.
Gambusia affinis
Heterandria formosa
Ictalurus catus
Lagodon rhomboides
Larimus fasciatus
Leiostomus xanthurus
Lepisosteus osseus
Lepomis auritus
Menidia beryllina
Menidia menidia
Micropogonias undulatus
Micropterus salmoides
Notemigonus crysoleucas
Perca flavescens
Pomoxis nigromaculatus
Pomoxis annularis
Strongylura marina
Trinectes maculatus
Urophycis regius

Larval and Juvenile Invertebrates:

Aulodrilus limnobius
Aulophorus flabelliger
Callinectes sapidus
Cassidinidea lunifrons
Corbicula manilensis
Cura foremanii
Dero digitata
Dugesia tigrina
Enallagma sp.
Eupera cubensis
Gammarus fasciatus
Gammarus tigrinus
Gyraulus sp.
Hyalella azteca
Ilyodrilus templetoni
Leptocella candida
Leptocerus americanus
Limnodrilus hoffmeisteri

Larval and Juvenile Invertebrates (continued):

Nais bretscheri
Nais communis
Oxyethira sp.
Pectinatella magnifica
Peloscolex multisetosus
Penaeus aztecus
Penaeus duorarum
Penaeus setiferus
Physa sp.
Plumatella repens
Pristina synclites
Stylaria fossularia
Stylaria lacustris
Urnatella gracilis

Appendix F. Species list of benthic macroinvertebrates reported from the Charleston Harbor Estuary during the period 1970-1985.

Ablabesmyia sp.
Acetes americanus
Aeverrillia setigera
Aglaophenia trifida
Agraylea sp.
Alcyonidium hauffi
Alpheus armillatus
Alpheus heterochaelis
Alpheus normanni
Amaroycian constellatum
Amathia distans
Anachis avara
Anguinella palmata
Arenaeus cribrarius
Asellus communis
Asellus intermedius
Asterias forbesi
Astrangia danae
Aulodrilus limnobius
Axinella sp.
Baetis sp.
Balanus amphitrite
Balanus eburneus
Balanus galeatus
Balanus improvisus
Barentsia laxa
Barnea truncata
Bowerbankia gracilis
Brachidontes exustus
Brachidontes recurvus
Brachyura sp.
Branchiura sowerbyi
Brentisia sp.
Bugula neritina
Busycon carica
Callinectes ornatus
Callinectes sapidus
Callinectes similis
Campanulina sp.
Cancer irroratus
Caprella equilibra
Cassidinidea lunifrons
Celleporina hassalli
Corbicula manilensis
Chaetogaster sp.
Chelonibia patula
Chiridotea sp.
Clibanarius vittatus
Clytia kincaidi
Conopeum tenuissimum
Corbicula manilensis
Cordylophora caspia
Corophium lacustre
Crassostrea virginica
Crepidula plana
Cricotopus sp.
Cryptochironomous sp.
Cryptosula pallasiana
Cura foremanii
Cuspidella humilis
Cyathura burbancki
Cyathura polita
Degesia tigrina
Dero digitata
Diadumene leucolena
Dicrotendipes sp.
Diplodonta descipiens
Dugesia tigrina
Dynamena cornicina
Ectopleura dumortieri
Edotea montosa
Electra monostachys
Enallagma sp.
Entomobryia sp.
Erpodbella punctata
Eteone heteropoda
Eudendrium carneum
Eupera cubensis
Eurypanopeus depressus
Exhippolysmata oplophorides
Ferrissia sp.
Gammarus daiberi
Gammarus fasciatus
Gammarus mucronatus

