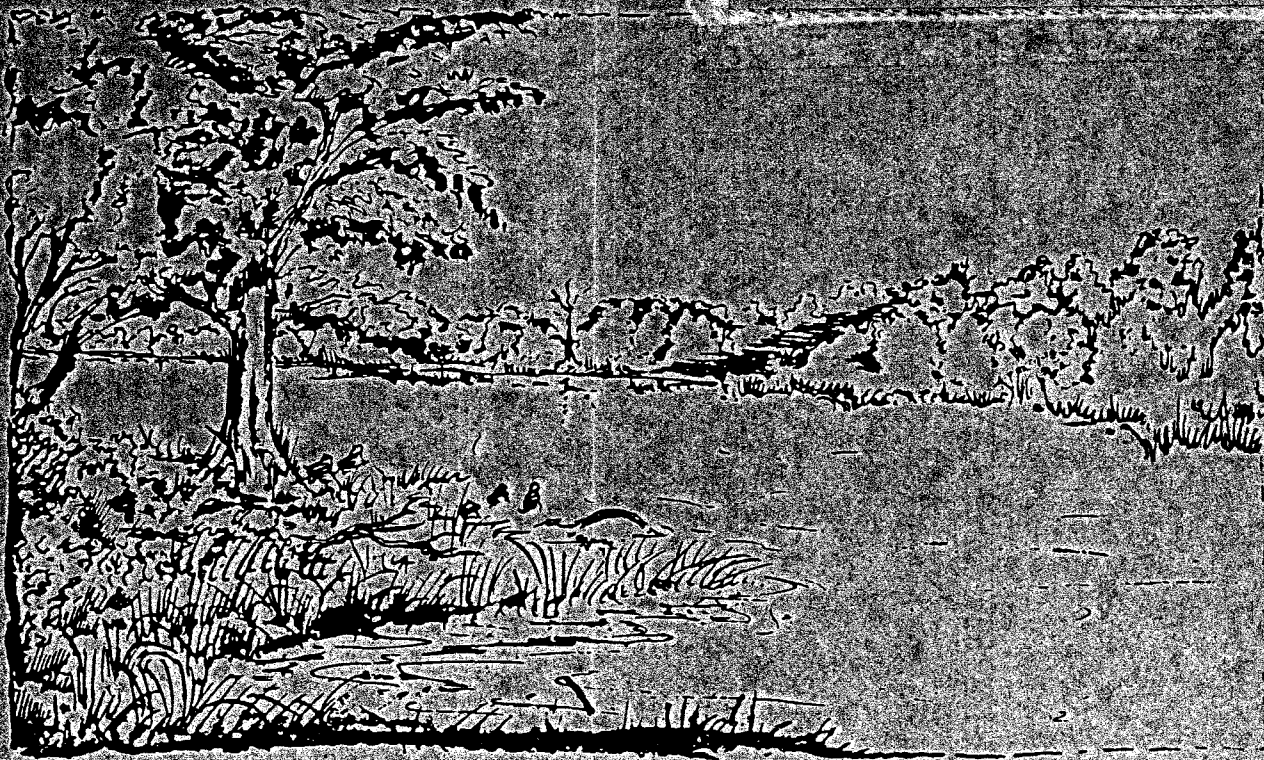


STATUS AND TRENDS REPORT

OF THE

ALBEMARLE-PAMLICO ESTUARINE STUDY

April 1991



**ALBEMARLE-PAMLICO
ESTUARINE SYSTEM**

Technical Analysis of Status and Trends

Albemarle-Pamlico Estuarine Study Report ⁹¹⁻⁰¹

April 1991

Edited by

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ALBEMARLE-PAMLICO ESTUARINE SYSTEM
Analysis of the Status and Trends

Albemarle-Pamlico Estuarine Study Program Report No. 90-01

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This report is based on a previous report developed under an agreement of the Albemarle-Pamlico Estuarine Study, among the NC Department of Environment, Health and Natural Resources, US Environmental Protection Agency/National Estuary Program, the Sea Grant College Program, and the Water Resources Research Institute of the University of North Carolina.

Editor: Jennifer Steel

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This study was conducted under financial support of the US Environmental Protection Agency (EPA) through its agreement with the NC Department of Environment, Health, and Natural Resources (DEHNR) as part of the Albemarle-Pamlico Estuarine Study. Substantial resources were contributed to the preliminary report by the University of North Carolina Sea Grant College Program and Water Resources Research Institute in staff time, equipment, and operations. Considerable contribution was provided by several institutions, agencies and individuals in the development of various analyses included in this report. Mr. Theodore Bisterfeld, EPA Region IV, Atlanta, served as the project officer and cooperated in all aspects of the study. Dr. Robert Holman, previous Program Director of the Albemarle-Pamlico Estuarine Study, Raleigh, provided valuable support and cooperation in getting access to necessary information and agencies. The staff of the Center for Geographic Information and Analysis, then in the NC Division of Statistics and Information, provided maps and data; we are grateful to them for responding promptly to many requests, often on short notice. We are grateful to all these organizations for helping make this report possible.

Our most special appreciation goes to all those individuals whose expertise and generosity contributed to the content of the report. All those who supplied special parts to the report are listed as authors for each chapter and will not be cited individually here. Each person spent concentrated periods of time preparing sections in areas in which he/she is an authority. For this effort there was no compensation. The support that all these experts received from their institutions and agencies is gratefully acknowledged. In addition to our own experts, we consulted nationally recognized estuarine scientists. We are especially grateful to Dr. Dianne Berile, Florida Institute of Technology and Executive Director of the Indian River Estuarine Federation, and Dr. Scott Nixon, University of Rhode Island School of Oceanography, for their suggestions and encouragement. We also appreciate the members of the Albemarle-Pamlico Estuarine Study Citizens Advisory Committees, Technical Committee, and Policy Committee, as well as staff members of various state and federal management agencies who provided information, suggestions, comments, and encouragement during the study.

We acknowledge and appreciate the cooperation and understanding of all who contributed under the constraints of limited time and resources. This was a difficult task, completed only because of the dedication, contributions, and cooperation of many people whose love and support of North Carolina's coastal resources are unsurpassed anywhere in the world.

EXECUTIVE SUMMARY

INTRODUCTION

In spite of a suite of laws enacted during the 1970s, many of the nation's critical coastal ecosystems are in serious decline. Public attention has turned once again to threatened estuarine systems -- Chesapeake Bay, Narragansett Bay, Buzzards Bay, Long Island Sound, Puget Sound, and San Francisco Bay -- areas in which decades of population concentration and industrial development have resulted in the contamination of sediments, and the dramatic declines of living resources.

The Albemarle-Pamlico (A/P) estuarine system in North Carolina had become another one of these threatened systems. It is the second largest estuarine complex in North America and a key nursery area for east coast fisheries. In 1987, the A/P system was designated as an estuary of national significance and was selected to be studied, along with those mentioned above, as part of the Environmental Protection Agency's (EPA) National Estuary Program. Thus, the Albemarle-Pamlico Estuarine Study was initiated, a cooperative research and management program between EPA and the State of North Carolina's Department of Environment, Health, and Natural Resources.

The purpose of the A/P Study is to find out how serious environmental problems are in North Carolina's estuaries and how the estuaries can be preserved and managed to maintain their environmental integrity and maximize the use and pleasure people derive from them. The A/P Study's efforts are focused and guided by four committees composed of concerned citizens and people with knowledge of environmental science, management, and law. For more than three years, scientists funded by the A/P Study and other state and federal agencies have focused their research efforts on the characterization of and changes in the A/P system. This report is a compilation of the results of those studies and many previous years of estuarine research.

Any attempt to understand and rectify the problems of the A/P system must be based on an understanding of the dynamics of the system. The A/P system is made up of Albemarle Sound (including Currituck and Croatan Sounds), Pamlico Sound (including Core, Roanoke, and Bogue Sounds), with their many tributaries, marshes, swamps, and wetlands. On the western side of the system, numerous rivers discharge fresh water into the sounds. On the eastern side, a chain of barrier islands with only a few inlets in the southern portion of Pamlico Sound, hold back the Atlantic Ocean. River flow, winds, and tides are the most important forces at work in this system. These dynamic forces act to push, pull, mix, stratify, and remix the water and affect numerous physical, biological, and chemical processes such as fish recruitment, stratification of the waters, and sedimentation.

People who live near the rivers and estuaries have seen striking changes in the environment. In places along the riverbanks, submerged grasses once grew in beds so thick that it was necessary to cut paths to pass between the open river and the shore. Today, in many places, the grasses are gone and with them the young fish and shellfish that grew and were nurtured among them. Often, the river waters are turbid and dirty looking. Vast swamp area once inhabited by snakes, bears, and other wildlife, have been cleared, drained, and planted as extensive fields of soybeans, wheat, and corn. Shopping centers and condominium complexes have sprung up near fragile marshlands, once nursery areas for fish and shellfish. Shellfishing areas have disappeared or have been closed to harvests because of contamination by human waste. Fishing catches have declined. many fish and crabs suffer skin and shell diseases and so cannot be sold for human consumption. Large algae blooms occur periodically in many of the estuaries, rendering some areas unfit for swimming or fishing. Anoxic events have decimated local populations of fish and shellfish.

How people view changes in the A/P system depends on how they want to use its resources. Increasingly, conflicts are arising among the uses and the users of the estuarine resources. Boaters may think that a quiet accessible harbor is a perfect place for a marina, but people who harvest shellfish from the area may be concerned about contamination from human waste, marine fuels, and other toxicants. A recreational fisherman may be happy to pull a shrimp trawl and take home a few dozen pounds of shrimp, but a commercial shrimper may be upset when thousands of recreational fishermen do the same thing and compete for the available resource. A farmer may want to use a small stream as a drainway to help lower the water table under one of his fields to keep his crops from drowning, but fishermen may regret the changes that the fresh water brings to a once productive primary nursery area. Commercial clammers may think that using a propeller wash to dislodge clams from the bottom is simply a more effective method of harvest, but those who understand the ecological value of submerged grasses and the harm that "clam kicking" can do, may think otherwise.

Use conflicts extend far upstream, too. Residents of inland cities and towns see "their" streams as water supplies and waste disposal resources. Coastal residents, however, expect those same streams to be clean when they reach the coast and to support wetland production, fish propagation, and other vital ecological functions.

This document summarizes the conditions and the trends that have been found in the A/P system and what is known about their causes.

CRITICAL AREAS

Submerged Aquatic Vegetation (SAV):

Status: SAV occurs in shallow low-salinity waters, in narrow bands along the eastern shores of Albemarle and Pamlico Sounds and in broad swaths across much of Core, Back, and Bogue Sounds. SAV habitat supports populations of bay scallops and numerous other species of shellfish, fish, and birds.

Trends: Scant historical observational records indicate an almost complete disappearance of SAV in the Pamlico River and Back Bay. In Currituck Sound major shifts in density and species assemblages have occurred; currently, SAV beds are greatly reduced in density and extent. In the western portion of Albemarle Sound significant (though unquantified) declines have also been documented. In the eastern portions of Albemarle and Pamlico Sounds, SAV appears to be quite stable.

Causes: On the western shores of the A/P system, the primary cause of the decline of SAV is believed to be related to increasing freshwater runoff, increased turbidity (from sediment-laden runoff, bottom-disturbing practices, and algal blooms), and encrustation by algae. Turbidity and encrustation effectively reduce the amount of light available to the plants for photosynthesis. On the eastern shores, decline is caused primarily by physical destruction or disturbance by dredges, boat propellers, and illegal fishing practices. If these conditions and practices continue, SAV will likely continue to decline.

Wetlands:

Status: There were an estimated 12,100 acres of tidal salt marsh (regularly flooded marsh) and 138,000 acres of non-tidal brackish marsh (irregularly flooded salt marsh) within the study area, according to a

1962 report (Wilson, 1962). The same report estimated that approximately 38,700 acres of nontidal freshwater marsh existed in the area. Significant tracts of riparian/alluvial forested wetlands ("wooded swamps and bottomlands") also exist; as of 1954 it was estimated that there were roughly 804,000 acres of these wetlands within the study area. Inland wetlands (pocosin and related wetlands and nonriverine swamps) also exist in significant numbers. Richardson (1981) estimated that as of 1979, 695,000 acres of pocosin wetlands remained in their natural state within the North Carolina portion of the study area; an additional 808,000 acres were either partially developed or, at the time, scheduled for development.

Trends: While mapping is incomplete and historical records are inadequate, there is evidence of extensive localized reduction of ecologically important emergent wetlands and inland wetlands. Tidal salt marshes and fringe swamps are now protected by regulations and quite stable in areal extent, but it is estimated that 25-50% of wetlands that line tributaries or lie well inland have been lost to development or altered so significantly that their functioning has been severely impaired. By 1979, 33% of the state's original pocosin acreage had been drained and the native vegetation permanently removed or altered; an additional 36% were either partially altered or scheduled for development.

Causes: Regulatory changes have helped to reduce losses of coastal wetlands to residential and commercial development, and losses of all wetlands to agricultural conversion and mosquito ditching. Major losses of freshwater wetlands still occur as a result of draining or filling for silviculture and commercial or residential development.

Nursery Areas and Fisheries Habitats:

Status: The suitability of protected nursery areas for fish, seagrass beds for scallops, sands or muds for hard clams, or hard substrate for american oysters may be influenced by freshwater runoff, bottom disturbing practices, or hypoxic and anoxic conditions. A program is in place to designate and protect fisheries nursery areas from harmful fishing practices. Analysis of juvenile abundances, indicates that most of these designated areas are currently functioning satisfactorily.

Trends: Scallop habitat (SAV) has declined in areas where turbidity has increased. Clam beds appear to be generally stable, fluctuating primarily in response to climatic and hydrologic variations. Oyster beds appear to be in decline in the Pamlico and Neuse River Estuaries due in part to disease, anoxia, fresh water inflows, and harvest pressures. Access to historical anadromous spawning habitats (rivers and tributaries to the Sounds) have been blocked by dams and reservoirs and limited by roads and culverts. No long-term records exist that allow trends in the areal extent of nursery areas to be determined, but records of juvenile abundance indicate continued health of existing nursery areas--no significant population trends of any major species have been found. Records of water quality (e.g., dissolved oxygen, turbidity, and salinity), however, indicate deteriorating conditions within some nursery areas.

Causes: Nursery areas and fisheries habitats, often located in shallow creeks, embayments, and tributaries, are particularly sensitive to effects of land and water uses. Continued increases in sediment, nutrient, or pollutant laden runoff from developed land and could further reduce these areas or impair their functioning.

Barrier Island Habitat:

Status: Over the past 300 years, human impact has reduced the original extensive coverage of maritime forest, shrub, herbaceous dune growth, and soundside high marsh, to remnant quantities. However, about two-thirds of the Outer Banks is now in public ownership.

Trends: Losses of habitat, other than intertidal salt marsh, continue at a substantial rate on private lands. Acreage in public trust ownership or jurisdiction is increasing the protection of some of these habitats.

Causes: Most losses result from urbanization and related development, which includes drainage removal of vegetation, installation of hard surfaces, off-road vehicle traffic, and altering dune slopes and configuration.

WATER QUALITY

Nutrients and eutrophication:

Status: The waters of the A/P system are phosphorous-rich and relatively nitrogen-limited. Blooms of algae require concurrent inputs of nitrogen and adequate sunlight, salinity, and temperature conditions -- a fairly common occurrence during the summer-fall warm, low-flow months.

Trends: Total annual phosphorous loading into the Neuse River is estimated to have increased 60% over the past century to 1.7 million kg/yr (1985). Most of that increase has occurred within the past 40 years due primarily to the increase in sewage discharge. Total annual nitrogen loading into the Neuse River is estimated to have increased 70% over the past century to 7.8 million kg/yr (1985). After declining in the 1950s and 1960s, loading increased rapidly as population growth overtook old gains in efficiency of wastewater treatment plants. Despite the increased loadings, concentrations of nitrogen and phosphorous in the water column have, in general, declined in the recent past. However, increased concentrations of chlorophyll *a* (an indicator of algal abundance) may account for the declining concentration of nutrients. Throughout the Neuse River, increased concentrations of chlorophyll *a* and changes in the species composition have been noted; specifically, nuisance blue-green algae have increased significantly. In the Pamlico River, concentrations of chlorophyll *a* have increased up-river (50% in 16 years) and in middle-river segments. Trends of the frequency of algal blooms have not been able to be documented, but species composition does not appear to have changed significantly. In the Tar-Pamlico, algal blooms have been associated with fish kills. Increases in the concentration of chlorophyll *a* have also been noted in upper Albemarle Sound and lower Chowan and Alligator Rivers.

Causes: Point sources (such as municipal wastewater treatment plants), nonpoint sources (diffuse sources of pollutants, sediment, and nutrients such as agricultural, silvicultural, and urban runoff, and direct atmospheric deposition), and internal nutrient cycling play major roles in determining nutrient availability. Depending on the system, point sources can contribute as much as 75% of the annual nutrient inputs, while in other systems, nonpoint sources have been known to contribute up over 60% of the nutrients. Particulate deposition of atmospheric nitrogen is thought to play a large role in estuarine eutrophication; in Chesapeake Bay, a very similar system, it is estimated to contribute 10 to 20% of the annual nitrogen inputs in the upper portions of the estuaries and 30 to 50% of the annual nitrogen inputs in the lower estuaries, open sounds, and coastal waters. Along with the right climatic conditions, these nutrients can cause blooms of algae, associated hypoxic or anoxic events, changes in the food chain, and even toxic conditions.

Metals and Toxicants:

Status: Studies of the concentrations of toxic pollutants within the water column describe generally safe and reasonable levels, but studies of the estuarine sediments indicate that areas of localized but severe enrichment exist, most often associated with known point source dischargers. There is some indication that, from parts of the A/P system, concentrations of dioxin (a probable human carcinogen) found in finfish tissues, have declined since last year, however, half of Albemarle Sound, portions of the Roanoke River, and the Chowan River still have health advisories posted for dioxin.

Trends: No long-term data base of sediment quality exists, but there is some indication of recent localized degradation due to anthropogenic loadings and disturbances. With such limited data, trends in the concentration of dioxin in sediment, water, and fish tissue are not reliable at this time. Long-term declines in concentrations of dioxin are expected, however, due to process changes in paper mills.

Causes: Municipal and industrial point source dischargers are considered to be responsible for the majority of localized degradation of the sediments. Long-term accumulation and biological and physical processes act to concentrate toxicants within the sediments, but biological effects of these toxicants are not yet known. Elevated levels of dioxin in fish tissues are primarily associated with pulp and paper mill effluents.

Freshwater Discharge and Flow Regimes:

Status: Alteration of the natural flow regimes of the tributaries to Albemarle and Pamlico Sounds can have significant effects upon the water quality and the health and distribution of flora and fauna in the receiving waters. In places, drainage ditches have reduced the salinity of receiving waters and have acted as conduits for the landward flow of brackish water. Overdraught of coastal aquifers has caused localized intrusion of brackish water. Dams have altered patterns of salinity and sedimentation, critical for the survival of many species of plants and animals. Construction and development have led to an increase of impervious surfaces, and so to an increase in stormwater runoff. The now inactive saltwater pumping station in Back Bay, Virginia caused major changes in salinity in the efforts to control the bay's habitat.

Trends: Mosquito ditching is no longer condoned and federal regulations have eliminated incentives to drain land for crop production. However, ditching associated with silvicultural practices is still exempt from 404 regions. Due to the complex hydrology of the estuarine system, precise trends of changing salinity remain unknown, but the pace of that change appears to be decreasing.

Causes: Artificial drainage of the wet interior of the study area, the pumping of groundwater, and the construction of dikes and dams may amplify natural hydrologic fluctuations.

Anoxia and hypoxia:

Status: Anoxia or hypoxia can stress or kill affected benthic and pelagic biota, however, such events are usually not wide-spread and are usually short-lived. These conditions are most common in the down-river sections of the tributaries and upper estuaries during periods of high runoff and in the up-river sections during periods of lower flow. Anoxic and hypoxic conditions can become established, broken-up, and reversed very quickly. These sporadic events seem to have little long-term impact on the health of the ecosystem as a whole.

Trends: There are no apparent trends of decreasing dissolved oxygen in the past 19 years of water quality data.

Causes: Data do not show a direct causal link between the size of the winter-spring algal blooms and the occurrence of anoxia or hypoxia. Anoxic and hypoxic conditions are usually caused by natural climatic and hydrologic conditions that result in concurrent warm temperatures (above 20 degrees Celsius) and stratification of the estuarine waters. These events may, however, be exacerbated by algal blooms caused by cultural eutrophication.

FISHERIES

Shellfish bed closures:

Status: The Division of Environmental Health, Shellfish Sanitation Branch conducts detailed Sanitary Surveys on a continuing basis. These bacteriological, hydrological, and shoreline surveys serve as the basis on which recommendations for closures are made to the Division of Marine Fisheries. Currently, roughly 36,000 acres within the study area are closed to the harvest of shellfish. Additional areas may be closed for a few days or weeks following a heavy rainfall. Within the A/P Study area, temporary closures are usually confined to tributaries in Carteret County. An area is closed to harvest until tests indicate a return to acceptable conditions. Bogue and Core Sounds, and select areas within Pamlico Sound are significantly affected.

Trends: Closures due to point source dischargers (primarily wastewater treatment facilities) have declined with improved technology and regulations, but the area subject to temporary closures due to nonpoint source and urban stormwater runoff has increased along with increasing development, keeping the total area closed to harvest relatively constant. Within the A/P Study area, roughly 15,000 acres are now subject to temporary closures due to contaminated stormwater runoff, indicating continued localized water quality degradation.

Causes: Freshwater discharge from drainage ditches can disrupt local salinity regimes and cause the degradation of shellfish beds. Bacterial contamination from point sources, improperly sited or maintained septic systems, urban and agricultural runoff, and marinas can cause the closure of shellfish beds.

Diseases:

Status: Several new or epidemic diseases have been documented recently among the fish and shellfish of the Albemarle-Pamlico region. Outbreaks of ulcerative mycosis (UM), a fungal infection primarily affecting menhaden in the Pamlico River, have occurred biannually in epidemic proportions since its first occurrence in 1984. "Red sore" disease first occurred among a wide variety of finfish in epidemic proportions in 1975; periodic outbreaks are still reported. The occurrence of "MSX" and dermocystidium ("dermo"), diseases fatal to oysters, was first reported as a widespread problem in 1988. Shell disease in blue crabs (found primarily in the Pamlico River) causes severe and aggressive lesions, it is infectious, and is often fatal. Even when not fatal, all of these diseases can make the affected organisms unmarketable.

Trends: Prevalence of fish diseases (especially UM) in the Pamlico River has increased dramatically since 1984, yet in other areas, such as Core Sound, disease is not considered to be a real problem, and in Albemarle Sound the prevalence of disease is considerably less than in the 1970s.

Causes: Causes of fish and shellfish diseases seem to be multiple and complexly interrelated, but general degradation of water quality has been associated with outbreaks of disease. Areas with elevated levels of toxicants such as metals in the water column or sediments have been associated with outbreaks of shell disease and UM, but no individual contaminants have been proven to be causal agents. Phytoplankton-produced toxins have been linked with increased mortality and susceptibility to diseases. Increased salinity occurring during periods of drought is believed to facilitate the spread of oyster disease. Decreased salinity has been associated with severe outbreaks of UM.

Commercial Fisheries:

Status: Dockside commercial landings data, compiled by the Division of Marine Fisheries, reflect not only stock sizes, but regulatory and market influences. In 1989 within the Albemarle-Pamlico Study area commercial fishermen landed a total (excluding menhaden) of 59.1 million pounds of fish and North Carolina fishermen as a whole landed 85.4 million pounds of estuarine-dependent fish.

Trends: In general, the total catch-per-unit-effort is decreasing despite improvements in fishing gear and methods. North Carolina's total commercial estuarine-dependent landings (including menhaden) have fluctuated 35 million pounds over the past five years from a low of 140.7 million pounds in 1987 to a high of 175.3 million pounds in 1988. Since 1988, landings have declined 14% to 151.5 million pounds.

Landings of catfish and striped bass have continued to decline since the 1970s. Landings of four other species have been in general decline since the early 1980s: river herring, American shad, croaker, and bluefish. Landings of flounder, weakfish, white perch, bay scallops, and oysters have shown a dramatic and sudden decline in the past one to three years. Coastal landings of flounder, for example, declined 60% in the past year. These declines may indicate declining stocks.

Commercial landings of hard clams, spot, and shrimp have remained fairly stable over time. Landings of blue crabs and Atlantic menhaden have continued to increase.

Causes: Specific causes of the declining landings are unknown, but several factors have been associated with the declines. Increased "effective effort" (the ability to inflict mortality) has significantly depleted some stocks. Fishermen have a greater impact on standing stocks because of the increased size and power of fishing vessels and improved electronics, fishing gear, and techniques. Alteration of riverine flow regimes has significantly reduced the habitat and reproductive success of anadromous fish. Declining water quality has been implicated in the reduced productivity of some primary nursery areas. Although trawling bycatch may negatively affect fish stocks, such an impact had not been demonstrated in the South Atlantic Region.