Gammarus tigrinus
Garveia franciscana
Garveia humilis
Glycera dibranchiata
Gyraulus sp.
Haploscoloplos fragilis
Hepatus epheliticus
Heteromastus filiformis
Hexapanopeus angustifrons
Hippolysmata oplophoroid
Hippoporina verrilli
Hyalella azteca
Hydractinia echinata
Hydroides dianthus
Hydrolimax grisea
Hydropsyche sp.
Ilodrilus cervix
Ilyanassa obsoleta
Ilyodrilus templetoni
Latreutes parvulus
Lepidactylus dytiscus
Leptochela serratorbita
Leptogorgia virgulata
Leucon americana
Libinia dubia
Libinia emarginata
Limnodrilus cervix
Limnodrilus hoffmeisteri
Limnodrilus udekemianus
Limulus polyphemus
Lolliguncula brevis
Lumbrineris sp.
Lysmata wurdemanni
Macrobrachium acanthurus
Macrobrachium ohione
Macrobrachium olfersii
Magelona sp.
Melita nitida
Mellita quinquisperforata
Membranipora arborescens
Membranipora tenuis
Menippe mercenaria
Metoporhaphis calcarata
Micropanope sculptipes
Microporella ciliata
Molgula manhattensis
Monoculodes edwardsi
Mulinia lateralis
Mytilopsis leucophaeata
Nais bretscheri
Nais communis
Neopanope sayi
Neopontonides beaufortensis
Nereis succinea
Nolella stipata
Notomastus sp.
Obelia bidentata
Obelia dichotoma
Ogyrides alphaerostris
Orthotrichia sp.
Ostrea equestris
Ovalipes ocellatus
Ovalipes stephensoni
Oxyethira sp.
Pagurus longicarpus
Pagurus pollicaris
Palaemonetes intermedius
Palaemonetes pugio
Palaemonetes vulgaris
Palpomya sp.
Panopeus herbstii
Panopeus occidentalis
Paranthus rapiformis
Parapleustes aestuarius
Paraprionospio pinnata
Parasmittina nitida
Paratendipes sp.
Peloscolex freyi
Peloscolex multisetosus
Penaeus aztecus
Penaeus duorarum
Penaeus setiferus
Pentaneura sp.
Periclimenes longicaudatus
Petrolisthes galathinus
Physa sp.
Placobdella multilineata
Placobella sp.
Plumularia floridana
Polycentrous sp.

Portunus gibbesii
Portunus spinimanus
Procambarus clarki
Procladius bellus
Pseudosida bidentata
Renilla reniformis
Rheotanytarsus sp.
Rhithropanopeus harrisii
Sabellaria vulgaris
Schizoporella errata
Scolecolepides viridis
Sertulania marginata
Sertularis stookeyi
Sicyonia brevirostris
Sicyonia dorsalis
Sicyonia laevigata
Siphlonurus sp.
Slavina apprediculata
Specaria josinae
Sphaerium transversum
Squilla empusa
Squilla neglecta
Stenonema sp.
Streblospio benedicti
Stylaria fossularia
Stylochus ellipticus
Tanystylum orbiculare
Tanytarsus sp.
Tellina sp.
Tharyx setigera
Trachypenaeus constrictus
Tricorythodes sp.
Upogebia affinis
Xenochironomus sp.
Xiphopenaeus kroyeri

Appendix G. Species list of finfish reported from the Charleston Harbor Estuary during the period 1970-1985.