Recreational Fisheries:

Status: Recreational anglers compete for many of the same species as commercial fishermen and account for a significant proportion of the total catch. For some species of fish, such as bluefish, red drum, and spanish mackerel, recreational harvest probably exceeds commercial harvest. 53% of all commercial vessel licenses are issued for recreational use.

Trends: Unfortunately, no long-term recreational landings data exist, so no trends can be inferred. In general, however, the total catch-per-unit-effort is decreasing, despite increasing effective fishing effort.

Causes: North Carolina is unique in the freedom it offers recreational fishermen to use commercial gear and in the scale of the recreational fishing industry. While the total number of angler trips has remained relatively stable (or even declined slightly) over the past ten years, effective fishing effort continues to increase with improvements in gear and techniques.

THE HUMAN ENVIRONMENT

Population:

Status: According to the 1990 Census, North Carolina A/P study area counties have roughly 1,898,000 permanent residents, an increase of 16.3% since 1980. Two of North Carolina's three fastest growing counties of the 1980s are within the study area: Dare County grew 70% and Wake County grew 40.5%. Census information indicates that Virginia's A/P counties also exceeded the Virginia state-wide growth rate in the 1970s and 1980s. This relatively rapid growth of the permanent population and a concomitant growth of the recreational or seasonal population places ever-increasing demands on and creates ever-increasing conflicts over the limited and fragile resource base.

Trends: The population of the entire A/P study area is expected to reach nearly 3 million by the year 2000. The rate of growth of NC counties within the study area, while locally varied, has continued to increase. During the 1970s these counties grew at a rate below that of the statewide average, but during the 1980s, they grew 16.3%, 28% faster than the statewide average of 12.7%. This trend of growth will be reflected in increasing demands on the resources and increasing costs of maintaining the quality of the coastal environment.

Causes: The diverse resource base, healthy economy, and pleasant climate have attracted large numbers of people to the A/P area. There is a direct correlation between the growth and development of this region and the stress that is placed on the coastal environment.

Resource Utilization:

Status: The A/P study area offers opportunities for a wide variety of uses including: agriculture, tourism, residence, fishing, forestry, construction, mining, defense, retail, wholesale, and service. Each of these comprises a significant sector of the North Carolina economy. Although the A/P watershed covers about 1/3 of North Carolina, agriculture, the largest industry in the A/P area, accounts for 50% of NC's hogs, 45% of NC's cropland, and 40% of NC's chickens. Tourism is one of the state's largest industries; the A/P region accounts for 32% of the state's total tourism revenues. One-third of the state's woodlands are located within A/P counties. Degradation of drinking water supplies is not a widespread phenomenon in the A/P study area, but localized problems do exist. Livestock production, agriculture, and residential and commercial development are major industries within the Virginia portion of the A/P watershed. As in North Carolina, these practices add to the stress placed on the estuarine system.

Trends: Land in crop production has been declining since 1980, reflecting world-wide agricultural trends. Woodland acreage has also been decreasing, but pine plantation acreage increased substantially from 1973 to 1984. Swine and poultry production have been increasing as a percentage of the state

total, but have not been expanding rapidly. Tourism-related industries are expanding rapidly within the A/P study area. Commercial fishing pressures, as measured by vessel licenses, have increased only slightly in the recent past. Marina development, an indicator of recreational estuarine use, has continued to increase (184% from 1970-1989). Travel and tourism are increasing within the study area (though their revenues remain a constant proportion of the statewide travel and tourism revenues). Forested land within the study area has been decreasing. Specific locations within certain aquifers suffer from salt water intrusion induced by overdraught. Surface water supplies are protected by existing water quality regulations.

Causes: Permanent and seasonal populations continue to grow throughout the A/P study area, bringing with them ever-increasing demands on the limited resource base. Continued land development, increased domestic and municipal freshwater demands and wastewater discharges, the increasing application of fertilizer (despite the decreasing acreage of cropland), the growth of the poultry industry, the large scale hog industry, phosphate mining, forestry practices, the growth of commercial and recreational fisheries, and continued marina development have given rise to the concerns about the preservation and conservation of habitat and living resources.

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I. INTRODUCTION AND BACKGROUND

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A. THE STUDY

A. 1. Background

During the last decade, the US Environmental Protection Agency has directed its attention to "management conferences" on estuaries of national concern in response to public concern that some of the nation's prominent estuaries were in stages of decline in spite of a plethora of laws and regulations enacted in the 1970s to protect them. Chesapeake Bay in Maryland and Virginia, was the first so designated. Later, Narragansett Bay in Rhode Island, Buzzards Bay in Massachusetts, Long Island Sound in New York, Puget Sound in Washington, and San Francisco Bay in California, were added to the list. The Albemarle-Pamlico Estuarine System of North Carolina was designated in 1987. A series of activities were initiated to culminate in 1992 with a comprehensive management plan to more effectively manage the system to reverse the trend of degradation. Considerable technical knowledge about estuaries exists in publications, reports, and the scientific community of state, federal, and private organizations. In addition, new information is being generated by studies supported by the Albemarle-Pamlico Estuarine Study. Only limited efforts have been undertaken to synthesize and integrate this knowledge into a comprehensive report. This technical report is an analysis of the status and trends and will serve as the foundation for development of the comprehensive management plan.

The Albemarle-Pamlico Estuarine Study is composed of a Policy Committee, a Technical Committee, two Citizens Advisory Committees, an Administrative Staff, and involved scientists and resource managers. It is designed to represent a full spectrum of interests and talents and to be governed by consensus.

The Albemarle-Pamlico Estuarine Study Policy Committee (on 15 August 1986) resolved that:

The goal of the Albemarle-Pamlico project will be to provide the scientific knowledge and public awareness needed to make rational management decisions so that the Albemarle-Pamlico Estuarine System can continue to supply citizens with natural resources, recreational opportunities, and aesthetic enjoyment.

The objectives of the project will include, but are not limited to, generating understanding of what is needed to maintain and, where necessary, restore the chemical, physical, and biological integrity of the estuary, the wildlife habitat of the estuary, and the production levels of recreational and commercial fisheries of the estuary.

This report is the starting point for achieving the goal and objectives of the Albemarle-Pamlico Estuarine Study.

A. 2. Purpose of the Status and Trends Report

This report is an attempt to synthesize the existing information about the Albemarle-Pamlico estuarine system and to assess the status and trends of probable causes apparent in the system. This report will establish the foundation for the development of a comprehensive management plan for the Albemarle-Pamlico Estuarine System.

The overall goal of this project is to provide agencies, scientists, and the public with an integrated packet of information describing the state of knowledge of the Albemarle-Pamlico estuarine system.

Specific objectives, therefore, were:

1. To develop an outline for each of the key issues of Critical Areas (Chapter II), Water Quality (Chapter III), Fisheries (Chapter IV), and Human Environment (Chapter V), and to set up a mechanism for analysis and summarization;
2. To direct the attention of an organized group of the State's top experts in each area to develop a consensus of the status of each key issue;
3. To generate a narrative of the status and trends of the resources, to analyze the probable causes of the major problems within the four key areas, and to test the conclusions against the theories of technical experts, organizations, and leaders of public opinion; and
4. To publish the current information in a technical document and to create a general interest summary for public use.

A. 3. Limitations of the Study

This exercise was approached through a series of work sessions in which the experts available provided their ideas about the status and trends of issues confronting the estuary. Data files available to and utilized by these experts form the basis for the technical analyses. Technical quality was emphasized more than completeness, i.e., it was concluded that it was far better to relate an accurate picture than to include every possible shred of data.

It should be emphasized that this is a "living document"; that is, further information and analyses will be added as they become available. A comprehensive management plan will be developed from this status and trends analysis.

A major limitation in the development of this report was the constraint of time compared to the magnitude of the task of analyzing the status and trends. The analysis of status and trends involved the input of a tremendous variety of interests in Albemarle-Pamlico estuarine system.

B. THE SETTING

B. 1. Geography and Boundaries

The Albemarle-Pamlico Estuarine System (A/P system) is one of the largest and most important in the United States. Covering approximately 2,900 square miles (Table I-1), the waters of the A/P system comprise the second largest estuarine system on the East Coast of the United States, exceeded in area by only the Chesapeake Bay. Individual "estuarine profiles" have been completed for the Albemarle and Pamlico systems (Copeland et al. 1983; 1984).

The A/P system comprises an extensive complex of creeks, rivers, swamps, marshes and open water sounds, dominating northeastern North Carolina (Figure I-1). Tributaries originating in the Piedmont serve as conduits from a major portion of North Carolina and southeastern Virginia. Albemarle Sound is the drowned portion of the Roanoke River and its extensive floodplain. Other major, lateral tributaries of Albemarle Sound include the Chowan, Perquimans, Little, Pasquotank and North Rivers in

Table I-1. Comparison of Albemarle and Pamlico Sounds (from the Albemarle-Pamlico Estuarine Study Work Plan).

| Item | Albemarle | Pamlico |
|--|------------------|-------------------|
| Area (km ²) | 2,330 | 5,200 |
| (mi ²) | 900 | 2,000 |
| Watershed (km ²) | 47,552 | 32,427 |
| (mi ²) | 18,360 | 12,520 |
| Percent area of state inshore total | 26 | 56 |
| Freshwater Inflow (ft ³ /sec) | 17,000 | 32,000 |
| Volume of Sound (billion ft ³) | 23.1 | 91.5 |
| (million acre ft.) | 5.3 | 21 |
| Time for inflow to replace volume | 6 weeks | 14 weeks |
| Salinity | low | moderate/high |
| Fisheries | anadromous/fresh | marine/anadromous |
| Percent catch of state total | 14 | 78 |
| Percent value of state total | 5 | 73 |

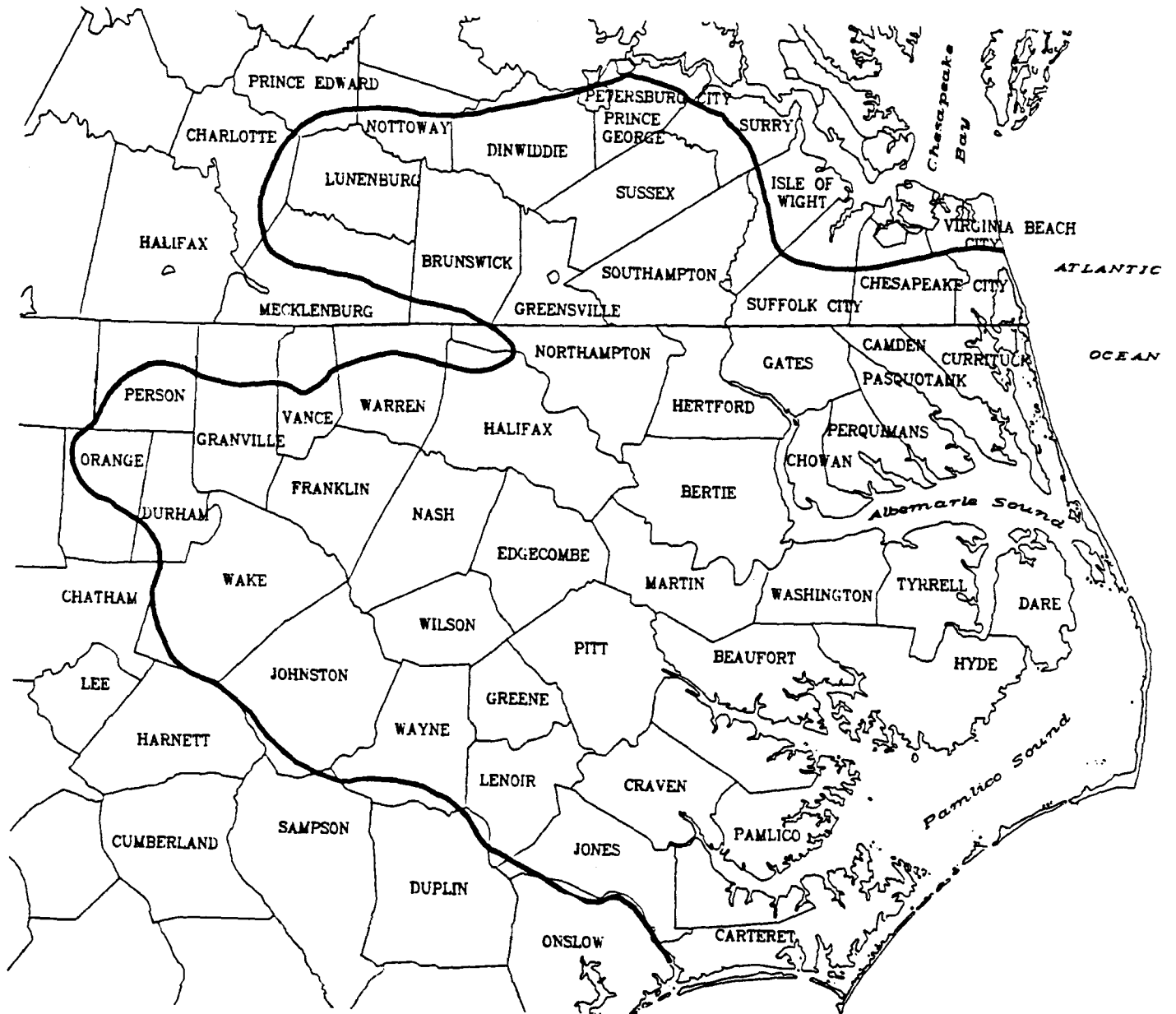


Fig. I-1. Albemarle-Pamlico Estuarine Study Area

the north; and the Scuppernong and Alligator Rivers in the south. Pamlico Sound is the drowned portion of the Tar and Neuse Rivers and their extensive floodplains. Several small, lateral tributaries drain off the low, flat, swampy coastal area, the largest one being the Pungo River in the north.

Neither sound is directly connected to the Atlantic Ocean; both lay behind an extensive chain of barrier islands referred to as the "Outer Banks". Albemarle Sound has three open-water estuaries at its eastern end that are parallel to the Outer Banks: the freshwater Currituck Sound to the north, and brackish Croatan and Roanoke Sounds to the south. Albemarle Sound is connected to the ocean only through Croatan and Roanoke Sounds via Pamlico Sound. As a result, Albemarle Sound is strongly influenced by freshwater flows and only marginally by the Atlantic Ocean. Pamlico Sound is connected to the ocean through several inlets including Oregon, Hatteras, Ocracoke, Drum, Bardon, and Beaufort. These tidal connections exert considerable oceanic influence on Pamlico Sound.

Albemarle Sound and Pamlico Sound, as well as Core, Bogue, and Currituck Sounds and Back Bay, are the focus of the Albemarle-Pamlico Estuarine Study and, therefore, of this report. The study area (Figure I-1), however, encompasses the entire drainage basin for the Albemarle and Pamlico Sounds, except for the portion of the Roanoke River Basin that lies above the Lake Gaston dam. This includes 36 counties in North Carolina (roughly 1/3 of the state) and 14 counties in Virginia (roughly 1/6 of the state).

B. 2. Geological Origin

Sediments and sedimentary rocks of marine origin underlie the entire sound region (Brown et al. 1972). These sediments were deposited when the ocean covered portions of the coastal plain on top of the same type of crystalline rocks that occur in the Piedmont. As the coastal system migrated back and forth across the coastal plain-continental shelf over the last 100 million years, layers of stratified rock were formed. The marine sediments range in thickness from 600 meters at Washington, North Carolina, to 1500 meters near Swanquarter, to over 3000 meters at Cape Hatteras (Figure I-2).

While each in the series of formations has a distinctive textural, mineralogical, and fossil composition, and while each was deposited during a specific period of geological time, these formations have little direct bearing on the present-day functioning of the Albemarle-Pamlico Estuarine System. Only the uppermost veneer of unconsolidated sediments has a direct bearing on the modern estuary. These sediments dictate the general characteristics of the estuarine margins, bottoms, topography, soil types, water drainage, and use of the adjacent land areas. The names and ages of formations shown in Figure I-2 place the present-day estuary and its sediments in context.

Sediments of interest for the current Albemarle-Pamlico estuarine system include those from the Upper Miocene to the Pleistocene and Recent. The Miocene sediments (roughly 250 million years old) contain several fossil layers and comprise the sediments from which the phosphate mining industry along the Pamlico River is derived. The Pliocene sediments, deposited during the time of rapidly changing sequence in coastal environments (25 to 1 million years ago), are extremely complex and include gravel, sands, clays, peats, and all possible combinations of these (Hartness 1977). Most of these units are not fossiliferous or, if they have been, the fossils are often partly or completely leached out by acidic groundwater moving through the surface aquifers. The Pliocene and Pleistocene sediments range in thickness from a few meters up to 20 or more meters throughout the inner and middle estuarine areas, increasing to 15 to 25 meters under the outer portions of the Albemarle-Pamlico estuarine system.

Recent sediments were formed during the Ice Ages of the Pleistocene, when the advancing and retreating ice sheets brought about worldwide fluctuations in sea level. When the last major glacial

| <u>ERA</u> | <u>y.b.p.</u> | <u>PERIOD</u> | <u>KEY</u> |
|-------------|---------------|---------------|------------|
| Recent | 12,000 | Quaternary | |
| Pleistocene | 600,000 | Quaternary | |
| Pliocene | 10,000,000 | Tertiary | ■ ■■■ |
| Miocene | 25,000,000 | Tertiary | |
| Oligocene | 35,000,000 | Tertiary | |
| Eocene | 55,000,000 | Tertiary | ■ ■■ |
| Paleocene | 65,000,000 | Tertiary | ■ ■■ |
| | 135,000,000 | Cretaceous | ■ ■■ |
| | 180,000,000 | Jurassic | ■ ■■ |
| | 230,000,000 | Triassic | ■ ■■ |
| | | | ■ ■■ |

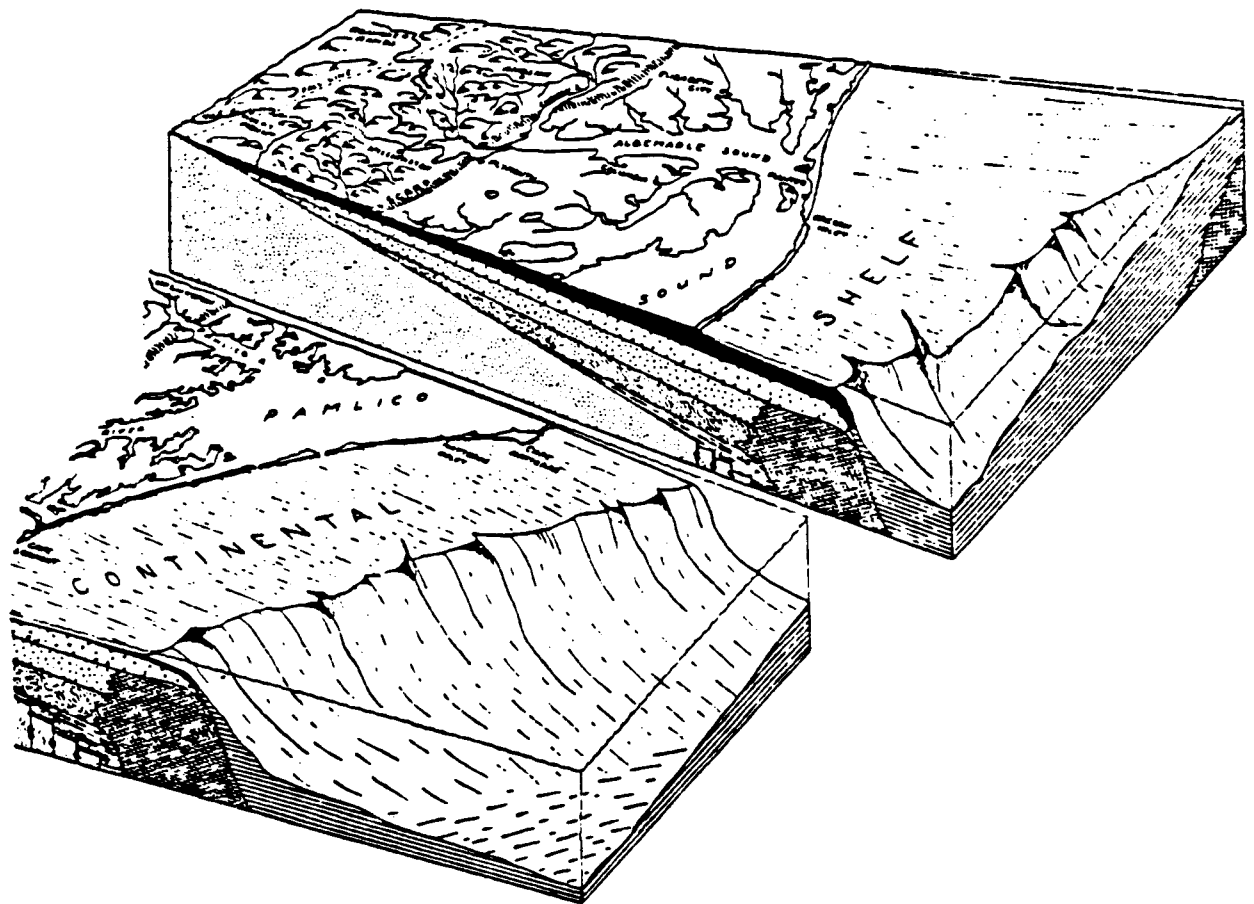


Fig. I-2. Cross-section of the Stratigraphy of Northeastern North Carolina. From Fairbridge (1960).

advance reached its maximum about 17,000 to 18,000 years ago, the edge of the continent was about 40 km east of Cape Hatteras. The land surface sloped gently seaward and was dissected by rivers and associated tributaries with moderately deep channels and broad flood plains. Climate and vegetation were such that maximum surface water discharge and sediment erosion occurred (Whitehead 1981). The products of such an environment were the coarse sands and gravels deposited on the North Carolina Coastal Plain.

The present rise of sea level began sometime after 17,000 years before the present (ybp) when the climate began to warm and glacial ice masses receded. The sedimentary and physical character of the present sound system began to be defined at that time. As the climate continued to warm, the vegetation slowly evolved into the hardwood and pine forests that characterize the southeastern United States today. And, the estuarine system impinged landward across the continental shelf to its current position.

A major geomorphic feature known as the Suffolk Scarp, or the Arapahoe Ridge, trends north and south across the western portion of the A/P system and divides the area into two distinct geomorphic provinces. This prominent sand ridge rises to 6 to 9 meters of elevation and represents an old barrier island shoreline formed by the sea during a previous Pleistocene interglacial period when sea level was higher than it is now. West of the Arapahoe Ridge, the terrain gently rises to the Piedmont. To the east lies the Pamlico Terrace, which has a low, flat surface sloping from 3 to 5 meters of elevation at the base of the scarp eastward to 0.3 to 0.6 meters of elevation at the end of the land peninsula. This geologic setting has resulted in low, poorly drained land with extensive swamps and pocosins composed of organic peat soils that generally thicken eastward.

B. 3. Climate and Land

The climate in the area of the Albemarle-Pamlico estuarine system is moderately mild and moist, creating a good environment for agriculture, forestry, and fisheries. Northeastern North Carolina and southeastern Virginia generally receive between 47 and 56 inches (120 and 142 cm) of rain per year, though spatial and temporal variation are great (Wilder et al. 1978). Dry years average about 35 inches (89 cm) and in wet years may reach 78 inches (200 cm) of rainfall. Seasonal distribution of precipitation is relatively uniform, with the highest precipitation occurring in association with thunderstorms in the summer and the lowest occurring during fall and spring. Temperature is moderate. January temperatures average between 6 and 8 °C (43 and 46 °F); the low seldom falls below -12 °C (10 °F). Summers are hot and humid, with the average daytime temperature often exceeding 32 °C (90 °F) in July and August. Although winds are variable, the prevailing winds are from the S-SW with average velocities of 9 to 10 mph (15 to 16 km/hr) (Clay et al. 1975). Special situations arise with northern winds of high velocities (most common in the winter), and localized thunderstorms, hurricanes, and tornadoes (most common during the spring, summer, and fall).

The area directly surrounding the Albemarle-Pamlico Estuarine System is heavily forested; in fact, about two-thirds of the land in the counties surrounding the sound system is in forest or under water (Table I-2). Land use studies indicate small urban areas and a generally rural setting. Land use changes in the area are primarily from forest to agricultural uses, not to urban development.