Acantharchus pomotis
Acipenser brevirostrum
Acipenser oxyrhynchus
Alosa aestivalis
Alosa mediocris
Alosa sapidissima
Aluterus schoepfi
Ambloplites rupestris
Amia calva
Anchoa hepsetus
Anchoa mitchilli
Ancylopsetta quadrocellata
Anguilla rostrata
Aphredoderus sayanus
Archosargus probatocephalus
Arius felis
Astroscopus y-graecum
Bagre marinus
Bairdiella chrysoura
Brevoortia smithi
Brevoortia tyrannus
Caranx hippos
Carcharhinus milberti
Carcharhinus obscurus
Carcharhinus plumbeus
Centrarchus macropterus
Centropomus undecimalis
Centropristis philadelphica
Centropristis striata
Chaetodipterus faber
Chasmodes bosquianus
Chilomycterus antillarum
Chilomycterus schoepfi
Chloroscombrus chrysurus
Citharichthys macrops
Citharichthys spilopterus
Conger oceanicus
Cynoscion nebulosus
Cynoscion nothus
Cynoscion regalis
Cyprinus carpio
Dasyatis americana
Dasyatis centroura
Dasyatis sabina
Dasyatis sayi
Diapterus olisthostomus
Dormitator maculatus
Dorosoma cepedianum
Dorosoma petenense
Elassoma zonatum
Eleotris pisonis
Elops saurus
Enneacanthus chaetodon
Enneacanthus gloriosus
Enneacanthus obsesus
Esox americanus
Esox niger
Etheostoma sp.
Etropus crossotus
Eucinostomus argenteus
Eucinostomus gula
Eucinostomus harengulus
Eucinostomus sp.
Evorthodus lyricus
Fundulus heteroclitus
Gambusia affinis
Gobiesox strumosus
Gobiomorus dormitor
Gobionellus boleosoma
Gobionellus hastatus
Gobionellus shufeldti
Gobiosoma bosci
Gobiosoma ginsburgi
Gymnura micrura
Heterandria formosa
Hippocampus erectus
Hypleurochilus geminatus
Hypsoblennius hentzi
Hypsoblennius ionthas
Ictalurus catus
Ictalurus furcatus
Ictalurus melas
Ictalurus natalis
Ictalurus nebulosus

Ictalurus platycephalus
Ictalurus punctatus
Labidesthes sicculus
Lagocephalus laevigatus
Lagodon rhomboides
Larimus fasciatus
Leiostomus xanthurus
Lepisosteus osseus
Lepomis auritus
Lepomis gibbosus
Lepomis macrochirus
Lepomis megalotis
Lepomis microlophus
Lepomis punctatus
Lutjanus griseus
Lutjanus synagris
Lucania goodei
Lucania parva
Megalops atlanticus
Membras martinica
Menidia beryllina
Menidia menidia
Menticirrhus americanus
Menticirrhus littoralis
Menticirrhus saxatilis
Micropogonias undulatus
Micropterus dolomieui
Micropterus salmoides
Monacanthus hispidus
Morone americana
Morone saxatilis
Mugil cephalus
Mugil curema
Mullus auratus
Mustelus canis
Mycteroperca microlepis
Myliobatis freminvillei
Myrophis punctatus
Notemigonus crysoleucas
Notropis petersoni
Noturus gyrinus
Ogcocephalus radiatus
Ophichthus gomesi
Ophichthus melanoporus
Ophidion marginatum
Opisthonema oglinum
Opsanus tau
Orthopristis chrysoptera
Paralichthys albigutta
Paralichthys dentatus
Paralichthys lethostigma
Peprilus alepidotus
Peprilus paru
Peprilus triacanthus
Perca flavescens
Pogonias cromis
Pomatomus saltatrix
Pomoxis nigromaculatus
Pomoxis annularis
Prionotus carolinus
Prionotus evolans
Prionotus scitulus
Prionotus tribulus
Rachycentron canadum
Raja eglanteria
Rhinoptera bonasus
Rhizoprionodon terraenovae
Rissola marginata
Sciaenops ocellata
Scomberomorus maculatus
Scophthalmus aquosus
Selene setapinnis
Selene vomer
Sphoeroides maculatus
Sphyraena guachancho
Stellifer lanceolatus
Stenotomus aculeatus
Strongylura marina
Symphurus civitatus
Symphurus plagiusa
Syngnathus floridae
Syngnathus fuscus
Syngnathus louisianae
Syngnathus scovelli
Synodus foetens
Trichiurus lepturus
Trinectes maculatus
Umbra pygmae
Urophycis earlli
Urophycis floridanus

Urophycis regius
Vomer setapinnis