Table I-2. Land Area and Land Use (in acres) in the Counties Surrounding Albemarle-Pamlico Estuarine System. From the US Soil Conservation Service National Resources Inventory of 1982.

| County | Total Acres | Water | Urban Etc. | Crop Land | Forest (total) | Wetlands |
|------------|-------------|-----------|------------|-----------|----------------|----------|
| Beaufort | 612,980 | 86,530 | 20,800 | 131,300 | 333,000 | 43,700 |
| Bertie | 471,379 | 22,784 | 2,100 | 95,600 | 331,800 | 93,300 |
| Camden | 203,770 | 49,857 | 300 | 40,400 | 93,900 | 69,100 |
| Carteret | 673,625 | 337,260 | 22,400 | 53,000 | 93,500 | 48,800 |
| Chowan | 154,784 | 38,622 | 3,300 | 49,100 | 55,800 | 11,900 |
| Craven | 487,213 | 38,272 | 21,900 | 76,400 | 250,500 | 69,800 |
| Currituck | 281,082 | 117,505 | 2,800 | 54,200 | 55,400 | 31,200 |
| Dare | 800,601 | 550,495 | 15,800 | 5,200 | 33,978 | 58,078 |
| Hyde | 871,136 | 471,635 | 800 | 117,000 | 170,800 | 121,600 |
| Pamlico | 368,186 | 150,119 | 2,900 | 36,700 | 138,700 | 50,900 |
| Pasquotank | 185,203 | 39,283 | 5,800 | 76,100 | 46,400 | 26,400 |
| Perquimans | 208,845 | 51,212 | 2,200 | 96,500 | 52,400 | 11,800 |
| Tyrrell | 383,143 | 122,778 | 200 | 61,900 | 187,000 | 187,000 |
| Washington | 264,486 | 52,243 | 2,000 | 81,400 | 115,800 | 47,200 |
| Total | 5,966,433 | 2,128,595 | 103,300 | 974,800 | 1,958,978 | 870,778 |
| Percent | | 36 | 2 | 16 | 33 | 15 |

B. 4. Hydrography

The Roanoke and Chowan Rivers are the main sources of freshwater for Albemarle Sound (Giese et al. 1979). Of the approximately 17,000 cubic feet per second (cfs) net, annual average freshwater inflow to Albemarle Sound, over half (8,800 cfs) is from the Roanoke River (Table I-3). Major sources of freshwater into Pamlico Sound (Table I-4) are Albemarle Sound (17,000 cfs), the Pamlico (Tar) River (5,400 cfs), and the Neuse River (6,100 cfs); the average annual inflow is 31,700 cfs (Giese et al. 1979). Freshwater input is not evenly distributed throughout the year; the highest runoff occurs during the late winter and early spring, and the lowest occurs during the fall.

Wind is the most important factor influencing short-term circulation in the Albemarle-Pamlico Estuarine System, with tides and freshwater inflows from tributaries playing secondary roles (Giese et al. 1979; Pietrafesa et al. 1986). The embayed lateral tributaries are very responsive to wind tides; winds blowing downstream may often drive most of the water from the embayment (Overton et al. 1988). Because of the shallowness of the sounds, their long fetch, and essential separation from the ocean, wind and wave action usually eliminate vertical stratification (especially in Albemarle Sound) except under certain calm or high-freshwater-inflow conditions.

The total annual average outflow from Albemarle Sound is larger relative to the sound's volume (about 5.3 million acre-feet) than the out flow from Pamlico Sound (32,000 cfs and 21 million acre-feet, respectively). This difference gives rise to an apparently much shorter time for inflow to replace the volume of water in Albemarle Sound than in Pamlico Sound (Table I-1). Combined with the almost total isolation of Albemarle Sound from the ocean, this results in very much lower salinity conditions than in the Pamlico.

Table I-3. Gross Water Budget (cfs) for Albemarle Sound, 1965-1975. From Giese et al. (1979).

| Month | Precipitation | Evaporation | Chowan Inflow | Roanoke Inflow | All Other Inflow | Total Output |
|-----------|---------------|-------------|---------------|----------------|------------------|--------------|
| January | 2,800 | 1,000 | 6,500 | 10,000 | 4,200 | 23,000 |
| February | 3,400 | 1,700 | 9,100 | 12,000 | 5,900 | 28,000 |
| March | 2,900 | 2,200 | 8,600 | 10,000 | 5,600 | 25,000 |
| April | 2,500 | 3,400 | 6,600 | 11,000 | 4,300 | 21,000 |
| May | 2,800 | 3,900 | 3,700 | 10,000 | 2,400 | 16,000 |
| June | 3,600 | 4,200 | 2,600 | 8,500 | 1,700 | 12,000 |
| July | 5,400 | 4,100 | 3,000 | 8,000 | 1,900 | 14,000 |
| August | 5,000 | 3,500 | 3,500 | 7,500 | 2,200 | 15,000 |
| September | 4,300 | 2,800 | 3,000 | 6,500 | 2,000 | 13,000 |
| October | 2,500 | 1,800 | 2,200 | 6,500 | 1,400 | 11,000 |
| November | 3,000 | 1,400 | 2,500 | 7,500 | 1,600 | 13,000 |
| December | 2,600 | 900 | 4,400 | 8,300 | 1,300 | 16,000 |
| Annual | 3,400 | 2,600 | 4,600 | 8,800 | 2,900 | 17,000 |

Table I-4. Gross Water Budget (cfs) for Pamlico Sound. From Giese et al. (1979).

| Month | Precipitation | Evaporation | Albemarle Inflow | Neuse Inflow | Tar Inflow | Total Output |
|-----------|---------------|-------------|------------------|--------------|------------|--------------|
| January | 6,800 | 2,300 | 22,800 | 8,700 | 7,600 | 44,200 |
| February | 7,900 | 3,300 | 28,300 | 11,000 | 9,700 | 54,500 |
| March | 6,600 | 4,900 | 25,000 | 9,700 | 8,600 | 45,800 |
| April | 5,400 | 7,500 | 21,300 | 6,700 | 5,900 | 32,400 |
| May | 6,600 | 8,600 | 15,500 | 5,800 | 5,100 | 24,800 |
| June | 9,300 | 9,300 | 12,200 | 3,200 | 2,800 | 18,400 |
| July | 12,600 | 10,000 | 14,200 | 4,600 | 4,000 | 25,700 |
| August | 12,100 | 7,700 | 14,700 | 5,600 | 4,900 | 30,000 |
| September | 10,800 | 6,100 | 13,100 | 4,300 | 3,800 | 25,300 |
| October | 6,700 | 4,100 | 10,700 | 4,000 | 3,600 | 21,200 |
| November | 7,100 | 3,000 | 13,300 | 4,200 | 3,700 | 26,600 |
| December | 7,000 | 2,000 | 15,600 | 5,700 | 5,000 | 31,800 |
| Annual | 8,300 | 5,700 | 17,200 | 6,100 | 5,400 | 31,700 |

B. 5. Groundwater Resources and Quality

Abundant groundwater occurs in the unconsolidated sedimentary deposits (Heath 1980), which range in thickness from a few meters along the fall line to more than 3,000 meters at Cape Hatteras (Figure I-2). Most of the groundwater available in the coastal plain is from the upper aquifer and the limestone aquifer (Wilder et al. 1978). The upper aquifer yields the most water and is the one most susceptible to contamination by land use activities. The water table lies very close to the surface in much of the low-lying areas around the sounds.

Coble et al. (1985) have reviewed groundwater resources of North Carolina. Giese et al. (1987) and others have summarized information on groundwater quality for North Carolina. The following discussion was drawn almost exclusively from these two sources.

B. 5. a. Overview. Groundwater supplies nearly 58% of the approximately 6.2 million people in North Carolina; about 435 million gallons per day of fresh groundwater is used in the State. Groundwater is economically important in the Coastal Plain province, where high-yielding aquifers supply most municipalities, industries, rural areas, and livestock. The lack of reliable groundwater supplies has been a limiting factor to economic growth in the eastern portion of the state, particularly in parts of northeastern North Carolina and the Outer Banks.

Roughly 20% of the annual Coastal Plain precipitation (44-56 inches) recharges the groundwater system in the Coastal Plain (Winner and Simmons 1977). Most of the water recharged to the groundwater system moves laterally through shallow aquifers and discharges to streams, thereby constituting a major part of surface water baseflow. Less than one inch per year of the recharge typically reaches the deep aquifers in the Coastal Plain.

In general, the quality of the groundwater in the Albemarle-Pamlico Estuarine region is good and most groundwater supplies meet drinking water standards (NC Department of Human Resources 1984). Treatment of groundwater is required in some places, however, because of naturally-occurring or human-induced water quality problems. The presence of salt or brackish water in all aquifers in the eastern part of the State is the most widespread naturally-occurring groundwater quality problem in the Albemarle-Pamlico estuarine region (Figure I-3). In locations where groundwater is pumped near naturally-occurring saltwater, the saltwater may encroach upon pumped wells, resulting in increased concentrations of dissolved solids in parts of the aquifer. In some areas near agricultural operations, elevated levels of nitrates are found in shallow aquifers. Other naturally-occurring conditions which may render untreated groundwater unsuitable for drinking include excessive hardness, extremes in pH, and unacceptably high concentrations of dissolved solids, chloride, fluoride, iron, manganese, and sodium. Radioactive radon gas may be dissolved in groundwater that occurs in rocks of higher-than-average uranium content and relatively low permeability. Rocks of this type include shale, clay, granite, and phosphate ore.

Human-induced contamination of groundwater generally results from the leachate from landfills, seepage from waste lagoons, seepage from underground storage tanks, accidental spills of chemical materials, and saltwater intrusion from overdraught. Aquifer recharge areas are generally the most vulnerable to contamination and, because groundwater moves slowly, the contamination may go undetected for years. These contamination problems are serious where they occur, but the best information indicates that known problems are local in extent.

B. 5. b. Principal Aquifers in the Albemarle-Pamlico Region. Four of the five major aquifers in North Carolina used for water supply are in the unconsolidated and partly consolidated sedimentary deposits of the Coastal Plain (Figure I-4). The four aquifers are the Surficial, the Yorktown, the Castle Hayne, and the Cretaceous aquifers. The areal extent and characteristics of the aquifers are given in

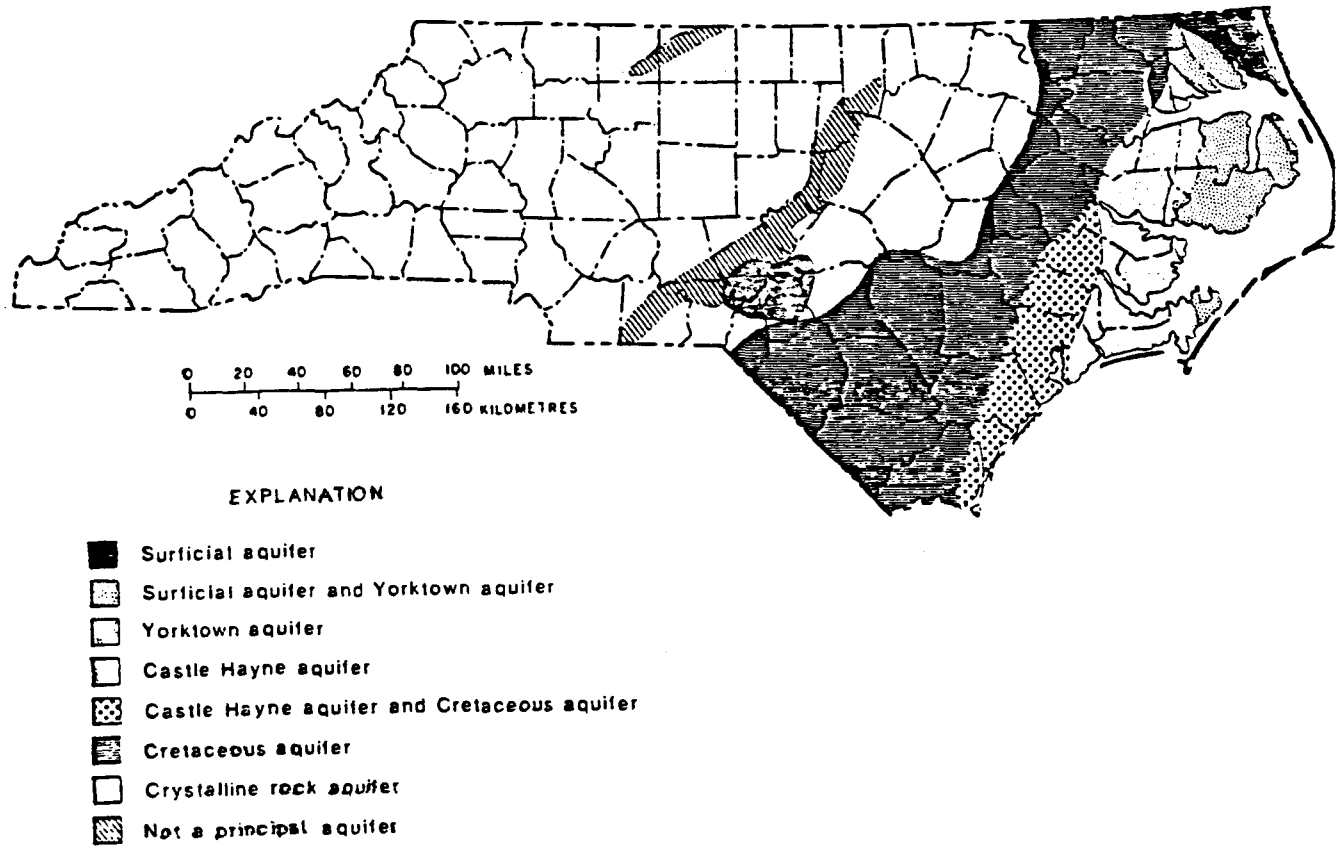


Fig. I-3. Principal Aquifers of North Carolina. From Coble et al. (1985).

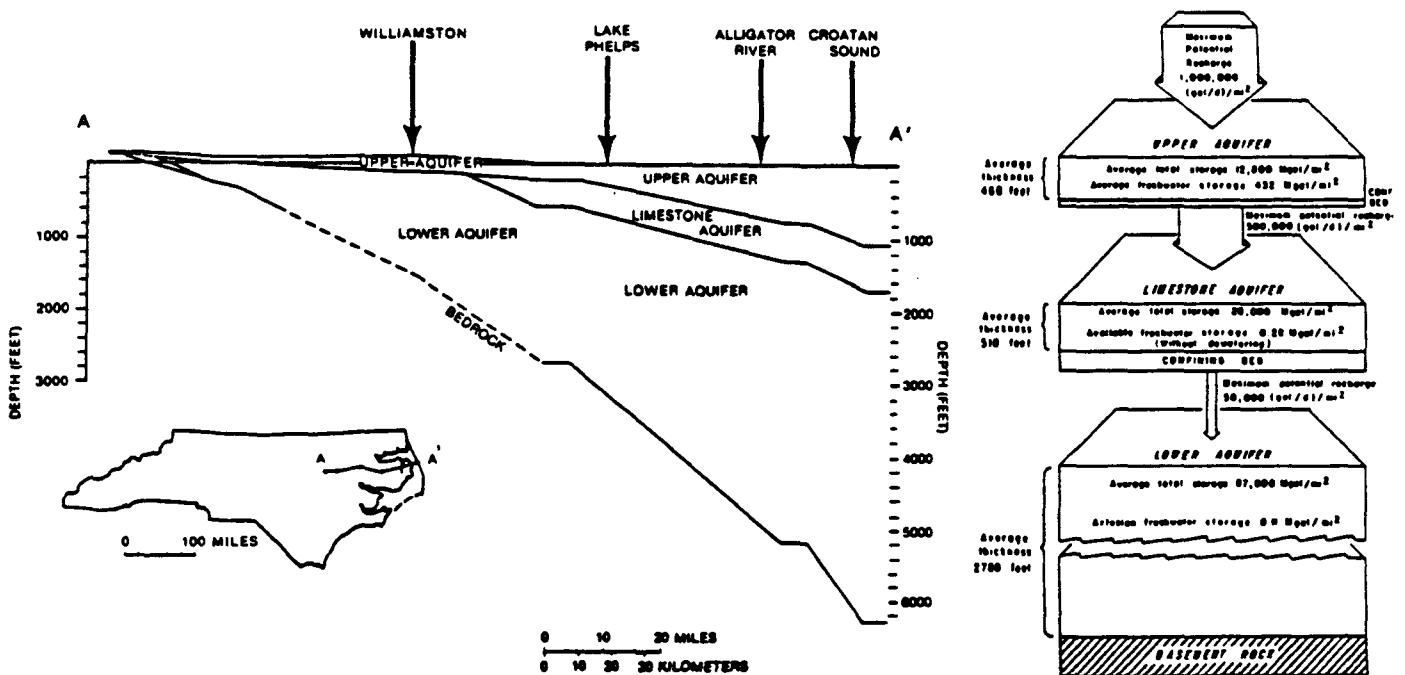


Fig. I-4. Cross-section of Aquifers (from Heath 1980) and Estimated Recharge and Storage of Aquifers (from Wilder et al. 1978) underlying the North Carolina Coastal Plain.

Figure I-3 and Table I-5, respectively. The fifth aquifer, which lies in the Piedmont and Blue Ridge provinces of the State, is the Crystalline-Rock aquifer.

The Surficial aquifer, which is a near-surface deposit of either marine-terrace sand and clay or of sand dunes, is a principal aquifer for the Outer Banks and the mainland north of Pamlico Sound (Figure I-3). Individual well yields from this aquifer typically range from 25 to 200 gpm (gallons per minute); but may exceed 500 gpm, particularly on the mainland.

The Surficial aquifer is the only source of freshwater, other than precipitation, for much of the Outer Banks. Because freshwater is seldom found more than 100 ft below land surface on the Outer Banks, water supplies are usually obtained from a large number of shallow vertical wells or from shallow horizontal wells. Even so, as a result of pumping or naturally-occurring conditions, the concentration of dissolved solids in water pumped from this area can exceed 500 mg/l, the national secondary drinking-water standard (US Environmental Protection Agency 1986).

On the mainland, the Surficial aquifer is between 50 and 200 feet thick, and may yield one million gpd (gallons per day) from small well fields. Dissolved solids concentrations, which are typically lower than on the Outer Banks, are generally less than 200 mg/l. The pH, on the other hand, may be as low as 5, rendering the water corrosive. Large amounts of humic material in some parts of the Surficial aquifer may make the water unsuitable for chlorination and public supply (US Environmental Protection Agency 1985). Upon chlorination, the humic material combines with chlorine to form trihalomethanes, which are thought to be carcinogenic.

Declines in water level in the Surficial aquifer are not widespread. Pumping one million gpd from a well near Elizabeth City resulted in no measurable decline in an observation well 0.5 miles from the well field.

The Yorktown aquifer is typically present between 50 and 150 ft below the land surface in the northern part of the Coastal Plain (Figure I-3). The Yorktown aquifer commonly yields 15-90 gpm to individual wells, although yields may occasionally exceed 500 gpm. Near Elizabeth City, the Yorktown aquifer supplies about 1.4 million gpd to a well field.

Background or naturally-occurring concentrations of sodium are higher in water from the Yorktown aquifer than from any of the other principal aquifers in North Carolina. The median concentration of sodium in samples from the aquifer was reported to be 38 mg/l; 25% of the samples had concentrations of sodium in excess of 130 mg/l (Giese et al. 1987). Although no state or national standards have been established for sodium in drinking water, the US Environmental Protection Agency (1985) proposed a health advisory guidance level maximum of 20 mg/l for drinking water. It appears that ion exchange is responsible for the high levels of sodium in the Yorktown aquifer (Wilder et al. 1978); calcium in the groundwater apparently exchanges for sodium in the aquifer materials, thereby increasing the concentration of sodium and decreasing the concentration of calcium in the groundwater.

Withdrawals from the Yorktown are generally minor and the aquifer is readily recharged. Consequently, widespread water-level declines have not occurred in this aquifer. Near Belhaven, withdrawals of about 1.2 million gpd over a period of about 10 years have resulted in a water-level decline of less than 10 feet.

The major source of freshwater in the southeastern coastal area, where nearly all aquifers contain some saltwater, is the Castle Hayne (Figure I-3). The Castle Hayne is the most productive of the state's principal aquifers. Wells that yield more than 1,000 gpm can be readily developed in the aquifer, and yields in excess of 2,000 gpm have been documented. Even in some locations, where aquifers above and below the Castle Hayne contain saltwater, the Castle Hayne still yields freshwater.

Table I-5. Aquifer and Well Characteristics in the North Carolina Coastal Plain. From Coble et al. (1985).

| Aquifer | Description | Depth (ft) | Yield (gpm) |
|-----------------|---|------------|--------------|
| Surficial | Sand, Silt, Clay & Gravel Unconfined or Partially Confined. | 40 to 175 | 25 to 500 |
| Yorktown | Sand & Clay. Partially Confined or Confined. | 50 to 190 | 15 to 500 |
| Castle Hayne | Limestone, Sandy Limestone & Sand. Confined. | 70 to 400 | 200 to 2,000 |
| Cretaceous | Sand, Clayey Sand & Clay. Confined. | 100 to 800 | 200 to 1,400 |

Water from the Castle Hayne is generally hard (121 to 180 mg/l calcium carbonate) to very hard (greater than 180 mg/l) and may require treatment for some uses. Hardness is lower near recharge zones, but increases with residence time in the aquifer. Iron concentrations are more likely to exceed the state drinking water standard of 0.3 mg/l in recharge areas, but iron precipitates out as the water moves through the limestone formation. Silica concentrations in excess of 50 mg/l are common, and saltwater may be found in the deeper parts of the aquifer.

The largest groundwater withdrawals in the state are made from the Castle Hayne aquifer in efforts to decrease artesian pressure and de-water overlying phosphate ore beds at a phosphate mine in Aurora, Beaufort County. Over 60 million gpd are withdrawn from the aquifer and, as a consequence, water levels have declined 5 feet or more in the Castle Hayne over an area of 1,300 square miles. Near the phosphate mine, a water level decline of over 80 feet since 1965 has been observed (Coble et al. 1985).

The Cretaceous aquifer (Figure I-3) is the most widely used aquifer in the Coastal Plain, with much of the withdrawal coming from the central and southern parts of the province. The aquifer occurs between 100 and 600 feet below land surface (800 feet in some sites) and is very thick relative to the other principal aquifers in the state. Individual wells in the Cretaceous aquifer typically produce between 200 and 400 gpm; some well fields in the aquifer produce more than one million gpd.

Water from the Cretaceous aquifer is generally soft and alkaline and requires little or no treatment for most uses. Water from some parts of the aquifer may, however, contain fluoride concentrations in excess of 4 mg/l, the maximum allowable concentration under national drinking water standards (US Environmental Protection Agency 1986). The presence of excessive fluoride may limit the use of water for drinking from some parts of the aquifer. Additionally, the Cretaceous aquifer generally contains brackish water in the deeper parts of the aquifer (Figure I-3).

Because the Cretaceous aquifer is heavily utilized throughout the Coastal Plain, declines in water level are widespread. An observation well in the Cretaceous aquifer near Kinston has shown water level declines of 80 feet or more since 1968. Because of withdrawals of 35 million gpd or more near Franklin, Virginia (about 10 miles north of the state line), water levels have declined over an area of several

thousand square miles in northeastern North Carolina. At the state line, water levels have declined about 45 feet since 1966 and are estimated to have declined as much as 100 feet since the early 1940s when the extensive withdrawals began.

There are two primary freshwater aquifers in southeastern Virginia. The Yorktown is a confined aquifer (discussed above) found at depth. There is also an unconfined aquifer in the deposits overlying the Yorktown aquifer. Both provide good quality drinking water, though some saltwater intrusion has occurred in the deeper parts of the Yorktown aquifer.

B. 5. c. Groundwater Management. The NC Division of Environmental Management (DEM) has the major responsibility for groundwater management and regulatory programs in the state. DEM administers the point-source permit program, which primarily regulates facilities that discharge to surface waters, but also includes unlined basins and holding ponds that have the potential to contaminate groundwater. The non-discharge permit program, also administered by DEM, is, in essence, a groundwater permit program that regulates activities such as sewer extensions, sludge disposal, land-application systems, and waste lagoons that do not discharge to surface waters. Monitoring to assure compliance with permits, is conducted at over 750 wells, which are monitored by the owners in accordance with the conditions of the permits.

A well construction permit must be obtained from DEM for public supply wells; industrial and irrigation wells; wells with a designed capacity of 100,000 gpd or greater; wells to be used for injection, recharge or disposal purposes; and non-domestic wells located in a designated Capacity Use Area (North Carolina Well Construction Act of 1967, Article 7-87-88). A Capacity Use Area is an area in which the renewal and replenishment of the groundwater supplies are believed to be threatened. Such areas are designated by the NC Environmental Management Commission. All well drillers must register annually with DEM and are required to report all well completions and abandonments.

Landfills are regulated by the NC Division of Solid Waste Management. The Division is responsible for monitoring solid and hazardous waste disposal sites and is responsible for the human health aspects of public water supply systems, including approval of sources of raw water and establishment of state drinking water standards.

B. 6. The Estuary and Society

Native Indians called Albemarle Sound "Weapemeoc" and lived around the area prior to the arrival of European settlers in the sixteenth century. Albemarle was first explored by Sir Walter Raleigh's colonists under the leadership of Ralph Lane during the spring of 1586. Not unlike today, Lane's Albemarle Sound expedition encountered bad weather, natives fiercely proud and defensive of their territory, and conflicts over presumed rights. While the details and characters have changed, people in the four centuries since have been and are the product and continuation of historical Albemarle Sound (Stick 1982).

The size and isolation of the Pamlico Sound limited early settlement by colonists. Beginning with the settlement of Jamestown, Virginia, in 1607, early settlement began north of Albemarle Sound and later spread southward. Settlers built homesteads along the shores, produced crops for export, and sailed their crafts from sound to sea through the inlets of Currituck and Roanoke in the 1600s. Throughout the seventeenth century, Albemarle Sound was the hub and heart of North Carolina, and Edenton, one of the colonial capitals, was the center of trade (Stick 1982). Numerous communities and small towns were established near the water, and land was cleared in ever-increasing acreage for agriculture. Fishing thrived and timber provided raw materials for local use and export. Southern migration continued, leading to the establishment of Bath on the northern shore of the Pamlico River Estuary in 1704. The sounds served as important highways for the transport of goods in colonial North Carolina and Virginia.

Even with the addition of a modern tourism economy, coastal North Carolina is still very dependent upon agriculture, forestry, and fishing just as it was 400 years ago. It is important that policy and management decisions be made with consideration of settlement history. The Albemarle-Pamlico estuarine system has dominated eastern North Carolina and southeastern Virginia for centuries and is bound to continue to do so.

C. ENVIRONMENTAL CONCERNS AND PROBABLE CAUSES

C. 1. Identification of Environmental Concerns

Definite changes have taken place in the Albemarle-Pamlico estuarine system in recent years. The "Albemarle-Pamlico Estuarine Study Work Plan" identified a series of environmental conditions that concern scientists, management agencies, and the public. There is a general impression that events of concern have become more frequent and that conditions that cause definitive environmental problems are not well understood.

C. 1. a. Declines in Fisheries Productivity. Major declines in commercial anadromous fisheries have occurred in the Albemarle-Pamlico region since the 1970s. Striped bass, shad, and river herring landings from the Albemarle Sound are greatly depressed from historic levels. Commercial landings of croaker, catfish, and flounder have declined since 1980. Blue crab landings have fluctuated, with a current lower-than-average catch. The shrimp catch, traditionally the most valuable of all North Carolina commercial fisheries, has declined over the last decade. Recreational fishermen often complain that "fishing is not what it used to be" and that the catch-per-unit-effort has declined over the past decade. The reasons for these declines remain equivocal, but undoubtedly include declining water quality, critical habitat loss or alteration, and over-fishing. Declines are expected to continue unless causes can be ascertained and corrective steps taken.

C. 1. b. Sores and Diseases. Recent outbreaks of ulcerative mycosis in commercially important species in the Pamlico present a major challenge. Up to 100% of the menhaden sampled in the Pamlico River estuary during the past five years were affected; other commercially important species (such as flounder and weakfish) were affected to a lesser extent. Recent investigations suggest that stress related to water quality degradation is an important factor leading to disease outbreaks, but epidemiological relationships are poorly understood. "Red sore disease" reached epidemic proportions in some commercial species in Albemarle Sound during the 1970s, but the causes for the outbreaks and the potential for re-occurrence remain ambiguous.

More recently, blue crabs from the Pamlico River estuary, with "holes" in their shells, have been reported. Preliminary research indicates that the holes are the result of microbial invasion, possibly facilitated by water quality degradation.

C. 1. c. Anoxia-Related Fish Kills. Fish kills reported from the Pamlico River estuary have increased significantly in recent years. Variability in inter-annual conditions and the lack of reliable reporting make trend analysis difficult, but the available information suggests that fish kills are becoming more common. Most of the fish kills seem to be related to oxygen depletion (probably because of eutrophication, increased organic oxygen demand, and stratification), but the causal mechanisms are still not fully understood. Regardless of the lack of specific documentation, fishermen complain that the intensity and extent of anoxic waters have increased recently.

C. 1. d. Changes in Distribution Patterns of Benthic Organisms. Historic changes in distribution patterns of important benthic organisms have been dramatic. Surveys suggest that viable oyster beds, for

example, have been displaced downstream roughly 10-15 miles in the Pungo, Pamlico, and Neuse Rivers since the 1940s. The causes of this displacement are uncertain, but changes in salinity, sedimentation patterns, and harvesting have been implicated.

Extensive beds of brackish water submerged macrophytes that existed in the western portion of the sounds in the 1970s had almost disappeared by 1985. This decline parallels similar declines that have been documented in the Chesapeake Bay and elsewhere. Reduction in submerged aquatic vegetation is of crucial environmental concern because this decline represents a reduction in fisheries and waterfowl habitats. While turbidity is believed to be a primary cause of decline, other physical factors may be contributing to the trend. Some recovery in several areas has been recently observed.

C. 1. e. Impairment of Nursery Area Function. The fringe marshes and small embayments of the Albemarle and Pamlico Sounds provide essential nursery functions for a majority of the commercial and recreational fish and shellfish in the North Carolina coastal area. Freshwater drainage, land-use changes, and eutrophication have jeopardized the functional aspects of the primary nurseries in several locations. Although the exact extent of impairment may prove difficult to estimate where historical data are lacking, restoration/mitigation may be easily accomplished through proper and timely assessment programs.

C. 1. f. Eutrophication. Blooms of noxious phytoplankton, in response to cultural enrichment of estuarine waters with nutrients, are well documented in the Albemarle-Pamlico estuarine system. The most notable blooms have occurred in the Chowan River (Albemarle) and the Neuse River (Pamlico) during the last two decades. Many other tributaries display periodic blooms, depending on flow regimes, nutrient loading, hydrography, and meteorologic conditions. While research has uncovered some of the environmental relationships between ambient conditions and algae blooms, scientists have not yet integrated all the information needed to explain how, when, and why blooms occur. Management for minimizing their occurrence is, however, slowly evolving.

C. 1. g. Habitat Loss. Human activities in the region of the Albemarle-Pamlico estuarine system have greatly affected ecosystem functions of estuarine and closely-linked wetland habitats. Dredging, draining, and filling of productive bottoms, marshes, and pocosins have significantly reduced their areal extent and modified the reproductive, migratory, and feeding patterns of a wide variety of aquatic and terrestrial organisms. The relative value of such habitat is poorly understood, and restoration or mitigation potential for impacted areas has yet to be evaluated. Implementation of new programs, such as the "Swampbuster" provision of the 1985 Farm Bill, should reverse the trend of declining acreage of wetlands.

C. 1. h. Shellfish Closures. Closure of shellfish waters in North Carolina, in response to Sanitary Surveys (bacteriological, hydrological, and shoreline surveys) performed by the Shellfish Sanitation Branch of the Division of Environmental Health, has remained relatively constant over the past few years. About 36,000 acres of estuarine waters in the A/P study area are classified as "prohibited". Often, after heavy rainfall, additional acreage is closed for several days to several weeks. Within in the A/P Study area, temporary closures are usually confined to tributaries in Carteret County. These roughly 15,000 acres of temporary closures represent continued localized degradation of estuarine water quality. Albemarle Sound does not contain productive commercial shellfish beds, but Pamlico Sound has oysters, clams, and bay scallops in several areas. Core and Bogue Sounds are significantly affected. Relationships between contamination and land-use characteristics are poorly understood. New techniques to more accurately measure contamination and potential human impact are needed so that management can more effectively allocate shellfish resources.

C. 1. i. Toxicant Effects. Very little is known about the effects of toxicants on estuarine organisms and the distribution of toxic substances in the Albemarle-Pamlico estuarine system. Specific locations have been identified where elevated concentrations of toxicants exist, but large-scale problems have not

been documented. Public concern has been voiced about the potential toxicity of specific constituents of permitted and proposed discharges, but in general, water quality is still good and only a few sediment "hot spots" have been identified to date. A three-phase survey of toxic contaminants in the A/P sediments is currently underway.

C. 2. Identification of Probable Causes

Human activities in the Albemarle-Pamlico estuarine system include agriculture, forestry, residential and commercial development, mining, national defense, recreational and commercial fishing, tourism and recreational development, and wildlife hunting and preservation. All these activities generate waste and/or changes in the landscape and land-use. During the time-frame in which the environmental concerns outlined above have become more apparent, human activities have undergone major changes.

C. 2. a. Agriculture. Agriculture is the largest industry in the 28 North Carolina counties of the central and northern Coastal Plain surrounding the Albemarle-Pamlico estuarine system. These counties generate an annual return of over \$1.5 billion from agriculture. The highly productive soils represent 45% of the State's cropland and produce 50% of the State's swine, 25% of the State's chicken, and a large proportion of the State's corn, soybean, tobacco, potato, wheat, and peanut crops.

The 1989 North Carolina Nonpoint Source Assessment Report (NC DEM 1989) lists agricultural practices as the dominant source of nonpoint source pollution for the surface waters of the state. Agricultural practices were found to be a significant source of water quality problems in approximately 67% of the degraded rivers and streams and 61% of the degraded estuarine waters (Nichols et al. 1990). In the Virginia portion of the A/P Study area, agriculture and swine production are considered to be the largest sources of water pollution.

In the lower areas east of the Suffolk Scarp and in southeastern Virginia, the major crops are corn, wheat, and soybeans. Farming activities are highly mechanized, and most individual operations are much larger than the statewide average. Soils require extensive drainage for most agricultural operations; consequently, large acreage are drained into networks of canals, the runoff from which eventually reaches the estuaries.

Concerns about agricultural impacts include (1) nutrient loading of receiving waters, particularly from animal wastes and fertilizers applied to fields; (2) increased freshwater peak flows into saline primary nursery areas; (3) degradation of water bodies from sedimentation; and (4) pathogenic microbes in shellfish areas. The degree to which agriculture causes declines in water quality depends upon many factors, including the weather, specific crops grown, and the application of Best Management Practices (BMPs). BMPs recommended for the Coastal Plain control soil erosion, sediment delivery, animal waste disposal, fertilizer runoff, and drainage water, and have been demonstrated to reduce the impact of agriculture on water quality.

Agricultural acreage is expected to remain relatively constant in the region during the foreseeable future. Relative mixes of crops and agricultural activities will vary interannually, depending upon economics and environmental conditions. Animal production (particularly hogs and chickens) is expected to continue to increase at a rate similar to that of recent years. The use of BMPs should reduce the potential for nonpoint pollution. The NC Agriculture Cost Share Program encourages widespread implementation of BMPs. Effective water management is proving to be very attractive to farmers and its use should increase.

C. 2. b. Commercial Forestry. Forest land of the A/P region produces raw materials for a diverse forest products industry. The forests also function as wildlife habitat, recreational areas, and filter and surge control mechanisms for fresh waters entering the sounds.

Analyses of recent US Forest Service woodland inventories and information from the NC Division of Forest Resources reveal the following trends in forestry activities:

1. Total forest area has declined at an average annual rate of about 20,000 acres per year during the past few years.
2. The areal extent of pond pine, oak-gum-cypress, and natural pine stands decreased between 1964 and 1984. Other hardwood types and pine plantations have increased during the same period.
3. Land ownership patterns have shifted; privately owned acreage has declined and corporately owned acreage had increased.
4. The annual rate at which pine plantations are established has decreased, and the degree of disturbance associated with plantation establishment has also declined.
5. The use of herbicides, prescribed burning, and fertilizer during the establishment of pine plantations has increased.
6. Installation rates of drainage systems in woodlands have declined. It is estimated that about 75 to 80% of the land owned by the forest industry, for which drainage is feasible has drainage systems in place.

C. 2. c. Residential and Commercial Development. Residential and commercial development varies greatly from one area to another in the Albemarle-Pamlico region. Residential uses, including trailer parks, condominiums, and housing neighborhoods, are concentrated near the ocean and around the shorelines of the sounds. Commercial uses, ranging from marinas to central business districts and shopping centers, are concentrated near population centers and the Outer Banks. The initial push to develop was concentrated at the oceanfront, but has recently expanded to the shores of the sounds and rivers further inland. Activities have been most concentrated in Dare, Carteret, Craven, and Beaufort Counties. These trends seem to be continuing.

C. 2. d. Mining and Industrial Development. The Albemarle-Pamlico estuarine area is not highly industrialized in comparison to other areas of the country, however, there are several, isolated, large manufacturing and mining operations close to the sounds that have potentially significant impacts on water quality. Notable examples include a phosphate mining and processing facility on the Pamlico River; pulp and paper mills on the Neuse, Chowan, and Roanoke Rivers; a metal plating operation on the Neuse River; and textile/synthetic fibers manufacturing plants on the Pamlico, Chowan, Roanoke, and Neuse Rivers.

Several smaller industrial operations, such as animal processing operations, fish houses, printing shops, chemical manufacturers, and boat builders or repairers lie around the shores and tributaries of the sounds. Industrial operations upstream also affect the estuary. Large-scale peat mining in the region is still a speculative venture.

C. 2. e. National Defense. The US Department of Defense operates 19 facilities, occupying more than 97,000 acres in the Albemarle-Pamlico region. Included are:

1. Atlantic Intracoastal Waterway -- Transportation activities have potential impacts from, for example, oil spills and discharge of petroleum by-products and wastes from vessels. Maintenance dredging generates intermittent impacts from increased turbidity and disposal of spoil. There is increasing use of the waterway by recreational crafts.

2. **Military Bases** -- The Cherry Point Marine Air Station is the largest installation adjacent to the sounds. It is a potential source of hazardous wastes and point source waste disposal.
3. **Bombing Ranges and Target Areas** -- Site-specific physical affects occur in these areas in and around the sounds. Broader and more significant impacts may result from interest conflicts among commercial fishermen, recreational users, wildlife, commercial and private aircraft, and travelers on the Intracoastal Waterway. Proposals have been recently offered to expand bombing ranges in the area.

C. 2. f. Waste Disposal. A major use of the Albemarle-Pamlico estuarine system and its tributaries is for the disposal of wastes generated by domestic, industrial, and defense facilities, and by other human activities in the watershed. Point source contributions come from identifiable facilities regulated by the North Carolina Division of Environmental Management. A very large proportion of the inputs are non-point in origin, and come from runoff from land-based activities and groundwater discharge.

Impacts of waste disposal are evident in the Albemarle-Pamlico system, but the exact causal relationships and magnitudes of effects are not well documented. Eutrophication, as expressed in algal blooms, is an obvious result of anthropogenic augmentation of nutrient fluxes. Other effects, such as the occurrence of ulcerative sores in fish and major shifts in the distribution and abundance of estuarine organisms, seem to be linked to waste loadings, but the causal relationships are extremely unclear.

C. 2. g. Commercial Fisheries. Commercial fishing was one of the primary trades practiced by the original settlers of the coasts of North Carolina and Virginia. The Albemarle-Pamlico estuarine system is the ecological basis for most of our fishing industry. Its diversity and setting result in a complex of habitats that support diverse exploitable fishery species. Gear and fishermen are equally diverse. The number of licensed vessels fishing in the area continues to increase. Most fishermen do not rely on single species of fish or shellfish, but pursue a variety of species over different seasons with different gear types.

Problems in commercial fisheries include over-fishing, conflicts in allocation of species and catch between commercial and recreational demands, by-catch from trawling and pound net fisheries and declining catches for several species. Other issues revolve around the impacts of mechanical harvesting of shellfish on the environment and the disturbance of habitat by traditional harvesting techniques.

C. 2. h. Recreational Fishing and Boating. Millions of man-days of recreational fishing occur in the Albemarle-Pamlico area on an annual basis. A large proportion of the boating activities in the area support the recreational fishing effort. Boating also occurs for commercial fishing, sailing, water skiing, and other recreational activities. In 1986, over 49,000 boats were registered in the 25 coastal counties in the study area (roughly 23% of the 218,000 boats registered in North Carolina), however many inland boaters and fishermen also utilize the sounds. Boating access consists of 64 public launching ramps and 117 privately owned or commercial access areas. Specific estimates of fishing and boating effort and fish harvest are not available, but the activity is increasing at a rapid rate.

C. 2. i. Tourism and Recreation. Tourism and recreation are significant and growing economic and developmental forces in the Albemarle-Pamlico area. Development of second homes and support facilities has accelerated. There is a general consensus that demand for recreational activities in the coastal area will continue to increase over the next few years. As recreation-related activities increase, human impacts in terms of waste disposal, water supply requirements, destruction of wildlife habitat, stormwater runoff from developed areas, and pollution associated with pleasure boats and marinas will become increasingly significant sources of stress on the estuarine environment.

C. 2. j. Wildlife Resources. The Albemarle-Pamlico estuarine system area is an important component of wintering waterfowl habitat in eastern North Carolina. Surveys have consistently shown that the majority of wintering Canada geese, snow geese, tundra swans, Brant geese, diving ducks, and sea ducks utilize the estuary system. A variety of other wildlife also utilize the diverse habitat of the area. Several threatened and endangered species are found around the sounds. Potential human impacts come from habitat loss, increasing hunting activities, and the development of private waterfowl impoundments.

The US Fish and Wildlife Service owns and manages 9 wildlife refuges in the area, encompassing 254,226 acres. These are Mattamuskeet, Swanquarter, Pungo, Cedar Island, Alligator River, Pea Island, Currituck, Mackay Island, and a portion of the Great Dismal Swamp (more recent proposals for sites on the Roanoke River and Dare/Tyrrell County peatlands will add to the total). Major management objectives include provision of optimal habitat for waterfowl and other migratory birds, preservation of threatened and endangered species, preservation of species diversity, preservation of prime examples of habitats, and provision of opportunities for wildlife-oriented education, interpretation and recreation.

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A. INTRODUCTION

The natural resources of the Albemarle-Pamlico (A/P) region constitute the foundation of the region's inherent wealth. Some components of this base, termed "resource critical areas," are particularly important in sustaining its vitality. We have viewed critical areas in the context of biophysical systems -- ecosystems, biotic communities, and habitats -- which are noteworthy: (1) because of their role in maintaining estuarine productivity, (2) as indicators of the environmental health of the region, or (3) because of their uniqueness, sensitivity to disturbance, or relationship to regional development.

Each type of critical area is characterized in terms of its distribution and biotic and abiotic attributes, its functional role in the larger A/P ecosystem, environmental factors which limit its occurrence, the adequacy of information upon which to make management decisions, and trends in its distribution and quality. Each section also contains a short summary of existing regulatory mechanisms governing the use and management of the critical area. Scientific names used in the text are based on Radford (1968) for plants and the American Ornithologists Union (1983) for birds.

From perusing the chapter, a reader should obtain an understanding of the importance of each critical area, the adequacy of our understanding of its composition and function, and the degree to which it is threatened by current or impending natural or human-induced factors. Such an understanding should enable administrators to better define tasks and allocate resources in the process of developing a management plan for the Albemarle-Pamlico region.

B. SUBMERGED AQUATIC VEGETATION

B. 1. Description

Worldwide, submerged aquatic vegetation (SAV) constitute one of the most conspicuous and common shallow-water habitat types. These angiosperms have successfully colonized standing and flowing fresh, brackish, and marine waters in all climatic zones, and most are rooted in the sediment. Frequently, SAV contribute a large portion of the total ecosystem productivity for the geographic region of which they are a part. Under optimum conditions some species may fix carbon at rates equal to or exceeding the rates of intensively farmed agriculture crops (Ferguson et al. 1980; Thayer et al. 1984b).

Organic matter produced by these systems, both particulates and dissolved organics, can be transferred to secondary consumers through microorganism and herbivore consumption and through detrital feeding. Leaves of SAV also provide a substrate for epibiotic organisms as well as a complex structural habitat for juvenile and adult macrofauna (Ferguson et al. 1980; Thayer et al. 1984a, 1984b, Kenworthy et al. 1988, and references cited therein).

Thus, a variety of primary and secondary sources of organic carbon in these communities provides multiple food resources for invertebrates and vertebrates. No less important is the protection afforded by the leaf canopy and the root mat systems. They provide refuge for pelagic and benthic organisms of both commercial and recreational importance in their larval, juvenile and adult life history stages (Adams 1979; Peterson 1982; Thayer et al., 1984b; Kenworthy and Thayer 1984;

Kenworthy et al. 1988). Not all systems, however, provide equivalent habitat utilization potential. The differences that do exist occur because of different species, leaf area, bottom coverage, and hydraulic regimes (Thayer et al. 1984b; Fonseca and Fisher 1986).

Accompanying these functional attributes of SAV systems are interactions among the above-ground or canopy portion of the meadow, the root mat, and the aquatic and sedimentary environments that further enhance the role and value of these habitats. The grass blades, by exerting drag forces on the overlying water, reduce current velocity within and across the meadow. Velocity reduction promotes sedimentation of inorganic and organic matter, reduces turbulence, and reduces scouring of the sediment (Fonseca and Fisher 1986). These processes significantly influence the ways in which animals feed and what they feed on within the meadows, the distribution of flora and fauna, and the general potential use of these systems by wildlife. A well-developed root mat enhances sediment stability, absorbs inorganic nutrients from interstitial water in the sediments, and releases both inorganic and organic nutrients into the interstitial water (Penhale and Smith 1977; Penhale and Thayer 1980, Penhale and Wetzel 1983). Leaves and their associated epibiota absorb nutrients from and secrete nutrients into the overlying water column. Therefore, where these systems are prevalent they modify mineral cycles of shallow water environments.

Those factors most frequently considered limiting to the distribution and success of SAV are salinity, turbulence, nutrients, and light. Because of physiological tolerances, long term salinity trends can influence the up-estuary or down-estuary distribution of most SAV. Little research, however, has been carried out on the physiological tolerances of most SAV species (McMillan and Moseley 1967). Most research on SAV-nutrient interactions has centered on nutrient recycling processes rather than the specific physiological nutrient requirements of the plants (Kenworthy et al. 1982). Under some circumstances submerged aquatic plants may be nutrient limited, with nitrogen being the most frequently implicated limiting nutrient for temperate marine species. However, the subjects of nutrient sources and availability, and the general nutritional requirements of SAV, require more research.

Light availability appears to be the primary factor limiting both depth of SAV occurrence and within-estuary penetration of most SAV (Thayer et al. 1984b; Dennison 1987; Stevenson et al. 1988; Davis and Brinson 1989). Research on the productivity of SAV species as a function of insolation and availability of photosynthetically active radiation, as well as research on changes in standing crops of plants, generally supports the hypothesis that light availability is a primary limiting factor. Light availability is a function of insolation, water clarity, and water depth; thus, factors affecting these parameters should effect the distribution of SAV.

B. 2. Status and Trends of Information

The majority of research on the temperate seagrasses, particularly eel grass (Zostera marina), has been conducted in only a few locations: around Beaufort, North Carolina (National Marine Fisheries Service (NMFS) and the University of North Carolina Institute of Marine Sciences (UNC/IMS)); Chesapeake Bay, Long Island Sound, and Rhode Island on the Atlantic coast; and a few locations on the Pacific coast. Much of the information gathered on this species is generally applicable to the other marine species common to the Albemarle-Pamlico Study area, such as Cuban shoalgrass (Halodule wrightii), and to the halotolerant species widgeongrass (Ruppia maritima). Likewise, the functional characteristics attributed to marine SAV are probably applicable to the brackish/fresh water complex of species. Information needs apply across the board, but if relative habitat values are to be established, there is a need for comparative research among habitats rather than on a single habitat type.

Research in the Beaufort area has demonstrated that eelgrass and shoalgrass are highly productive and provide an important substrate for epibiotic organisms that contribute to the overall productivity of the system (see citations in Thayer et al. 1984b). Data also are available on population growth rates, sediment-plant-nutrient interactions, epibiotic communities, and factors influencing SAV meadow formation and dynamics (Kenworthy et al. 1982; Fonseca et al. 1983; Thayer et al. 1984b).

Information available from Bogue Sound, Back Sound, and Core Sound provides the major data base on faunal utilization of seagrasses in North Carolina. Publications by researchers at NMFS and UNC/IMS describe epibenthic and benthic invertebrate communities and the utilization of these marine SAV habitats by fishery organisms (Summerson and Peterson 1984; Thayer et al. 1984b). Larval and juvenile fish and shellfish including gray trout (Cynoscion regalis), red drum (Sciaenops ocellatus), spotted seatrout (Cynoscion nebulosus), mullet (Mugil cephalus), spot, (Leiostomus xanthurus), pinfish (Lagodon rhomboides), pigfish (Orthopristis chrysoptera), gag grouper (Mycteroperca microlepis), white grunt (Haemulon plumieri), silver perch (Bairdiella chrysoura), summer flounder (Paralichthys dentatus), southern flounder (P. lethostigma), brown shrimp (Penaeus aztecus), pink shrimp (P. duorarum), blue crabs (Callinectes sapidus), hard shell clams (Mercenaria mercenaria), and bay scallops (Argopecten irradians concentricus) utilize the SAV beds as nursery areas. They are the sole nursery grounds for North Carolina bay scallops. SAV meadows are also frequented by adult spot, spotted seatrout, summer and southern flounder, pink and brown shrimp, hard shell clams, and blue crabs. Investigations are being conducted by NMFS on recruitment of fish and blue crabs to SAV and the role played by SAV as refuge from predation. Ospreys, egrets, herons, gulls, and terns feed on fauna in SAV beds, while swans, geese, and ducks feed directly on the grass itself. Green sea turtles (Chelonia mydas) also utilize seagrass beds, and juveniles may feed directly on the seagrasses.

Little research has been done on the ecology of the extensive SAV meadows of Pamlico and Albemarle Sounds. Information that does exist generally is limited to commercial fishery and nursery habitat surveys, some of which was summarized in Epperly and Ross (1986). Little evidence of faunal/habitat research exists other than bird censuses and, possibly, nursery habitat assessments conducted in the brackish water SAV communities of the A/P Study area.

Limited information exists on the distribution, extent, composition, and seasonality of SAV habitats in the A/P complex. The estimate of 200,000 acres of SAV in North Carolina is similar to that of salt marshes in the state. Further, this estimate ranks North Carolina second only to Florida in extent of marine SAV. Ground-based transect studies (Davis and Brinson 1980, 1983, 1989) and aerial photography with ground-truth surveys (Vicars 1976; Carraway and Priddy 1983) have been used to assess SAV distribution. The SAV distribution data base is limited to specific parts of the A/P Study area and a variety of time periods. Recently, detailed aerial photography and ground truthing have been conducted (Ferguson et al. 1989a, b). The only available charts of SAV distribution are for marine SAV (Carraway and Priddy 1983; Ferguson et al. 1989a, b).

The only area in North Carolina with a significant historical record of observations and/or biomass of brackish water SAV is Currituck Sound. For this reason it is difficult to determine whether there have been major losses or gains in abundance or changes in distribution in the A/P Study area as a whole. The literature on Currituck Sound has been reviewed by Davis and Carey (1981) and Davis and Brinson (1983).

Studies have sporadically documented the status of SAV in the Currituck Sound since 1909. After a review of unpublished literature, Sincock (1966) inferred that lush SAV was present in the Sound from the mid-1800s until around 1918, at which time deterioration began. Slime mold and

increased water temperatures, it is believed, weakened the SAV and made it susceptible to the virus Labryinthula. Black spots and necrosis set in, resulting in the slow demise of the SAV population, and the disruption of other organisms which had depended upon the SAV, such as the Black Brant Goose, scallops, and fish. Throughout the eastern coast of North America and the western coast of Europe, 90% of the SAV was lost to this disease in the 1930s. This deterioration, hypothesized to be caused by a virus, was known as the "Wasting Disease" and was attributed to pollution from Norfolk Harbor entering the Sound via the Albemarle and Chesapeake Canal. In 1932 operation of canal locks began and the situation gradually improved -- SAV began to return to the Sound. By 1967, Eurasian watermilfoil (Myriophyllum spicatum), an exotic, had become a pest species in the sound, but it has caused few problems since about 1978. Transects that had been sampled in 1973 by Kearson (1976) were rerun in 1978 (Davis and Carey 1981). Eurasian watermilfoil biomass in the Sound was about one-half that of 1973; the decrease was attributed to unusual weather conditions which contributed to water turbidity and turbulence. Further decreases were noted by 1988 (Davis and Brinson 1989). Widgeongrass gradually increased in range, abundance, and biomass from 1973 to 1988, but this species has a low overall biomass in the Sound. Most of the widgeongrass biomass appears in embayments and between marsh islands; these areas were poorly represented in the transects.

SAV, often dense and diverse, was present in most of the littoral of the Perquimans River in 1988. The North River was characterized by moderate to dense Eurasian watermilfoil in creeks and embayments, and other species of SAV were present (Davis and Brinson 1989). The Little River also had high areal coverage and biomass of SAV; Eurasian watermilfoil and, perhaps, leafy pondweed (Potamogeton foliosus) were often in abundance. In contrast to the Perquimans and Little Rivers, the Pasquotank River had become essentially barren by 1988. The only significant rooted aquatic macrophyte biomass in the Chowan River in 1973-1974 was yellow waterlily or spatterdock (Nuphar luteum) and water willow (Justicia americana) (Twilley et al. 1985).

Until the mid-1970s, SAV was common in the upper half of the Pamlico River estuary (Davis and Brinson 1976, 1989). By 1985, however, SAV biomass had been reduced to about 1% of that of the 1970s and only widgeongrass was present (Davis and Brinson 1989). An after-the-fact analysis of the decline suggests that unusual weather conditions in 1978 contributed to the problem. Any tendency toward re-establishment of wild celery (Vallisneria americana), previously the most important species in the estuary, was probably negated by the drought-induced extremely high salinities prevalent in 1981 (Davis and Brinson 1989). Wild celery reappeared in the Pamlico River in 1987 (Davis and Brinson 1989) and spread rapidly in the middle reach in 1988, whereas only traces of wild celery were present in the embayments along the western shore of Pamlico Sound. However, this population appeared stressed relative to populations in Currituck Sound and most sites in the Neuse River. The reasons for the poor growth of SAV in areas of the Pamlico River, where it once flourished, are not clear. Light attenuation appeared similar to that in a wild celery bed in the Neuse River and was less than that in a SAV bed in Currituck Sound. Epibiotic growth was generally light to undetectable on the plants in the Pamlico River in July 1989. High salinities and a heavy epibiotic load may have affected wild celery growth in the Pamlico River in 1988, as we hypothesize occurred in 1981. During spring and early summer 1989, low salinities occurred following heavy rains. This reduced salinity appeared to cause an increase in health and vigor of wild celery in Nevil Creek and tributaries of the Pamlico River.

Among the tributaries of the Pamlico River, Chocowinity Bay, Blounts Creek, Bath Creek, South Creek, Goose Creek, Pungo River, Pantego Creek and Pungo Creek, had little or no SAV in 1988 (Davis and Brinson 1989). The same was true for Slocum Creek, Clubfoot Creek, and Adams Creek for the Neuse River and for Bay River. SAV was sometimes present in the sub-tributaries in these systems. Except for locally dense Eurasian watermilfoil in tributaries of North and South Creeks of the Pamlico River system, horned pondweed (Zannichellia palustris) and widgeongrass comprised

practically all the SAV biomass in tributaries. Horned pondweed commences growth in winter and tends to be replaced by widgeongrass in May and June. These species are generally present in the littoral of smaller creeks to around the 1-1.2 m depth contour, especially in the upper and middle reaches of the creeks. Thus, there tends to be SAV cover on these creeks throughout most of the year.

Small and generally healthy beds of wild celery were noted in a short stretch of the narrow southern littoral of the upper reach of the Neuse River estuary in 1988 (Davis and Brinson 1989). Traces of widgeongrass are present on both sides of the estuary. Assuming similar environmental conditions, the potential for areal increase of wild celery is highly restricted by morphologic features of the Neuse River, such as a narrow littoral in the low salinity reach.

Occasionally, seagrasses (eelgrass and shoalgrass) and widgeongrass occur in the same areas. The co-existence of the three grasses is unique to North Carolina, and because of the different temporal abundance patterns exhibited (Thayer et al. 1984b), feeding habitat and refuge for fish and shellfish are provided almost year-round by these species.

Initial maps of SAV distribution in Bogue, Back and Core Sound were prepared by Carraway and Priddy (1983). Based on photographs taken in 1981, the NC Department of Transportation estimated there to be a total of 16,901 acres of SAV in their study area. Of the total, 75% was located in Core Sound (from Lighthouse Channel to a line between Camp Point and Core Banks), 13% was located in Back Sound (east and south of a line from Shackelford Jetty to the north end of Middle Marsh to the southeastern corner of Harkers Island and running along the south shore of that island to Lighthouse Channel), and 12% was located in western Bogue Sound (from Bogue Inlet to a line running from east of Gales Creek to Rock Point).

Under funding from the A/P Study, the Beaufort Laboratory of NMFS conducted a visual aerial survey of Core Sound and eastern Albemarle and Pamlico Sounds, and photographed Core Sound and eastern Pamlico Sound at scales of 1:24,000 and 1:50,000 (Ferguson et al. 1989b). The project also collected seagrass samples in Core, eastern Pamlico, Croatan, Roanoke, Albemarle, and Currituck Sounds to provide ground-level verification for aerial photo-interpretation of SAV distribution and regional data on SAV species composition. Project personnel also delineated SAV from 1985 photography of southern Core Sound and produced charts of seagrass habitat in Core Sound from Cape Lookout to Drum Inlet.

This project delineated 11,844 acres of SAV. Roughly 88% occurred along the eastern shore of Core Sound and roughly 12% occurred along the western shore of Core Sound (Figure II-1). SAV was limited to a maximum depth of about 2 meters, probably as a result of light attenuation in turbid water. Widgeongrass was uncommon but occurred most frequently along the western shore (mainland side), whereas shoalgrass was more abundant on the eastern shore. Eelgrass provided most of the plant biomass throughout the sample area but eelgrass and shoalgrass were of almost equal importance on a leaf number basis (Ferguson et al. 1989a).

Ferguson et al. (1989b) observed a number of SAV habitats that had gone unrecorded in the 1981 study and noted an increase in size for others, particularly in the deeper waters of southern Core Sound. Control of the timing of photography (low tide, and high water and air clarity) and photographic quality increased ability to delineate SAV and probably accounted for the increased SAV acreage estimate in 1989.

Figure II-2 shows the approximate location of seagrass habitat in Pamlico Sound based on previous reports, aerial overflights, analyses of the 1985 photography, and preliminary analysis of 1988 photography (Ferguson et al. 1989b). It is estimated that marine SAV covered approximately 200,000 acres of bottom habitat from Bogue Inlet to Oregon Inlet including Bogue, Back, Core and southern and eastern Pamlico Sounds. About 80% of this total is along the southern and eastern periphery of Pamlico Sound; however, the interpretation and mapping of this area is incomplete. Preliminary analysis of ground truth samples indicates that all three species (eelgrass, shoalgrass, and widgeongrass) coexist in the area north of Drum Inlet; shoalgrass is somewhat more dominant (numerically) in both the northern Core Sound area and the southeastern Pamlico Sound area. As is the case for southern Core Sound, SAV almost exclusively occurred at depths shallower than 2 meters.

Unlike the drastic changes and shifts that have occurred in the brackish water SAV community of the A/P region (Davis and Brinson 1989), the marine SAV community appears relatively stable, at least since the recovery of eelgrass from the "wasting disease" of the 1930s (see Thayer et al. 1984b for discussion). The drought and increased water clarity during the summer of 1986 apparently caused an increase in SAV abundance in southeastern Pamlico Sound and a concomitant increase in bay scallop densities. Evidence is emerging, however, that "wasting disease-like" characteristics are showing up in some of the eelgrass populations in southern Core Sound, Back Sound, and Bogue Sound (Fred Short, University of New Hampshire, pers. com.).

The number of permits requested for development activities that potentially impact SAV populations is increasing, as is evidence of clandestine removal of seagrasses. Clam-kicking (the harvest of hard clams utilizing powerful propeller wash to dislodge the clams from the sediment) is a contentious issue within the state of North Carolina. The scientific community is convinced that mechanical harvesting of clams damages SAV communities (Peterson et al. 1983, 1987). The scallop fishery also could be harmed by harvest-related damage to eelgrass meadows (Thayer and Stuart 1974; Fonseca et al. 1984).

B. 3. Management

A number of federal and state laws require permits for modification and/or development in SAV. These include Section 10 of the Rivers and Harbors Act (1899), Section 404 of the Clean Water Act (1977), and the North Carolina Coastal Area Management Act (CAMA). Section 404 prohibits deposition of dredged or fill material in waters of the United States without a permit from the US Army Corps of Engineers. CAMA established the Coastal Resources Commission and requires a permit from the Division of Coastal Management for development activities in designated Areas of Environmental Concern.

The Fish and Wildlife Coordination Act gives federal and state resource agencies the authority to review and comment on permits, while the National Environmental Policy Act requires the development and review of Environmental Impact Statements. The Magnuson Fisheries and Conservation Act of 1976 established eight regional Fishery Management Councils (FMC). The FMCs are responsible for developing fishery management plans to insure the protection and conservation of our commercial and recreational fisheries. The Magnuson Act has been amended to require that each management plan include a habitat section as part of the document. In fact, each of the 8 regional FMCs has established a habitat subcommittee which may recommend that permit requests submitted to

the Corps of Engineers be denied because the proposed activity would impact upon habitat critical to the fisheries in question.

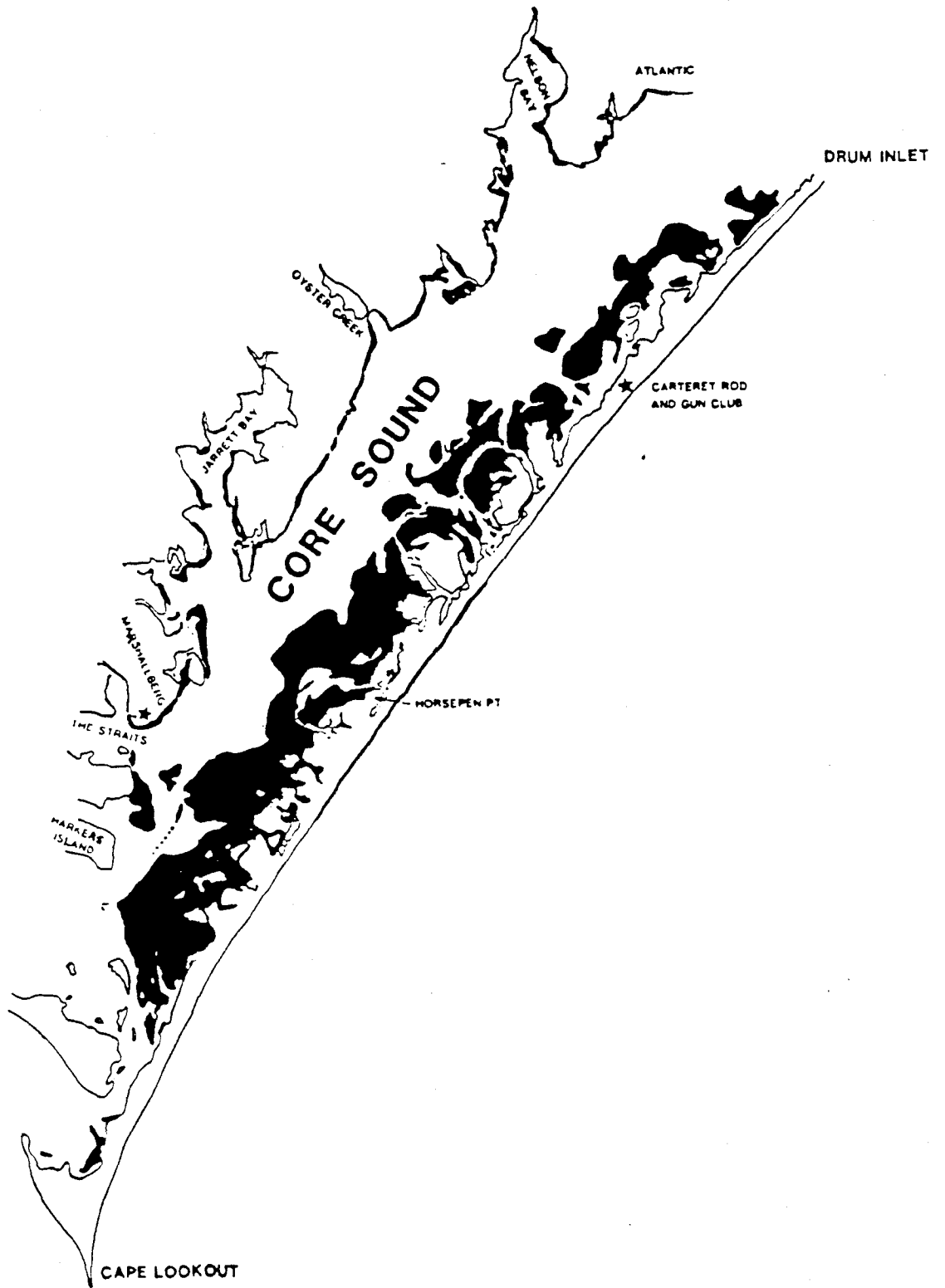


Fig. II-1. Southern Core Sound with location of submerged aquatic vegetation. From Ferguson et al. (1989b).

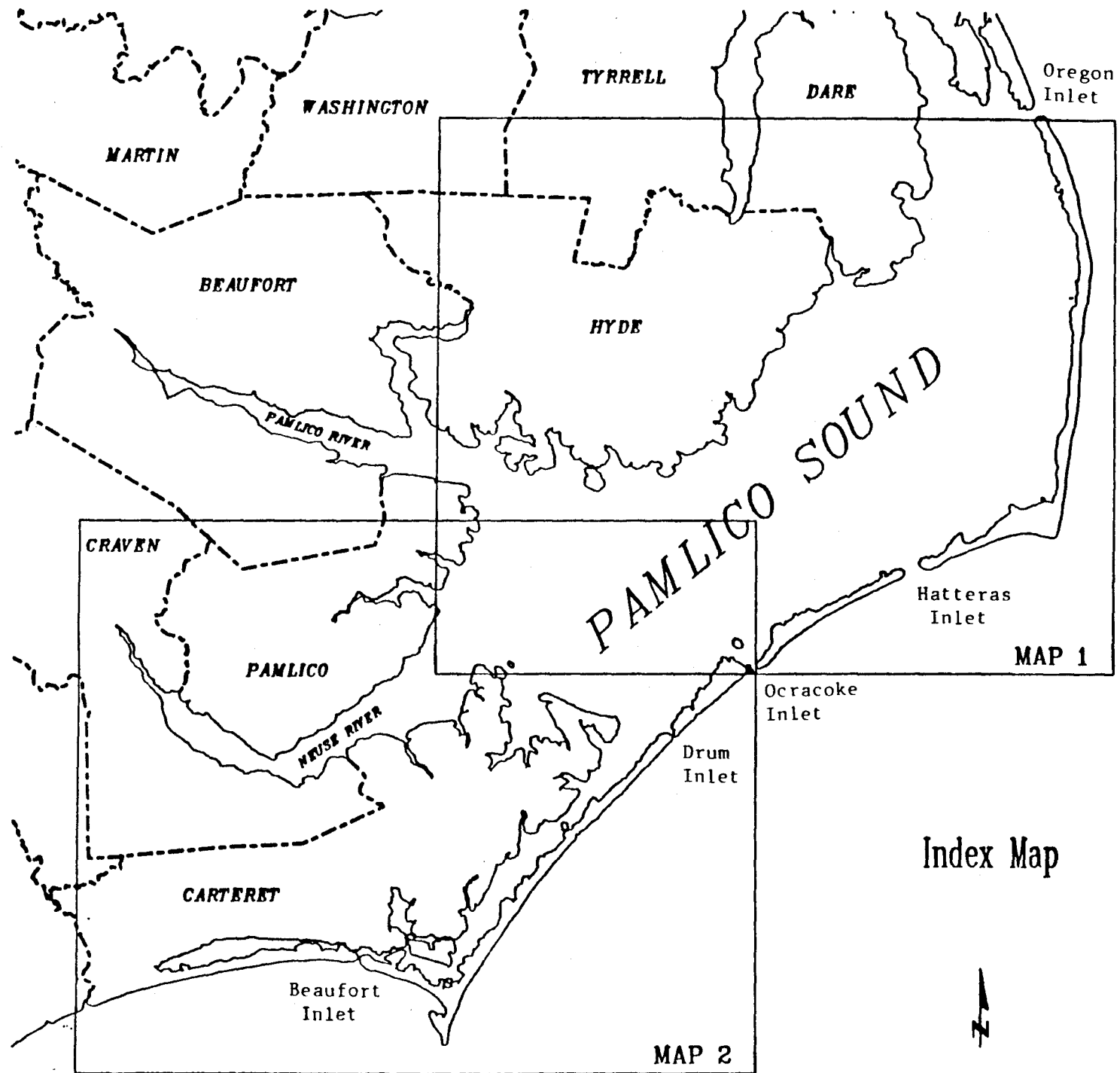
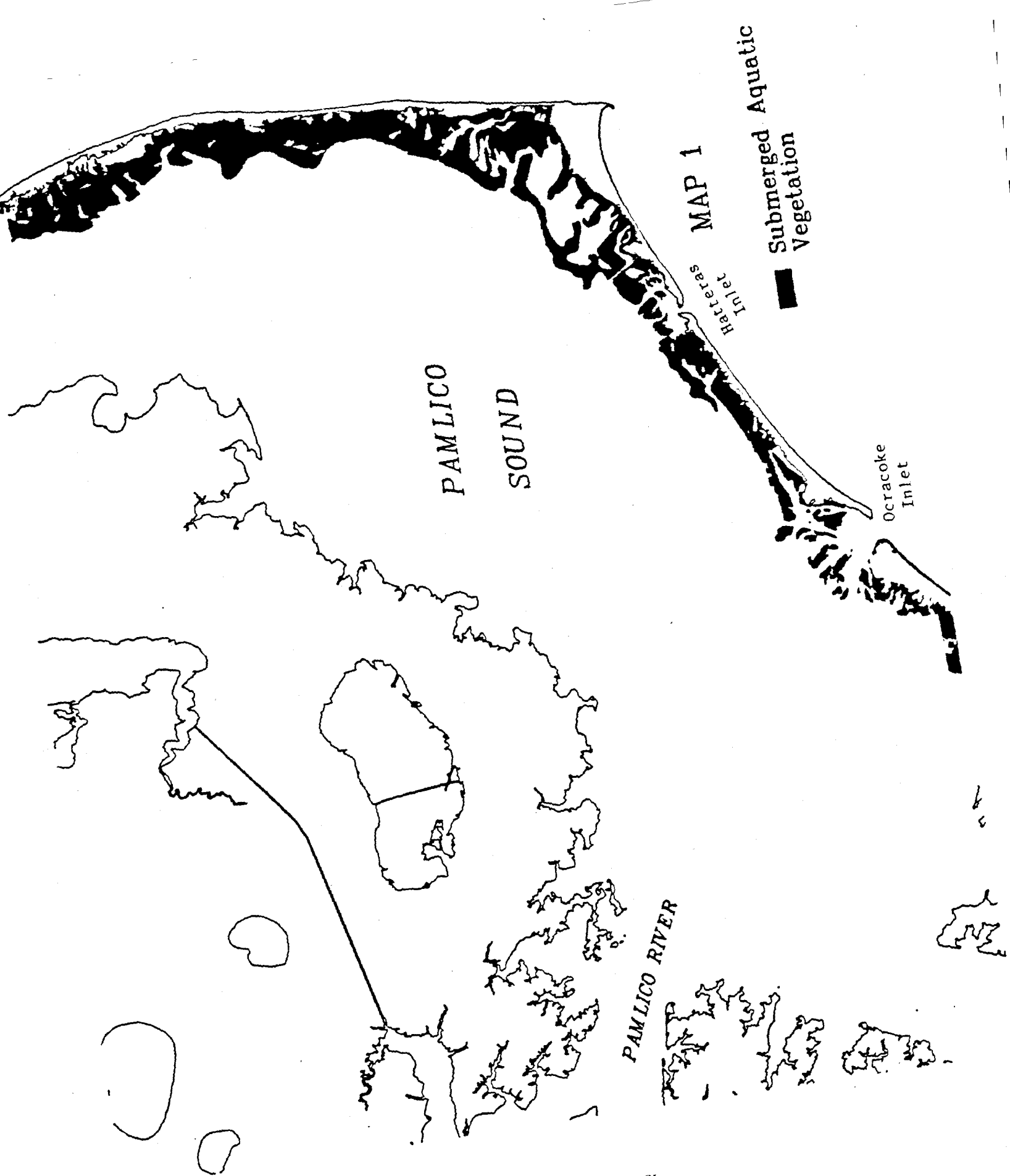


Fig. II-2. Approximate locations of seagrass habitat (SAV) in Bogue Sound, Core Sound, and eastern Pamlico Sound. SAV beds shown were acquired from multiple sources, 1981-1988. From Ferguson et al. (1989b).



MAP 1

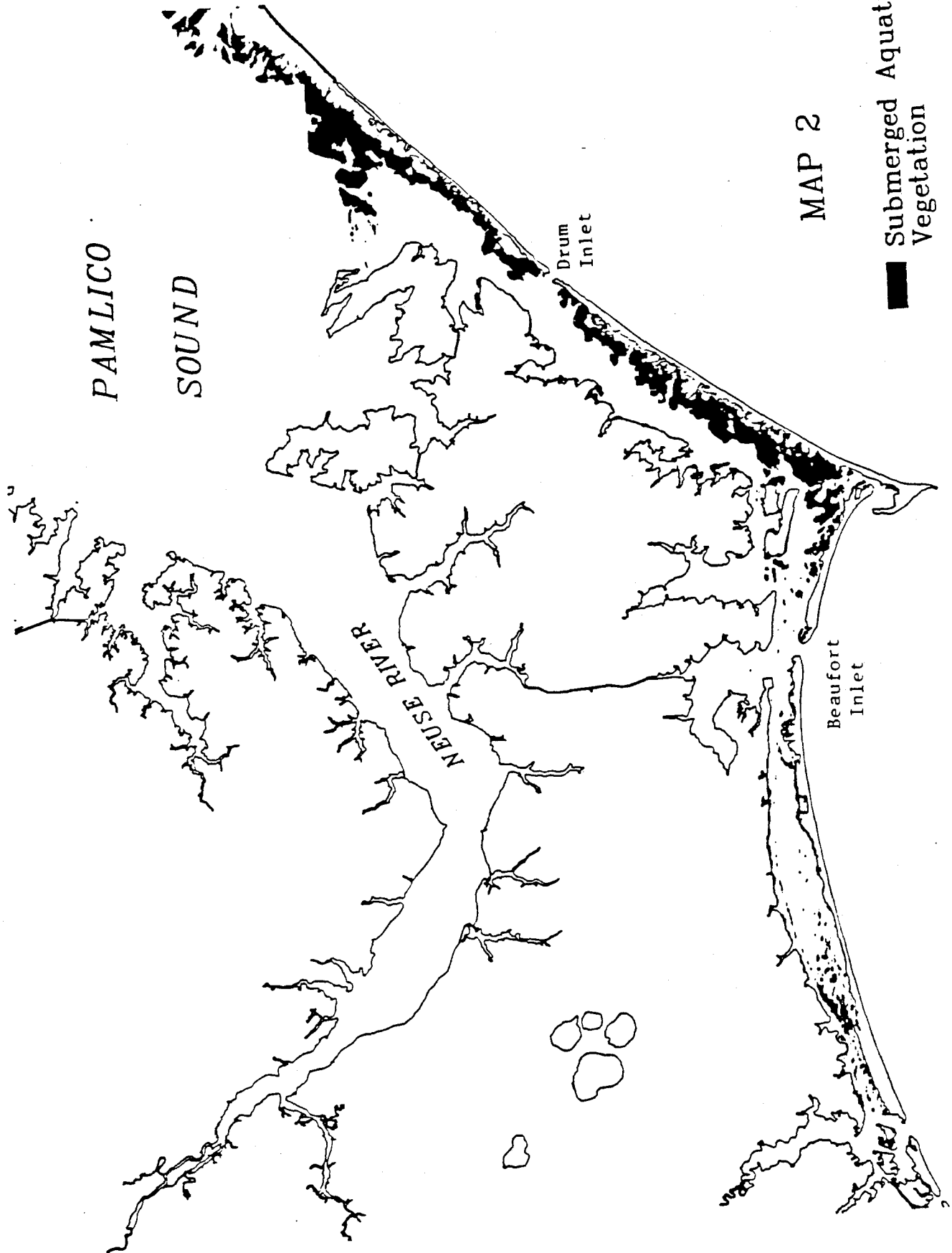
Submerged Aquatic
Vegetation

PAMLICO
SOUND

Hatteras
Inlet

Ocracoke
Inlet

PAMLICO RIVER



PAMLICO
SOUND

NEUSE RIVER

Drum
Inlet

Beaufort
Inlet

MAP 2

■ Submerged Aquatic
Vegetation

These federal and state resource agencies and the FMCs must be made aware of a number of potential sources of degradation of SAV. Factors influencing the existence of SAV have been discussed in detail in a number of publications (e.g., Thayer et al. 1984b; Davis and Brinson 1989; Fonseca In Press).

Degradation of SAV habitat is most easily understood when broken down into categories of indirect and direct causes. Direct causes include dredging and filling, regulated through Section 10 and Section 404 permits. Indirect losses of SAV are more subtle and difficult to assess. These losses center around changes in light availability caused by changes in turbidity (see Description). Turbidity may result from upland runoff -- either suspended sediments or dissolved nutrients. The introduction of additional nutrients from terrigenous sources often leads to plankton blooms and increased populations of epiphytes on the plants, reducing the light received by the SAV plants themselves. Groundwater enriched by septic systems also may infiltrate SAV areas and have the same effect (Fred Short, University of New Hampshire, pers. com.). Other indirect causes of SAV loss may be ascribed to changing hydrology which may in turn affect salinity and flushing. Reduction in flushing can cause an increase in the salinity and ambient temperature of a water body, thereby stressing the plants. Increases in flushing can mean decreased salinity, and increased turbidity and near-bottom mechanical stresses which may damage or uproot plants.

Conservation of existing SAV habitat is critical to the maintenance of the living estuarine resources that depend on these systems. These habitats cannot be readily restored; in fact, we are not aware of any seagrass restoration project that has ever avoided a net loss of seagrass habitat (Fonseca et al. 1987, 1988). In recognition of this, the staff of the National Marine Fisheries Service Beaufort Laboratory have published guidelines that are being used by NMFS and other agencies for the management and restoration of SAV in the hope that these guidelines will be used to enhance the success of restoration of SAV when it is necessary.

C. WETLANDS

C. 1. Introduction

C.1.a. Description of Wetland Types. Wetlands can be categorized in a variety of ways. For instance, wetlands can be broken down according to "coastal" and "noncoastal/inland" wetlands, according to the Cowardin et al. (1979) classification, according to location in the landscape, according to dominant vegetation, or based on other characteristics. It was decided that, for this "Critical Areas" chapter, a description and discussion of wetlands based on the form of the dominant vegetation in the wetland might be most readily understood. The wetland categories in the following discussion are marshes, scrub-shrub wetlands, and forested wetlands. These categories are also general enough to be used with wetlands information from a variety of sources.

The definition of marsh is consistent with Mitsch and Gosselink (1986) and is included in what Cowardin et al. refer (1979) to as emergent wetlands. The definitions of scrub-shrub wetlands and forested wetlands are from Cowardin et al. (1979). A marsh is characterized by erect, rooted, herbaceous (nonwoody) plants. In most years this vegetation is present for most of the growing season; dominant vegetation is usually perennial. Emergent wetlands occur in four of the five systems described by Cowardin et al. (1979): estuarine, palustrine, lacustrine, and riverine.

Scrub-shrub wetlands are areas dominated by woody plants less than 20 feet in height (Cowardin et al. 1979). Scrub-shrub wetlands occur largely in the estuarine and palustrine Systems. The types of woody vegetation that dominate these wetlands include true shrubs, young trees, and trees or shrubs whose growth has been stunted due to environmental conditions. Scrub-shrub wetlands may be relatively stable vegetative communities, or they may be successional stages leading to forested wetlands (Cowardin et al. 1979).

Forested wetlands are characterized by woody vegetation that is at least 20 feet tall (Cowardin et al. 1979). As with scrub-shrub wetlands, forested wetlands occur only in the palustrine and estuarine systems. This wetland type typically possesses an overstory of trees and an understory of young trees or shrubs. Overstory and understory trees may be broad-leaved deciduous, needle-leaved deciduous, broad-leaved evergreen, and/or needle-leaved evergreen. These forested types can be subdivided into a number of physiographic and vegetational categories.

The organization of wetlands in this document does not allow for the easy inclusion of Carolina bays, which are geological features that, as a group, may contain a variety of wetland types. These ecosystems are found primarily in the coastal plain of the Southeastern United States (Sharitz and Gibbons 1982), and according to Prouty (1952), they are especially concentrated in a band running from southeastern North Carolina to northeastern Georgia. Carolina bays are oriented in a northwest to southeast direction, and their origin is unknown (Sharitz and Gibbons 1982). Because of their variety of size, depth, substrate and water permanence, Carolina bays support a wide range of vegetational types. Many Carolina bays contain pocosin type vegetation, while others contain marshes, swamps, lakes with aquatic vegetation, or a combination of these, and upland vegetation due to extensive drainage and alteration (Sharitz and Gibbons 1982). Early European settlers called these ecosystems "bays" because of the evergreen shrubs and bay trees that were typically found on their margins.

Carolina bays range in size from less than 200 feet in length to more than 5 miles. The latter example, Lake Waccamaw in North Carolina, however, is not of a typical size (Sharitz and Gibbons 1982). In North Carolina, these ecosystems occur primarily in the southeastern corner of the state, with the majority in the middle coastal plain. Unfortunately, there is no comprehensive information currently available as to the approximate number and status of Carolina bays in the State or the Albemarle-Pamlico Estuarine Study area. The N.C. Natural Heritage Program is, however, presently conducting natural areas inventories in the A-P study area. Thus far they have identified as natural areas Carolina bays in the following A-P counties: Gates, Chowan, Currituck, Pitt, Carteret, Wayne, and Craven (Mike Schafale, North Carolina Natural Heritage Program, personal communication, 1992). Additionally, there are Carolina bays containing wetlands in Jones, Lenoir, and Edgecombe Counties; these Carolina bays have not been developed, but have been impacted to some extent. There also may be other relatively undisturbed Carolina bays in the study area that have not been identified by the Natural Heritage Program.

C.1.b. Regulation and Conservation of Wetlands

C.1.b.1. Federal Laws. Section 404 of the Clean Water Act (33 U.S.C. 1344) authorizes the Secretary of the Army, acting through the Chief of Engineers, to issue permits, after notice and opportunity for public hearing, for the discharge of dredged or fill material into waters of the United States. Waters of the United States are defined in 33 CFR 328.3 (a)(1 to 7). Wetlands are a subset of the Waters of the United States (33 CFR 328.3 (a)(3 and 7) and are defined as those areas that are

inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. (See Appendix A for the various federal definitions of wetlands.) Wetlands generally include swamps, marshes, bogs, and similar areas. A related law is Section 401 of the Clean Water Act (33 U.S.C. 1341). Section 401 requires any applicant for a federal permit to conduct any activity that may result in the discharge of a pollutant into waters of the United States to obtain certification from the State in which the discharges originates. The certification states that the discharge will comply with the applicable state effluent limitations and water quality standards. In North Carolina, the Division of Environmental Management and in Virginia, the State Water Control Board are the State agencies which issue these 401 Water Quality Certificates. In general, before a Section 404 permit is issued by the U.S. Army Corps of Engineers for the placement of dredged or fill material in waters of the United States, a 401 Water Quality Certificate must be obtained or waived from the North Carolina Division of Environmental Management (NCDEM) or the Virginia State Water Control Board (VSWCB). If a 401 Water Quality Certificate is denied by either the NCDEM or the VSWCB, a Section 404 permit can not be issued by the U.S. Army Corps of Engineers from (U.S. EPA et al, 1991).

The Regulatory Branches of the Wilmington and Norfolk Districts, U.S. Army Corps of Engineers are charged with carrying out the policies and programs adopted pursuant to Section 404 of the Clean Water Act. Their main offices are located in Wilmington, NC and Norfolk, VA.

In response to the intense pressures upon, and because of the importance of, the coastal zone of the United States, Congress passed the Coastal Zone Management Act (P.L. 92-583) which was signed into law on October 27, 1972 (NOAA, 1978). The Act authorized a Federal grant-in-aid program to be administered by the Secretary of Commerce, who in turn delegated this responsibility to the National Oceanic and Atmospheric Administration's Office of Coastal Zone Management (NOAA, 1978). The Coastal Zone Management Act of 1972 has been amended several times since its passage, most recently in November, 1990 (P.L. 101-508). Section 309 of the 1990 amendments established the Coastal Zone Enhancement Grants Program, which makes funds available to states for, among other things, improving wetlands protection in their coastal zones. Section 6217 of the 1990 amendments established the Coastal Nonpoint Pollution Control Program, which also includes wetlands management provisions. The Coastal Zone Management Act of 1972, as amended, affirms a national interest in the effective protection and development of the coastal zone by providing financial and technical assistance and encouragement to coastal states for the rational management of their coastal zones (Jim Wuenschel, North Carolina Division of Coastal Management, personal communication, 1992). Section 307 of the Coastal Zone Management Act of 1972, as amended, requires that all Federal permits must be consistent with the state's Federally approved coastal zone management programs (NOAA, 1978). This requirement applies to permits issued under Section 404 of the Clean Water Act. In North Carolina, the Division of Coastal Management and in Virginia, the Council of the Environment are responsible for issuing these state consistency determinations.

C.1.b.2. State Laws. The passage of the North Carolina Coastal Area Management Act (CAMA) during the 1974 Session of the General Assembly demonstrated the State's strong and continued interest in protecting its coastal resources. The main elements of CAMA are local land use planning, regulations for development in Areas of Environmental Concern (AEC) and permit coordination in the State's 20 coastal counties. There are also special programs for beach access and estuarine sanctuaries. Policy for the Coastal Management Program is set by the Coastal Resources Commission (CRC), with advice from the Coastal Resources Advisory Council (CRAC). The program is administered by the Division of Coastal Management (DCM). The DCM is part of the North

Carolina Department of Environment, Health, and Natural Resources. Its main office is in Raleigh, with field offices in Elizabeth City, Washington, Morehead City, and Wilmington (Source Unknown).

The DCM has permit authority in Coastal Wetland AEC's. For these purposes Coastal Wetlands are defined as 'any salt marsh or other marsh subject to regular or occasional flooding by tides, including wind tides (whether or not the tide waters reach the marshland areas through natural or artificial watercourses), provided this shall not include hurricane or tropical storms'. Pursuant to the CAMA definition of Coastal Wetland AEC's, tidal wetlands are all irregularly and regularly flooded wetlands under the influence of either wind-driven or lunar tides. Therefore, according to the CAMA definition of Coastal Wetland AEC's, brackish marshes described below (in section C.2.b.) as non-tidal and irregularly flooded marsh, are regulated as coastal wetlands. Essentially, coastal wetlands are wetlands containing the following species: 1) Smooth Cordgrass, 2) Black Needlerush, 3) Glasswort, 4) Salt Grass, 5) Sea Lavender, 6) Bulrush, 7) Saw Grass, 8) Cat-tail, 9) Salt Meadow Grass, and 10) Giant Cord Grass. Within Coastal Wetland AEC's, various use standards apply. "Uses which are not water dependent will not be permitted in coastal wetlands...Uses that are water dependent (and, hence, may be permitted in Coastal Wetland AEC's) include: utility easements, docks, wharfs, boat ramps, dredging, bridges and their approaches, revetments, bulkheads, culverts, groins, navigational aids, mooring pilings, navigational channels, simple access channels and drainage ditches (Laura Pena, Division of Coastal Management, personal communication, 1992).

The Coastal Management's counterpart in coastal Virginia is the Virginia Marine Resources Commission (VMRC) located in Newport News. The VMRC is responsible for managing and regulating the use of Virginia's submerged land, tidal wetlands, and coastal primary sand dunes (Williams et al, 1990). Under Virginia law, tidal wetlands include both vegetated and nonvegetated intertidal areas (Williams et al, 1990). Vegetated wetlands include all the land lying between and contiguous to mean low water and an elevation above mean low water equal to a factor 1.5 times the mean tidal range at the site and upon which is growing at least one of the botanical species specified in the Virginia Wetlands Act as amended (Williams et al, 1990). Nonvegetated wetlands include all the land lying contiguous to mean low water and between mean low water and mean high water at the site (Williams et al, 1990).

The North Carolina Division of Environmental Management, 401 Water Quality Certification Program's statutory authority to enact regulations for implementation of the provisions of the Clean Water Act is contained in NCGS 143-215.3(a)(1) and (c). Regulations contained in 15A NCAC 2H.0500 outline the application procedures and the authority of the Director to issue or deny certification. Effective October 1, 1989, the North Carolina Environmental Management Commission (EMC) adopted rule 15A NCAC 2B .0109 which is titled 'Waters affected by dredge and fill activities.' This rule is consistent with U.S. Environmental Protection Agency guidance and U.S. Army Corps of Engineers regulations (Ron Ferrell, North Carolina Division of Environmental Management, personal communication, 1992).

In 1989, the general assembly passed the Virginia Water Protection Permit Act (62.1-44:15.5) which authorizes the Virginia State Water Control Board to issue permits pursuant to Section 401 of the Clean Water Act. Virginia has the right to certify that projects requiring a federal permit such as a 404 Permit will not harm water quality or existing uses of State waters (Williams et al, 1990; Joe Hassell, Virginia State Water Control Board, personal communication, 1992).

Both the Federal regulatory program under the Clean Water Act and the State Coastal Management Program under CAMA are complex and dynamic programs. These programs are still

evolving and are subject to change. For this reason any individual who contemplates development should contact the U.S. Army Corps of Engineer District Office in Wilmington, North Carolina at telephone (919) 251-4511 if the project is in North Carolina or the office in Norfolk, VA at telephone (804) 441-7652 if the project is in Virginia. If the project is located within the 20 North Carolina Coastal Counties, the DCM office in Raleigh, North Carolina should also be contacted at (919) 733-2293. If the project is in coastal Virginia, the VMRC should be contacted at (804) 247-2200.

C.1.b.3 Other Federal Programs for Wetlands Conservation. The Emergency Wetlands Resources Act of 1986 (EWRA) (Public Law 99-645), encourages the conservation, management, and acquisition of wetlands nationwide through increased cooperation among Federal, State, and local governments and private interests (U.S. Fish and Wildlife Service 1989). Section 301 of the EWRA established the National Wetlands Priority Conservation Plan (NWPCP). The U.S. Fish and Wildlife Service developed the NWPCP to assist decision makers in identifying specific wetlands that deserve consideration for State and Federal acquisition using Land and Water Conservation Fund appropriations (U.S. Fish and Wildlife Service 1989). According to the NWPCP, eligible wetlands must meet three wetlands assessment threshold criteria, which are, in turn, based on 1) wetland scarcity, 2) degree of threat, and 3) wetland functions and values. With the assistance of State and Federal agencies, private organizations, academic researchers and other individuals with expertise in North Carolina's wetlands, the U.S. Fish and Wildlife Service recommended that 21 wetland sites in North Carolina be included in the National Wetlands Priority Conservation Plan. Twelve of these sites are in the Albemarle-Pamlico Estuarine Study area. They are: Roanoke River; Currituck Outer Banks; Buxton Woods; Kitty Hawk Woods; U.S. 264 Low Pocosin; Swift Creek Floodplain; Scranton Hardwoods; Upper Alligator River Pocosin; White Oak River Floodplain; Scuppernong River Swamp Forest; and East Dismal Swamp (U.S. Fish and Wildlife Service 1990a).

In Virginia, twenty-three wetland sites found in the Albemarle-Pamlico Estuarine Study area were included in the National Wetlands Priority Conservation Plan (U.S. Fish and Wildlife Service 1990b). These are: Meherrin River Wetlands; Nottoway River Wetlands; Rowanty Swamp; Beaver Pond Creek; Skipper's Bog; Blackwater River Wetlands; Zuni Pine Barrens; Nottoway Falls; Powell Creek Marsh; Upper Chippokes Creek; Ward's Creek; Assamoosick Swamp; Kirk Tract; Cypress Swamp; Great Dismal Swamp; Nansemond River/Bennett Creek Marshes; South Quay Pine Barrens; Crouch Creek/Timber Neck Creek; Sussex Schoolhouse Swamp; Blackwater Creek; North Landing River Wetlands; Stumpy Lake; and West Neck Creek.

The "Swampbuster" provisions of the Food Security Act of 1985, as amended by the Food, Agriculture, Conservation and Trade Act of 1990, disallow eligibility for the U. S. Department of Agriculture program benefits to any farmer who converts a wetland by draining, dredging, filling, leveling, or other methods, to allow for the production of an agricultural commodity. Most wetlands that were converted to agricultural purposes prior to December 23, 1985, are not subject to the "Swampbuster" provisions. The Soil Conservation Service, in consultation with the U. S. Fish and Wildlife Service, is responsible for wetlands determinations and conservation requirements under this Act. To determine whether or not agricultural producers have wetlands on their land that fall under "Swampbuster" provisions and what activities are allowed in those areas, producers should contact their local office of the Agricultural Stabilization and Conservation Service.

The 1990 Food, Agriculture, Conservation, and Trade Act (Public Law 101-624) amended the Food Security Act of 1985. The 1990 Act created the Wetlands Reserve Program (WRP), with the purpose of aiding landowners in the restoration and protection of wetlands on their land, including farmed wetlands and prior converted wetlands (i.e., those in which the area was converted prior to

December 23, 1985) (Public Law 101-624, Sec. 1237). The new WRP is administered by the Agricultural Stabilization and Conservation Service (ASCS), with assistance from the Soil Conservation Service (SCS) and the U. S. Fish and Wildlife Service (USFWS). The current total enrollment goal for the WRP is one million acres by the end of 1995. North Carolina is one of eight pilot States participating in the WRP in 1992. Landowners that participate in the WRP enter into either a permanent or 30-year wetland easement (Public Law 101-624, Sec. 1237). The SCS and the USFWS work with the landowner to develop an acceptable wetland easement conservation plan in order to restore the area to a functional wetland. The ASCS will share the costs of the wetland restoration and make easement payments to the landowner. The amount paid by the Federal government to WRP participants is determined by the ASCS.

There are many other Federal laws and programs that directly and indirectly affect wetlands. In addition to those already mentioned, these include, but are not limited to: the Migratory Bird Hunting and Conservation Stamp Act (16 U.S.C. 718), which requires waterfowl hunters to purchase "duck stamps"; the Coastal Barrier Resources Act of 1982 (16 U.S.C. 3501) and its 1990 amendments, the Coastal Barriers Improvement Act; the Agricultural Credit Act of 1987 (P.L. 100-233), which established the Farmers Home Administration Conservation Easement Program; the North American Wetlands Conservation Act; and Section 305 of the Coastal Wetlands Planning, Protection and Restoration Act.

C.1.c. Nation-wide, State-wide or Region-wide Wetland Trends. The U.S. Fish and Wildlife Service (USFWS) conducted a national survey of wetlands in the 1950s (i.e., Shaw and Fredine 1956). This survey covered approximately 40 percent of the lower 48 States, and concentrated on wetlands important to waterfowl. Information on North Carolina wetlands is reported in Wilson (1962). Because it was later recognized that the nation's wetlands were changing, from both natural and human-induced activities, and the many values of wetlands were becoming better understood, the USFWS established the National Wetlands Inventory (NWI) in 1974 (Wilens and Tiner 1989). The goal of the NWI Program is to produce and distribute scientific information on the characteristics and extent of wetlands across the country. The Program's purpose is to provide wetlands data, in the form of wetland status reports and maps, for quick and accurate resource decision-making and to promote the wise use of the nation's wetlands. See Appendix A for the USFWS definition of "wetland."

The first major study of the NWI focused on wetlands trends in the lower 48 States between the mid-1950's and the mid-1970s (Freyer et al. 1983). According to Freyer et al. (1983), there was a net loss of over 9 million acres of wetlands in the lower 48 states over the 20-year period. The average annual net loss was 458 thousand acres, with the average annual net loss of palustrine wetlands, inland wetlands, at 439 thousand acres and the average annual loss of estuarine wetlands, coastal wetlands, at 19 thousand acres. The U.S. Fish and Wildlife Service, in its reports, defines "loss" as "drained or otherwise converted."

Hefner and Brown (1985) reported mid-1950's and 1970's acreage for a number of wetland categories for ten southeastern states. Of the ten states, North Carolina had the third greatest overall acreage of wetlands, following Florida and Louisiana. The North Carolina acreage estimate was 5.69 million with a percent standard error of 5.9 (Hefner and Brown 1985). This estimate can also be stated in the following manner: there is a 68 percent chance that, as of the mid-1970's, North Carolina's wetland acreage was between 5,354,290 and 6,025,710; and there is a 95 percent chance that, as of the mid-1970's, North Carolina's wetland acreage was between 5,018,580 and 6,361,420.

According to Hefner and Brown, in the mid-1970's 47 percent of the wetlands in the lower 48 states were in the Southeast. Over the 20-year study period, wetland losses in the Southeast accounted for 84 percent of the nationwide losses (Hefner and Brown 1985). In these ten states, wetland acreage decreased by nearly 8 million acres of the 9 million lost nationally. From the mid-1950's to the mid-1970's, there was an overall loss of 7 percent of the region's estuarine wetlands, compared to an overall loss of 15 percent of palustrine wetlands. Approximately two-thirds of the estuarine wetland loss was due to conversion to deepwater habitat (i.e., bay bottoms and navigation channels), and one-third was due to urban development (Hefner and Brown 1985). At the same time in the Southeast, most losses of palustrine wetlands were due to agricultural development (Hefner and Brown 1985). Many of the pocosins and Carolina bays of eastern North Carolina were converted for agricultural purposes. Palustrine forested wetlands are the most abundant wetland type in the Southeast, and this wetland type experienced the greatest loss at over 5.5 million acres. This figure accounts for 92 percent of the national loss of forested wetlands over the 20-year period.

A U.S. Fish and Wildlife Service report to Congress estimated that the area that now comprises the lower 48 states contained approximately 221 million acres of wetlands at the time of Colonial America, i.e. the 1780s. (Dahl 1990). Over a 200-year time period, the lower 48 states lost an estimated 53 percent of the original acreage, leaving approximately 104 million acres of wetlands in the 1980s. This amounts to the loss of over 60 acres of wetlands per every hour between the 1780s and the 1980s (Dahl 1990).

Dahl's report contains data for each state on percent wetlands loss over the 200-year period. Dahl (1990) estimated that the area that is now North Carolina possessed 11.09 million acres of wetlands in the 1780s. By the 1970's the wetlands acreage had dropped to 5.69 million acres (percent standard error of 5.9). In the 1970's, therefore, North Carolina possessed 51 percent of the wetlands that existed in colonial times. For comparative purposes, 22 states have lost 50 percent or more of their original wetland resources, compared to North Carolina and Virginia, which have lost an estimated 49 and 42 percent, respectively. For the North Carolina coastal plain, this situation was confirmed by Cashin (1990).

Stockton and Richardson (1987) analyzed trends in wetland permitting in the coastal area of North Carolina from 1970 to 1984. Development trends under the Coastal Area Management Act (CAMA), the Dredge and Fill Law, and Section 404 of the Federal Water Pollution Control Act were analyzed through the review of over 3000 CAMA and Dredge and Fill permit files. The four general types of wetlands included in the study were high marsh, low marsh, wooded swamp, and "other". The study did not include information on the losses of freshwater wetlands, such as pocosins and freshwater marsh.

Stockton and Richardson determined that 1740 hectares, or 4300 acres, (estimated error range of 11.5 to 23.5 percent) of coastal wetlands had been altered over the 15-year period. The 1740 hectares included the alteration of nearly 2 percent of the State's salt marshes reported by Wilson (1962). A few large projects in the 1970s were responsible for the majority of wetlands developed over the study period. The total acreage of coastal wetlands converted each year decreased, but the number of permits issued during the 1980s increased. The researchers also reported that 60 percent of the permits involving vegetated wetlands altered high marsh. Stockton and Richardson (1987) pointed out that their study did not address the impacts to wetlands of agriculture and forestry, because those activities are exempt under CAMA laws.

The Emergency Wetlands Resources Act of 1986 (16 U.S.C. 3931 (a)) requires that the status and trends study conducted by the National Wetlands Inventory (Frayer et al.) be updated every 10 years. In accordance with that requirement, the U.S. Fish and Wildlife Service recently released the status and trends report for the mid-1970s to the mid-1980s. The study was designed to yield national acreage estimates with a 90 percent degree of certainty that the estimates are within 10 percent of the actual wetland acreage totals for the lower 48 states.

Dahl and Johnson (1991) estimated that the lower 48 states contained 105.9 million acres of wetlands in the mid-1970s, and approximately 103.3 million acres in the mid-1980s. Over the 9-year study period, this represents a net loss of 2.6 million acres of wetlands, or approximately 290 thousand acres per year. Freshwater wetland types accounted for 98 percent of the loss, while estuarine wetlands accounted for 2 percent of the loss. Seven states in the southeast, including North Carolina, each lost 100 thousand acres or more of palustrine forested wetlands.

From the mid-1950s to the mid-1970s conversion of wetlands to agricultural uses accounted for 87 percent of all wetland losses (Frayer et al. 1983). In comparison, from the mid-1970s to the mid-1980s wetland conversion to agricultural uses accounted for 54 percent of the losses, while conversions to "other" uses accounted for 41 percent of the losses (Dahl and Johnson 1991). The "other" category includes wetlands that had been cleared and drained, but had not yet been put to a recognizable use. Urban land uses caused approximately 5 percent of the wetlands loss.

Another trend study assessed the extent and causes of wetland conversions in the North Carolina Coastal Plain (Cashin et al. In press). Cashin et al. estimated wetland conversions over two time periods - from presettlement to the early 1980s, and from the early 1950s to the early 1980s. In the study, wetlands were defined as "...areas which had natural vegetation on hydric soils and unaltered hydrology (e.g., without ditches)." The authors defined and determined wetland alterations in the terms of "...the support of wetland function and values." For instance, where a natural vegetative community on hydric soils was present in the 1950s, but by the early 1980s its vegetation or hydrology had been "...sufficiently disturbed to alter wetland structure, function, or values..." the wetland was considered to have been altered. The authors used soils surveys, NWI maps, aerial photographs, and random field checks to establish the presence of hydric soils and hydrophytic vegetation on the sample sites.

The study used 27 sample sites, 19 of which contained predominately nontidal wetlands and 8 of which contained predominately tidal wetlands. Cashin et al. (in press) report that 51.3 percent (+/- 12.6 percent) of the sample sites' historic wetlands were impacted by the early 1980s to the extent that they "...no longer fully supported their original wetland functions and values." Separate estimates for nontidal and tidal wetlands were also reported. Approximately 52.4 percent (+/- 11.4 percent) of historic palustrine wetlands were altered by the early 1980s, while approximately 12.2 percent (+/- 20.3 percent) of the historic estuarine wetlands were altered by the early 1980s (Cashin et al. In press). (Note the high confidence interval reported for the estuarine wetland estimate, probably largely due to the small sample size of 8 sites). Cashin et al. reported that the major causes of wetland alteration were forestry and agriculture; other causes included urbanization, road construction, and rural residential development.

Other studies have focused on wetland acreage and conversions or trends in North Carolina. These studies include: Richardson (1981); Moorhead (1991); N.C. Department of Environment, Health, and Natural Resources (1991); and Field et al. (1991). All of these studies (except for Field et al.

(1991) which reported existing wetland acreage), as well as the NWI studies discussed above, indicate that there has been a downward trend in North Carolina's wetland acreage.

C.2. Marshes

C.2.a. Tidal Marshes (Regularly-flooded, lunar tide saltmarsh)

C.2.a.1. Description. Tidal marshes have three major components: tidal creeks without vegetation, regularly flooded smooth cordgrass marsh ("low marsh"), and the irregularly flooded portion consisting of a mixture of species (high marsh). Tidal creeks are at the lowest elevation and are the conduit for water exchange between the greater estuary and the salt marsh surface. These creeks are extensions of mud flats, a community treated in more detail by Peterson and Peterson (1979). The smooth cordgrass community represents the core of the salt marsh. It is often further divided into zones occupied by tall, intermediate, and short forms of smooth cordgrass. The high marsh contains a greater number of species; black needlerush, saltmeadow grass, and salt grass are common dominantes or co-dominates. At the highest elevation, high marsh grades into upland vegetation.

Tidal flushing, hydroperiod, and salinity are the principal abiotic factors determining zonation in the salt marsh environment. Tidal flushing transports dissolved and particulate material. Inorganic sediments are transported by tidal currents from deltaic riverine sources or from long-shore currents in the ocean. The sediments are deposited on the marsh surface, but accumulate preferentially next to tidal creeks. This process results in creek-side levees of higher elevation and coarser particle size than the sediments in the marsh interior. The presence of coarser sediments in the levees facilitates flushing of porewater in these creek-side sediments.

The salinity of the rhizosphere is controlled by the fluxes of water and salt. Porewater salinity in the levees tends to remain close to that of adjacent estuarine waters because of the relatively frequent hydraulic exchange and better internal drainage than more isolated localities. Porewaters of the short smooth cordgrass zone often reach hypersaline conditions during protracted periods of warm rain-less weather, high rates of evapotranspiration, and minimal hydraulic exchange (e.g., during neap tides) (Nestler 1975). In the high marsh, precipitation contributes much to the site's water balance, and salinities may be low enough to support shrubs and other plants intolerant of high salinities (wax myrtle, groundsel-tree, and marsh elder).

Vascular plants are prevented from growing in tidal creeks because of the long hydroperiod and strong currents. The number of species is restricted in the smooth cordgrass zones because of high porewater salinity, frequent inundation, and anoxic, high-sulfide porewaters associated with frequent inundation. There is greater species richness in the high marsh because of less stressful conditions overall: (1) periods of water table drawdown allow sediment aeration, (2) lower porewater salinities develop because of infrequent estuarine flooding, and (3) precipitation assumes greater importance as a source of water.

The zonation of vegetation in salt marshes is one of the best studied phenomena in ecology (Adams 1963; Kurz and Wagner 1957). From the elevation where colonization by emergent plants begins, smooth cordgrass forms monospecific stands with occasional patches of barren sediment or glasswort. It is not until the high marsh is reached that black needlerush and its associates, saltmeadow

grass and salt grass, create most of the cover. There is an overall increase in species richness with a decrease in stress (as porewater salinity and inundation decreases).

Within the smooth cordgrass zone, tall, medium, and short forms are commonly recognized. This differentiation in height forms is most pronounced in marshes with high tidal amplitude, but the phenomenon is apparent even in microtidal marshes. The tall form occupies levees, apparently because of improved exchange of porewater with the tidal creek and flushing from precipitation ameliorate the concentrations of salt and hydrogen sulfide (Howes et al. 1986), and likely increase the supply of nutrients. The intermediate height form is exposed to moderate abiotic conditions. The most poorly flushed areas, toward the marsh interior, are exposed to a combination of high salinity stress and high sulfide concentrations. Here, the short form dominates. Ecologists have debated whether the growth forms are genetically or environmentally controlled. It has been recently demonstrated that height differentiation is maintained for several generations when the plants are grown under common conditions (Gallagher et al. 1988).

Epibenthic and epiphytic algae are components of the salt marsh that may produce as much as 25% of the aboveground biomass and may represent a food source more easily digested than the grasses (Teal 1986). A number of insects and spiders utilize the marsh. Numerous species of wading birds and waterfowl and one species of turtle, the diamondback terrapin feed on the marsh. Common marsh birds range from rails, willets, ducks, and geese that feed mostly on the marsh surface, to marsh wrens and red-winged blackbirds that build nests in the grasses. Mammals, less conspicuous inhabitants of the marsh, are represented by the rice rat, hispid cotton rat, raccoon, muskrat, otter, mink, and nutria, recently introduced into North Carolina.

The periwinkle is one of the most conspicuous faunal organisms on the marsh. Fiddler crabs may also occur in great numbers. Because of shallow flooded conditions on the marsh surface, fish size is restricted. Among the species commonly found within the marsh are striped killifish, mummichog, and sheepshead minnow. This is but a small proportion of the fish species that actually utilize the marsh surface; numerous others occupy the marsh only during times of inundation.

Tidal marshes represent an ecologically productive ecosystem within a relatively unstable geomorphic environment. Semidiurnal flushing by tides and accumulation of sediments appear to compensate for the stresses of high salinity and prolonged waterlogging that would otherwise depress primary production. As a result of the high volume of water exchange with the estuarine environment, much research has addressed the importance of the flux of nutrients and organic matter between the marsh and the estuary. Originally the "outwelling hypothesis" was developed to explain the ecological significance of tidal salt marshes (Odum 1980). Marshes were depicted as exporters of nutrients and organic matter to the estuary, a process which was perceived as largely responsible for the marshes' importance to estuarine fisheries. However, salt marshes, like other wetland ecosystems are intrinsically depositional environments and so require imports of particulate matter and suspended sediments to exceed exports. While some organic matter may be exported to adjacent waters (Hopkinson and Wetzel 1982), it is unlikely to be the only link between fisheries yield and tidal wetland production. Nixon (1980) pointed out many of the flaws in conceptualizing salt marshes principally as nutrient sources for open-water estuarine environments.

Tidal salt marshes are of direct benefit for mankind due to their function in supporting finfish and shellfish fisheries and waterfowl populations, shoreline stabilization, water quality improvement, and to their aesthetic value. From the fisheries standpoint, tidal salt marshes are the most highly valued of all wetland types in the region. Continued productivity of the state's estuarine fisheries depends upon

preserving these areas because of their strong hydrologic and biologic coupling with estuarine waters. The extent to which fish utilize the marsh surface is regarded increasingly as one of several principal factors in the maintenance of estuarine dependent fish populations (see Section F). Resident marsh invertebrates, such as fiddler crabs, snails, and oligochaetes, occur in high densities in many salt marsh sediments, and represent essential food not only for fish, but for blue crabs, wading birds, and terrestrial mammals (Teal 1986). This being the case, the export of organic matter no longer needs to be invoked as sole support for the importance of tidal marshes to estuarine food webs. However, exchanges of materials are not trivial. Water, salt, and sediment exchanges are fundamental to the very existence of these marshes. Hopkins and Wetzel (1982) argue that nearshore ecosystem metabolism is dependent on organic carbon exports from riverine and wetland environments along the Atlantic coast of the southeastern United States.

A more realistic functional tidal salt marsh paradigm focuses upon the importance of water exchange between the estuary and the vegetated marsh. This purely hydrologic coupling has embedded within it many biogeochemical and biotic processes. From one perspective, the marsh is a product of the estuary, dependent on tidal forces and all of the chemical and biotic variables associated with tidal exchange. Significant components of the estuarine environment are dependent on the free exchange of water which allows fish to feed on the salt marsh surface and organic carbon to be exported principally in dissolved form.

Intertidal flats - Along with salt marshes, seagrass beds, unvegetated subtidal bottoms, and the overlying water column, intertidal flats are a component of the estuarine system (Peterson and Peterson 1979). Intertidal flats are the unvegetated bottoms of sounds, lagoons, estuaries, and river mouths, which lie between the high and low tide marks, distinguished by the extremes of spring tides (Peterson and Peterson 1979). The sediments of intertidal flats are composed of mud and sand, in a vast range of relative proportions. Rather than containing plants such as grasses, shrubs, or seagrasses, intertidal flats are abundant with benthic microalgae, such as diatoms, dinoflagellates, filamentous green algae, and blue-green algae. The benthic diatoms are usually the most abundant group.

Intertidal flats are physically and biologically open systems; nutrients, organic material, and living organisms are able to enter and leave the habitat. These flats produce usable plant material in the form of algae, which are directly used on the intertidal flat by consumers (deposit-feeding and suspension-feeding benthic invertebrates). Thus, intertidal flats serve as a substrate where plant material from primary production is consumed and subsequently transformed into animal biomass; intertidal flats receive material exported from saltmarshes and seagrass beds which is consumed by benthic invertebrates (Field et al, 1991). Some of the animals that consume this plant material are commercially important and directly harvested, i.e., oysters and hard clams. Other higher level consumers, such as blue crabs, shorebirds, some shrimp, and larger bottom-feeding fishes utilize the benthic invertebrates as a food source.

The majority of probing and wading shorebirds do most of their feeding on the intertidal flats, which are also a major location for feeding by planktivorous, herbivorous, or detritivorous baitfishes. Baitfishes are a major prey for wading birds, aerial-searching birds, piscivorous ducks, and predatory fishes (Field et al, 1991). Marine fishes during postlarval states are also dependent on intertidal flats for protection.

"Intertidal flats are most important for what consistently happens on them rather than what is permanently found on them..." Intertidal flats are also important to the functioning of the entire estuarine system (Field et al, 1991).

C.2.a.2. Status of information. Information on the components and functions of tidal salt marshes can be extrapolated from studies conducted elsewhere within certain geographic limits. Species composition of the irregularly flooded portion of tidal marshes change with latitude. For example, in Delaware, black grass replaces black needlerush as a dominant species in the high marsh area of tidal marshes. In south Florida, red mangrove replaces smooth cordgrass in the regularly flooded portion. However, even with changes in species of the dominant vegetation, physical processes are likely to remain similar because of their close relationship with ecosystem structure.

The surface area of tidal salt marshes reported by Wilson (1962) is listed by county in Table II-1. This could be quickly remeasured in the Albemarle-Pamlico Estuarine Study region using National Wetland Inventory maps which are available for most of the area in which these marshes occur. The impacts of documented human disturbances between 1970 and 1984 are listed in Table II-1 (Stockton and Richardson 1987). The largest areas permitted for alteration, 766 acres in Pamlico Sound and 297 acres in Currituck Sound, are principally nontidal brackish marsh.

C.2.a.3. Acreage. Table II-2 shows the 1988 Landsat Data for the land use/land cover data for the entire A/P Study Area (Khorram et al, 1992). According to the Landsat data set, low marsh/riverine swamp (category 18) has a total of about 166,790.1 acres. Low marsh/riverine swamp are dominated by Spartina alterniflora, Scirpus spp., and Juncus roemerianus. Additional information regarding the 1988 Landsat Data is found in Appendix C. Approximately 31,100 acres of intertidal flats are found in the Albemarle-Pamlico Estuarine Study region (Field et al, 1991).

C.2.a.4. Trends. In the Albemarle-Pamlico Estuarine Study region, the geographic distribution of tidal salt marshes is limited relative to that of the nontidal marshes because of tidal flushing, sediment source, and salinity. These same abiotic variables are the ones most critical to maintaining the integrity of these marshes. Tidal salt marshes are most vulnerable to change from any modification that alters the free exchange of water and materials between the estuary and the vegetated surface. This includes natural phenomena, such as the creation or closing of inlets during storms, and human activities, such as the creation of impoundments, the construction of dikes, drainage canals, and other types of alteration of water flow. Reduction in sediment source as a result of inlet migration has been demonstrated to result in loss of tidal marsh surface area (Hackney and Cleary 1987). When tidal marshes are deprived of sediment sources during periods of relative sea level rise, increasing hydroperiod is responsible for the loss of the marsh ecosystem.

The relatively high level of protection afforded these ecosystems suggests that substantial future losses will not occur as a result of direct impacts such as dredging and filling. However, indirect impacts, such as building barriers to landward migration in response to sea level rise, will diminish tidal marsh coverage. The technology for creating tidal salt marshes is relatively advanced.

The Landsat data found in Table II-2 shows the acreage for the regularly flooded marshes in the Albemarle-Pamlico Estuarine Study region (Khorram et al, 1992). Appendix C provides a detailed discussion on the Landsat Data.

Mosquito control by means of grid-ditching is no longer condoned, but was commonplace for many years. There are no records of how much tidal marsh was ditched or of the exact locations of the ditching, so historical losses can only be estimated. Open marsh water management as a means of mosquito control will continue to place pressure on these ecosystems, especially as population centers encroach upon them. Studies on the ecological effects of open marsh water management are currently

in progress at West Onslow Beach (Alice Anderson, NC Division of Health Services, 1988, personal communication).

Table II-1. Surface Area Estimates in Acres of Three Sea Level Controlled Wetland Types (From Wilson 1962).

| County | Tidal salt marsh(1) | Nontidal brackish marsh(2) | Nontidal freshwater marsh(3) | Alterations Hectares (4) | 1970-84 No. Permits |
|----------------------------|---------------------|----------------------------|------------------------------|--------------------------|---------------------|
| Pamlico Sound | | | | | |
| Carteret | 10,000 | 38,599 | 0 | 49 | 595 |
| Pamlico | 0 | 15,001 | 0 | 766 | 210 |
| Beaufort | 0 | 450 | 4,050 | 74 | 240 |
| Hyde | 1,601 | 29,902 | 3,400 | 86 | 95 |
| Dare | 499 | 15,501 | 5,199 | 148 | 325 |
| Total | 12,100 | 99,450 | 12,649 | | |
| Albemarle-Currituck | | | | | |
| Tyrrell | 0 | 0 | 551 | 2 | 50 |
| Chowan | 0 | 0 | 299 | 2 | 60 |
| Camden | 0 | 0 | 1,601 | 12 | 35 |
| Currituck | 0 | 0 | 23,601 | 297 | 140 |
| Total | 0 | 0 | 26,049 | | |

Note: Original nomenclature used in Wilson was: (1) regularly flooded marsh, (2) irregularly flooded salt marsh, (3) shallow fresh marsh. (4) Estimated from bar graph in Stockton and Richardson (1987).

Note: Acreage figures were calculated and rounded from hectare figures therefore, column totals may not equal exactly the sum of the individual column components.

**TABLE CA-4: LAND USE/LAND COVER FOR THE ENTIRE
ALBEMARLE-PAMLICO ESTUARY STUDY AREA**

LANDSAT DATA (1988)

| CATEGORY | NAME | DESCRIPTION | ACRES |
|-----------------|--------------------------------|--|--------------|
| 1 | Border | Pixels outside of the classification area and areas obscured by cloud cover. | 4,434.6 |
| | | TOTAL | 4,434.6 |
| 2 | Water | Lakes, reservoirs, ponds, estuaries, and sounds. Also includes streams or rivers wide enough to be resolved by TM. | 2,272,346.5 |
| | | TOTAL | 2,272,346.5 |
| 3 | Low Density Development | Residential, commercial and industrial complexes. Areas where structures and/or pavement cover is about 25% to 50%. | 79,703.3 |
| 4 | Medium Density Development | Residential, commercial and industrial complexes. Area where structures and/or pavement cover is about 50% to 85%. | 185,054.1 |
| 5 | High Density Development | Residential, commercial and industrial complexes. Areas where structures and/or pavement cover is greater than 85%. | 35,987.0 |
| | | TOTAL | 300,744.4 |
| 6 | Agriculture, Bare Soil & Grass | Cropland and pasture, bare and grass covered soils. Includes all land cleared for agriculture or silviculture activities. Wide transportation corridors, beach grass, golf courses, large athletic fields and other grassy features are also in the class. | 4,253,712.8 |
| 12 | Disturbed Land | Bare fields which have undergone recent disturbance; predominantly agricultural fields and clear cuts, but also includes some developed areas such as sites being prepared for construction or around quarries. | 160,730.4 |
| | | TOTAL | 4,414,443.2 |

| CATEGORY | NAME | DESCRIPTION | ACRES |
|----------|----------------------------|--|-------------|
| 7 | Low Density Vegetation | Areas which have some vegetative cover but are not forested. Fallow fields, cleared areas, in early successional stages, and some landscaped residential areas, some narrow road systems, wide utility corridors, and weed covered spoil piles are included in this class. | 468,203.1 |
| | | TOTAL | 468,203.1 |
| 8 | Pine Forest | Medium and high density conifer stands; also high pocosins which have a high density (greater than 50% crown closure) of pine. | 2,231,338.5 |
| 10 | Hardwood Forest | Hardwood stands found predominantly in upland areas, on gently sloping interstream divides or in drier low lying areas. Stands dominated by oak, hickory, elm, and maple. | 1,543,519.2 |
| 11 | Pine/Hardwood Forest | Stands of mixed conifer and deciduous hardwood. | 956,094.2 |
| | | TOTAL | 4,730,951.9 |
| 9 | Bottomland Hardwoods | Hardwood stands found predominantly in the floodplains of streams and rivers. These stands are dominated by deciduous species such as lowland species of maple, black gum, oak, elm, sweetgum, sycamore, birch, and ash. | 676,228.1 |
| 14 | Riverine Swamp (Marsh) | Forests occurring along the major Coastal Plain rivers and their tributaries and on sites associated with nearly permanent freshwater. Dominated by gum-cypress swamp, but also including maple, birch, sycamore, sweetgum and oaks. | 501,278.7 |
| 15 | Evergreen/Hardwood Conifer | Dominated by evergreen hardwood shrubs and small trees (magnolias and bay forest); usually found in association with Riverine Swamp or in high pocosins which have a low density of pond or loblolly pines. | 537,020.3 |
| 16 | Atlantic White Cedar | Generally even-aged stands of Atlantic White Cedar which occur on peaty, acidic soils. In areas where drainage channels are bordered by pine forest, the mixed pixel response (black -tannic waters/pine) appear to emulate the response of Atlantic White Cedar. | 9,190.0 |
| 17 | Low Pocosin | Predominantly areas with organic soils supporting evergreen and deciduous shrubs, vines, briars and cane. | 255,047.2 |
| 18 | Low Marsh/Riverine Swamp | Regularly flooded marshes dominated by <u>Spartina alterniflora</u> , <u>Scirpus</u> and <u>Juncus</u> (cordgrass, bulrushes, and black needlerush). Soils in the area generally rich in organic mater and remain wet most of the year. | 166,790.1 |

| CATEGORY | NAME | DESCRIPTION | ACRES |
|----------|----------------------------|---|--------------|
| 19 | High Marsh/ Riverine Swamp | Generally irregularly flooded marshes dominated by <u>Spartina cynosuroides</u> , <u>Typha</u> or <u>Phragmites</u> (giant cordgrass, cattail and reeds). In general, these areas are slightly less rich in organic matter but in the fall and winter a thick mat of dead marsh may form. | 30,081.8 |
| | | TOTAL | 2,175,636.2 |
| 13 | Shadow and Mixed Pixel | In the Piedmont, includes shadows (in high density developed areas) and pixels which are a mixture of water and trees (bordering lakes and ponds). In the Coastal Plain, many wet areas with organic soils (Riverine Swamp and Low Marsh) were confused with shadows. | 43,404.2 |
| | | TOTAL | 43,404.2 |
| 20 | Sand/Dune Grass | Bare, dry sandy soils. Confined to the Coastal Plain, this class includes sand dunes or bare sandy ridges, and also occurs in agriculture fields which have patches of sandy, well-drained soils. | 34,784.8 |
| | | TOTAL | 34,784.8 |
| | | Total Acres for the A/P Study Area | 14,444,948.9 |

* All acreage data was obtained from five Landsat Thematic Mapper scenes covering 97% of the Albemarle-Pamlico estuarine study area (Khorram et al, 1992). Additional information be found in Khorram et al. 1992.

C.2.b. Nontidal marsh (Irregularly-flooded, wind-tide, brackish marsh)

C.2.b.1. Description. Nontidal brackish marshes are widely distributed along the mainland of Pamlico Sound and the back-barrier areas remote from inlets. In the Albemarle Sound, they occupy most of the shoreline of Durant Island. In the area of Nags Head Woods, fresh water is much more important and the plant species move toward dominance by saw grass, cattail, and bulrush. Many of these species become more important in areas of nontidal fresh water such as Currituck Sound.

Nontidal brackish marshes receive water from estuarine flooding and from precipitation. Estuarine flooding occurs when wind direction, force, and duration are sufficient to cause accumulation of the estuarine water in the vicinity of the marsh. For marshes in the southwestern portion of Pamlico Sound, northeast storms and the northeast-southwest orientation of the sound create conditions facilitating marsh flooding. Estuarine flooding is least frequent during the warmest period of the year when southwesterly winds are prevalent and the annual sea level cycle is at its minimum (Brinson et al. 1991b). Periods of drought and high evapotranspiration may cause drawdown of the water table below the marsh surface and aeration of the sediments.

Free water exchange between marsh and estuary is necessary to maintain salinity gradients across the marsh. Any obstruction to salt water inflow, such as an impoundment, is likely to cause the salinity to decrease. Where the shorelines of these marshes are exposed to high wave energy, wetland is lost to erosion at the same time that storm levees develop along the retreating margins. Because the elevation of these levees is higher than interior portions of the marsh, drainage of rainfall and estuarine flood waters is impeded. Salinity of the interstitial water of the surficial sediments tends to be greatest in this poorly drained area because estuarine flooding imports dissolved salts and evapotranspiration removes freshwater. With the exception of impounded areas, salinity in nontidal brackish marshes decreases from the low outer-marsh edge where inputs by estuarine flooding are common, to the marsh interior where rainfall dominates site water balance.

The most potentially threatening abiotic process confronting these wetlands is the rise of sea level and its relation to wetland growth and evolution. Without the marsh surface, the remainder of the wetland functions and values would not exist. Although sediment accumulation is predominantly controlled by hydrology, an abiotic process, accretion of organic-rich sediments and decayed plant matter in these marshes is, in part, controlled by biotic processes. Tidal marshes, on the other hand, normally depend upon the mechanical deposition of inorganic sediments to maintain a surface elevation favorable for plant growth.

Unless sediment supplies are large, as they are in the fringe marshes of deltaic environments, shoreline erosion due to local wave activity may have profound effects on the structure of these ecosystems. In Pamlico and Albemarle Sounds, most of the sediment derived from continental sources is deposited subtidally (Pickett and Ingram 1969) leaving little available for marsh building processes. Because of the large size of the estuaries, fetch is usually adequate for strong wave activity to develop. Sediment supplies are insufficient and distribution is inadequate to compensate for shoreline losses due to wave activity. Various sources have reported mean shoreline recession rates in the sounds to range up to 6 meters per year (Stirewalt and Ingram 1974; USDA Soil Conservation Service 1975; Bellis et al. 1975).

Where wave exposure is high, marshes have levees of storm-derived sand which can reach dune-like proportions. This situation occurs on the northern shoreline of Piney Island (Point of Marsh) in southern Pamlico Sound and on Durant Island in Albemarle Sound. More commonly, exposed areas

have a sand layer that overlies the predominately organic sediment. This appears to armor the shoreline, diminishing the rate of erosion. Moderately exposed areas are more common, however, and the levee of moderately exposed areas consists of a mixture of peat, clay, and sand. In protected embayments where levees are not present, wave activity undercuts the shoreline and appears to facilitate erosion.

The marshes, with their top layer of organic rich peat, tend to occur on a basal structure of either sand or lagoonal clay. Some peats may be up to 2 m in thickness (Benton 1979; Brinson et al. 1991a), while in other places the rhizosphere is but a thin veneer of organic matter on top of basal sands. The thicker deeper organic sediments are more common in the eastern part of the Albemarle-Pamlico Estuarine Study region. Deep peats also occur in western areas where marshes occupy drowned stream valleys.

Many sources lump "nontidal brackish" tidal marsh with "irregularly flooded" tidal marsh because both have virtually the same species compositions. The distinction is made between the two marsh types here because of their fundamentally different landscape positions which affect geomorphic and hydrologic processes critical to many wetland functions. High marshes in tidal regimes are isolated from direct lateral exchanges of water and nutrients between marsh and estuary by intervening smooth cordgrass marsh. Nontidal brackish marshes, in contrast, are shoreline features directly adjacent to the estuary. For the majority of the shoreline of Pamlico Sound, nontidal brackish marshes are the interface between the estuary and either upland ecosystems or interior wetlands such as pocosins (see Landsat Data Table II-3). Porewater salinities vary according to the salinity of the adjacent estuary and decrease with distance into the marsh interior.

Nontidal brackish marshes are often called "black needlerush marshes" or "Juncus marshes" because of the prevalence and frequent dominance by black needlerush. Gradients in salinity and flooding result in parallel changes in species composition. Black needlerush usually occupies the most nearshore regions with highest salinity and longest hydroperiod where Sea Ox-eye and salt grass also are common. Elevated levees may have additional species such as giant cordgrass and marsh elder, presumably because of better drainage and the lower salinity of the porewater.

Several floristic descriptions of nontidal brackish marshes exist. Cooper and Waits (1973) studied a back-barrier marsh near Hatteras inlet. Marshes in the South Creek area, dominated by black needlerush, giant cordgrass, and other freshwater to brackish tolerant species, were described and aboveground biomass accumulation for several community types was estimated (Bellis and Gaither 1985). Aboveground primary productivity of black needlerush in the area appears to be modest (Williams and Murdoch 1972; Christian et al. 1990). There have been no reports of below-ground production. Marshes that occur in the protected margins of these tributaries vary in species composition over short distances. These are the wetlands that appear to be migrating upstream into forested wetlands of the tidally influenced floodplains of the tributaries (Brinson et al. 1985). Information is also becoming available on broader expanses of marsh that occur on interflaves and islands in the Pamlico Sound (Brinson 1992; A. Anderson, N.C. Division of Health Services, and W. Kirby-Smith, Duke University Marine Lab, personal communication, 1988). These large marshes are dominated by black needlerush, saltmeadow grass, giant cordgrass, salt grass, and saw grass may be locally dominant or mixed in with black needlerush.

Decreasing salinities and decreasing hydroperiod toward the marsh interior allow salt intolerant species to persist, most notably trees and shrubs. This transition from dominance by marsh rushes and grasses, through a mixture of marsh and shrubs, and finally to a forested wetland or upland, is also

common in the fringe wetlands of Pamlico Sound. The specific effects of hydroperiod and salinity are hard to distinguish, however, because they both tend to decrease from the marsh edge to interior.

If Cedar Island National Wildlife Refuge marsh is representative of the brackish marshes of Pamlico Sound, fish are more widely distributed in this type of system than previously thought. A study of the Cedar Island marsh found that several species of fish (striped killifish, mummichog, and mosquito fish) on the marsh surface can be considered a full-time resident species of the marsh rather than a migratory assemblage that moves between the estuary and the marsh interior (Marraro et al. 1989). Unlike tidal marshes where twice daily flooding allows fish temporary access to the marsh surface for feeding, the fish on nontidal marshes must endure the marsh surface environment for most of their lives. Fish diets range from aquatic insects to detritus. The food availability for fish on the brackish marsh surface differs sharply from that of fish feeding on tidal salt marshes where invertebrates of marine origin dominate the diet. Nontidal brackish marshes contain many more larval and adult insect species (Marraro et al. 1991). Numerous species of transient fishes also move on to the marsh when it is flooded, utilizing this interface for feeding and refuge. Mosquito fish, Sheepshead minnow, and three species of killifish were the dominant species found on Cedar Island marsh and have been collected and observed over 2 km from the shoreline (Marraro et al. 1991). Their presence is likely to have a strong influence on aquatic food webs of the marsh.

Many of the same species of mammals and birds that utilize tidal salt marshes also are found in nontidal brackish marshes, probably because of the similar vegetation. Several species of rails, for example, nest and over-winter in brackish marshes. Marsh wrens, seaside sparrows, and red-winged blackbirds are the most abundant birds sighted during daylight hours (Davis et al. 1991).

Nontidal brackish marsh ecosystems may be among the most underrated in North Carolina; they have tremendous aerial coverage, yet there is little understanding of their landscape function. Many people assume that since tidal marshes receive the majority of protection and public notice, they are the only type of marshes worth protecting. In North Carolina, where nontidal brackish marshes are the principal wetland type bordering estuaries, their position alone argues that they are performing some of the same vital functions that tidal marshes perform elsewhere.

C.2.b.2. Status of information. The life history characteristics, salinity tolerance, flooding tolerance, and growing season dynamics of the nontidal brackish marsh dominant species, black needlerush, and other common species like saltmeadow grass and salt grass, are well understood (Eleuterius 1975). In the lower salinity portions of marshes, the many possible factors that determine a given species composition are not well understood. In higher salinity regions, tolerance to saline conditions is a major factor.

We do not know the extent of alteration or how alterations are distributed geographically. These would be fairly easy to determine and document using aerial photographs. The ecological function of altered marshes has not been studied. Studies of ditched marshes are needed to determine whether they should be rehabilitated to their former condition and, if so, how this should be done. Since sea level rise is a most critical process affecting the accretion of marsh surface, the response of marsh alteration needs to be evaluated. Almost two decades ago, Kuenzler and Marshall (1973) developed research recommendations for these marshes that have not yet been completely implemented. One of the biggest threats to the brackish marsh resource is that the accretion capacity of these areas may be impeded, effectively eliminating them as sites for future wetland processes.

The status of waterfowl impoundments at Pamlico Point (Goose Creek) and other sites is not known. Although extensive efforts are undertaken to promote populations of waterfowl and wading birds, accurate and complete records of waterfowl use of public and/or private impoundments do not exist.

C.2.b.3. Acreage. Table II-2 shows the 1988 Landsat Data for the land use/land cover data for the entire A/P Study Area (Khorram et al, 1992). According to the Landsat data set, high marsh/riverine swamp (category 19) has a total of about 30,081.8 acres. Please note, high marsh/riverine swamp does not include Juncus roemerianus. Juncus roemerianus is included in Category 18 - low marsh/riverine swamp - in the earlier discussion. The high marsh/riverine swamp (Category 19) category includes irregularly flooded marshes dominated by Spartina cynosuroides, Typha spp., or Phragmites australis. Additional information regarding the 1988 Landsat Data is found in Appendix C.

C.2.b.4. Trends. The distribution of nontidal brackish marshes will not change unless inlets are altered by storms or human activities. Creation of more abundant and wider inlets would decrease the ratio of nontidal marshes relative to tidal marshes.

Traditionally these marshes have been altered to create impoundments to attract waterfowl and to reduce populations of mosquitoes. A moratorium has been placed on ditching for mosquito control, however, the potential for these areas to recover to their original, unaltered condition is not known (Kuenzler and Marshall 1973).

C.2.c. Freshwater marsh

C.2.c.1. Description. Nontidal freshwater marshes are, in many respects, similar to nontidal brackish marshes. They are part of the continuum toward lower salinity regimes in which the abundance of or dominance by halophytes is greatly diminished. However, species such as black needlerush may be common in some areas in spite of prevalence by species less tolerant to salt. It is not known why these marshes persist in areas that otherwise might be conducive for establishment of fringe swamp. The nontidal fresh marsh ecosystem probably functions much like nontidal brackish marsh, but is not as affected by salinity. Evapotranspiration, for example, might be higher in nontidal freshwater marshes than in brackish marshes because of the lower osmotic stress required for water uptake. The transitional nature of nontidal freshwater marshes and the presence of salt tolerant species intermixed with non-halophytes make it difficult to identify unique environmental characteristics or characteristics that distinguish their development from that of forested wetlands (Table II-2).

It is also difficult to distinguish the boundary conditions between freshwater and brackish water nontidal marshes. Wilson (1962) lists most of the nontidal freshwater marshes in Beaufort, Hyde, Dare, Camden, and Currituck Counties (Table II-1). Nearly half of all such marshes appear to be in Currituck County alone.

This section of the report emphasizes the nontidal freshwater marshes in the northern part of Currituck Sound for several reasons: (1) much of the freshwater nontidal marsh in the state occurs there, (2) Currituck Sound has had a long history of water quality problems, and (3) the region is undergoing rapid development and land use changes that warrant attention if its wetland resources are to be protected.

No information could be found on the depth and composition of sediments underlying the marshes, although Sincock (1966) reported extensive analyses for sediments in open-water areas of the Currituck region. Salinities vary, but tend to remain below about 2-3 ppt. Higher salinities in the southern portion of Currituck Sound, restrict the abundance of freshwater vegetation. Historically, salinity has periodically increased due to the intrusions of seawater through 8 major and numerous small breaks in the barrier islands during storms. The highest salinity recorded in Currituck Sound was roughly 33 ppt (Sincock 1966).

The species richness of these marshes tends to be higher than that of brackish marshes. Common species reported for northern Currituck Sound are: cattails, arrowheads, olneyi three square, seashore mallow, smartweeds, salt grass, chair-maker's rush, and black needlerush (U.S. Department of Interior 1980). Other species may include saltmeadow cordgrass, spikerush, sugarcane plumegrass, pennywort, and switchgrass (Refuge Manager, Mackay Island National Wildlife Refuge, personal communication 1989).

The Draft Environmental Impact Statement prepared for the National Wildlife Refuge on the Currituck Outer Banks (U.S. Department of Interior 1980) describes a transition near Monkey Island between the freshwater marsh in the north and the brackish marsh in the south. Sincock's report (1966) contains maps of the Back Bay and Currituck Sound depicting dominant marsh types between 1958 and 1964. Most of the aforementioned species occurred north of Monkey Island, but black needlerush, giant cordgrass, and saw grass were prevalent in the south. Sincock (1966) stated that annual vegetative dominance in the northern marshes responds to burning every 2 or 3 years and to grazing by snow geese. Burning is initiated by muskrat trappers when the marshes are dominated by rank growths of cattail. After fire, succession begins with umbrella-sedge, spike-rush, and smartweed, to olneyi three square, giant bulrush, and validus bulrush, and culminates with cattail and seashore mallow. If an inlet opens in the Currituck Sound for a protracted period of time, the freshwater component of wetland vegetation along the sound side of Currituck Banks would be replaced by types characteristic of brackish marsh. Such an event would have a large impact on the overall extent of nontidal fresh marsh because so much of the state's resource is located in this area.

This marsh type is not nearly as widespread as nontidal brackish marshes. They do, however, provide important waterfowl and sports fishing resources. Although submerged aquatic vegetation (SAV) provide most of the food for waterfowl in the area, Sincock (1966) estimated that the marshes satisfy 25% of the demand.

It is unknown whether fish utilize nontidal freshwater marsh. Young fish are likely to find cover and food in abundance. Currituck Sound obviously represents good habitat for waterfowl and fish (bass in particular) but the functional relationship of the fresh marshes to other components of the larger estuarine ecosystem has not been well established.

C.2.c.2. Status of information. Most of the research and surveys in the Currituck Sound have focused upon submerged aquatic vascular plants (SAV) (Sincock 1966; Davis and Carey 1981; Davis and Brinson 1983) and its importance to waterfowl. There are no records of research papers on the emergent freshwater communities except for the brief descriptions in Sincock (1966). There is, however, no reason to believe that the environmental conditions in which the species of nontidal freshwater vegetation live differ greatly from those in other geographic regions. Fish utilization of these marshes, however, probably differs greatly from that of freshwater tidal marshes (Odum et al. 1984) which share some of the same plant species.

The most recent summary of information is a report prepared by the Currituck Sound Task Committee (1980) and the field guide for NC National Estuarine Research Reserve by Taggart and Henderson (1988).

C.2.c.3. Acreage. Table II-2 shows the 1988 Landsat Data for the land use/land cover data for the entire A/P Study Area. According to the Landsat data set, there is no category which accurately describes the acreage for nontidal freshwater wetlands. Category (Category) 14 combines freshwater marsh and riverine swamp (dominated by gum-cypress swamp, but also include maple, birch, sycamore, sweetgum and oaks). Additional information regarding the 1988 Landsat Data is found in Appendix C.

C.2.c.4. Trends. Of the nontidal freshwater wetlands affected by development in the Albemarle-Currituck area, those in Currituck County and Currituck Sound have suffered considerable loss, second only to Pamlico County during 1970-84 (Table II-1). The proximity of Currituck County to Virginia Beach, Virginia, a major metropolitan area, makes it very attractive for outdoor recreation and the development of second homes. In fact, the area is becoming known as the playground of the wealthy from the Virginia Beach area. What was once a relatively remote, unpopulated, agricultural region of North Carolina will undoubtedly undergo a pattern of development similar to other attractive coastal regions of the state.

Waterfowl hunting and sports fisheries remain fundamental uses of these marshes. Commercial fishermen who favor a brackish water environment and sports fishermen who wish to maintain fresh water in the system are at odds from a management perspective.

C.3. Scrub-shrub Wetlands

Scrub-shrub wetlands are, according to the wetland classification system used by the U.S. Fish and Wildlife Service, areas dominated by woody plants less than 20 feet in height. According to Cowardin et al. (1979), scrub-shrub wetlands occur only in the Estuarine and Palustrine Systems. The types of woody vegetation that dominate these wetlands include true shrubs, young trees, and trees or shrubs whose growth has been stunted due to environmental conditions (Cowardin et al. 1979). Scrub-shrub wetlands may be relatively stable vegetative communities, or they may be successional stages leading to forested wetlands.

C.3.a. Estuarine scrub-shrub wetlands Estuarine scrub-shrub wetlands are characterized by salt-tolerant woody vegetation less than 20 feet in height. A small acreage of the project area is estuarine scrub-shrub wetlands. These areas occur predominately on the mainland side of barrier islands and will be discussed under Section E of this chapter (i.e., beaches, dunes, flats, etc.). Species such as groundsel-tree, marsh elder, sea ox-eye, and Southern bayberry may dominate estuarine scrub-shrub wetlands.

C.3.b. Palustrine scrub-shrub wetlands

C.3.b.1. Description. Palustrine wetlands occur in the country's interior and consist primarily of freshwater wetlands (U.S. Fish and Wildlife Service 1984). Palustrine scrub-shrub wetlands are freshwater wetlands dominated by woody vegetation less than 20 feet tall. As stated above, this wetland type includes areas vegetated with true shrubs or young trees.

Pocosins are the most predominant type of freshwater scrub-shrub wetland in the A/P Study Area. (See Appendix A for a definition of pocosin.) These isolated inland wetlands are dominated by a dense, nearly impenetrable cover of evergreen and deciduous shrubs, with scattered trees. They share many species in common with bay forests and Atlantic white cedar forests, which are considered in the forested wetland section. Within the Albemarle-Pamlico region, pocosin vegetation is most common on lower terraces of very flat topography where poor drainage has favored peat accumulation (paludification), a process which began approximately 5,000-7,000 years ago along small stream channels and in depressions (Whitehead 1981). Peat subsequently accumulated to create "high-center" bogs, with the deepest peats occurring in the bog centers. Rainfall is the only input of surface water to such bogs (i.e., they are ombrotrophic). Water tends to flow out of pocosins in all directions.

Pocosin peats are classified as medihemists and medisaprists, meaning that although fibrous organic matter is abundant in the surface horizons, subsurface layers have undergone extensive decomposition (Dolman and Buol 1967; Daniels et al. 1984). Nevertheless, most of these peats contain considerable quantities of wood (Otte 1981). Pocosin soils are profoundly nutrient poor, especially with respect to phosphorus (Woodwell 1958; Wilbur and Christensen 1983; Wahlbridge 1986). This is a consequence of the limited nutrient contents of rainwater and the separation of plant roots from mineral-rich substrates. In general, nutrient availability is lowest in bog centers (low pocosins) and highest in bay forests and Atlantic white cedar forests.

A mixture of evergreen and deciduous shrub species dominate pocosins, including titi, fetter-bush, sweet and bitter gallberry, and honeycup. Pond pine, sweetbay, and loblolly bay occur as scattered emergent individuals. In the most nutrient-deficient locations plant production is severely limited, but the diversity of shrub species may be quite high. Sphagnum species may form extensive "hummocks and hollows" in some locations. On shallower peats and in areas with greater nutrient inputs, production and shrub stature increases, but the diversity of shrub species decreases. Pond pines may grow to heights of over 33 feet in these "high pocosins." It should be noted that pocosins, both those dominated by shrubs and those dominated by trees, are described in this section. However, sources for the acreage data, Landsat and Forest Inventory and Analysis, distinguished between shrub and forested pocosins. Acreage data, therefore, are presented separately for shrub and forested pocosins. Trend information from Wilson (1962) and Richardson et al. (1981) did not distinguish between the two, and data from these studies are presented in this section of the report.

In the most nutrient-limited situations, pocosin vegetation represents a successional climax. Although fires burn through these ecosystems roughly every 30-50 years (Christensen 1981), pocosins show no sign of succeeding to other community types in the interim years. Many pocosin species are preadapted to invade disturbed areas and consequently dominate early successional stages following disturbance on more productive sites. Frequent disturbance such as repeated fire or cutting will tend to maintain pocosin vegetation under such conditions. Such successional pocosin communities are often distinguishable by the presence of such species as red maple, black gum, and loblolly pine and are widespread in the Albemarle-Pamlico region (Schafale and Weakley 1985; Christensen 1988).

Pocosins serve as habitat for animal species, including the Hessel's hairstreak butterfly, the federally-threatened American alligator, the black bear, white tailed deer, the bobcat, the marsh rabbit, the gray squirrel, and the federally-endangered red-cockaded woodpecker (Richardson in press). Lynch (1982) recorded 51 breeding bird species from a forested pocosin in Martin County. A Dare County pocosin and associated nonalluvial swamp forest were found to support 15 of the 16 species of warblers and 7 of the 8 species of woodpeckers that are known to breed in the North Carolina Coastal Plain (Potter 1982; Peacock and Lynch 1982). The extensive pocosin and nonalluvial swamp areas are

especially important for area-sensitive forest interior species, which include neotropical migrant species such as the great crested flycatcher, prothonotary warbler, hooded warbler, worm-eating warbler and Swainson's warbler. These species are dependent on a large unbroken tract during the breeding season (Whitcomb et al. 1981). Some geneticists believe that thousands of contiguous acres may be required to assure the survival of forest interior bird species (Whitcomb 1977). The continued existence of the black bear in coastal North Carolina is dependent upon the maintenance of large relatively undisturbed tracts of pocosins and swamps (Hamilton 1978).

Pocosins also have important functions related to water quality. Runoff usually does not exit pocosins through streams as in most systems. Runoff occurs as sheetflow moving slowly across the entire surface, or if the surface of the pocosin is not flooded, water moves in the root mass and poorly decomposed organic material in the upper soil profile. Very little flow occurs below the surface layer because of the low hydraulic conductivity of the well-decomposed lower layers (Daniel 1981; Pate 1981). During summer and fall, evapotranspiration is high, and only after heavy or prolonged rains are soils saturated to the point where sheetflow occurs. In winter, when evapotranspiration is low, the soil is often saturated and surface water is present. Even under these conditions, rates of runoff rise slowly after storms, often peaking several days after the rain. Elevated discharges may persist several days after the rain before slowly tapering to a normal flow. Whenever runoff occurs, the stormwater moves in a diffuse layer out of the pocosin or nonalluvial swamp forest and discharges over a broad reach of shoreline along a bordering stream or estuary. This characteristic delivery pattern reduces extreme low flow and high flow events. Runoff from these areas is also low in nutrients, essentially free of suspended sediments, and acidic. Therefore, the runoff from pocosins has a significant stabilizing affect on water quality and the salinity balance of receiving waters (Daniel 1981). Salinity balance is especially important in maintaining the productivity of estuarine nursery areas. Additionally, pocosin peat acts as a sink for the positive heavy metal ions introduced by atmospheric transport. The peat is a natural reducing environment due to the abundance of organic ions.

Pocosins have received considerable research attention in the past decade. Comprehensive reviews of their status, soils, hydrology, and vegetation can be found in Richardson (1981), Sharitz and Gibbons (1982), Ash et al. (1983), and Christensen et al. (1988). Specific information relevant to localities in the Albemarle-Pamlico region can be found in Musselman et al. (1977), Kirk (1979), Lynch and Peacock (1982a,b), and Peacock and Lynch (1982a,b).

C.3.b.2. Acreage. Table II-2 shows the Landsat data for the A/P Study Area. According to the Landsat data set, the acreage of "low pocosin" (category 17) in the North Carolina and Virginia portions of the study area is 255,047.2 acres. The Landsat data set defines "low pocosin" as "Predominately areas with organic soils supporting evergreen and deciduous shrubs, vines, briars and cane."

The A/P Study Area contains excellent examples of pocosin wetlands. The Alligator River National Wildlife Refuge (NWR) contains forested and scrub-shrub pocosins. The refuge is located in Dare and Tyrrell Counties, and approximately 99 percent of the refuge is wetland. In addition to pocosins, Alligator River NWR contains Atlantic white cedar swamp, cypress/hardwood and hardwood/mixed pine wetlands, and freshwater marsh. Pocosin Lakes NWR lies between the Albemarle and Pamlico Sounds in Tyrrell, Hyde, and Washington Counties. The majority of this refuge is also wetland, and the predominant type is southeastern shrub bog, or pocosin. Most of the refuge's pocosin has been drained to some extent due to previous agriculture and timbering activities. Disturbed areas are, however, now in various stages of regrowth. Other wetland types at Pocosin Lakes include bottomland hardwood forest, Atlantic white cedar, and freshwater marsh. Another refuge in the A-P

study area, the Great Dismal Swamp NWR, located in Virginia and North Carolina, also contains small areas of scrub-shrub pocosins. Other large areas of pocosin wetlands include: Dismal Swamp State Park managed by the N.C. Division of Parks and Recreation; Gull Rock Game Land managed by N.C. Wildlife Resources Commission; Croatan National Forest managed by the U.S. Forest Service; and Goose Creek Game Land managed by the N.C. Wildlife Resources Commission (Taggart 1981). Lynch and Peacock (1982a,b) and Peacock and Lynch (1982a,b) list other preserved sites.

C.3.b.3. Trends. Wilson (1962) surveyed North Carolina wetlands, including pocosins, in 41 counties nearest the coast. According to Wilson (1962) pocosins primarily occur in counties that are located within 40 miles of our coastal waters; pocosins were defined as bogs in which soils are "...moist to waterlogged..." and "...often flooded in winter months..." Wilson estimated pocosin acreage by county and included only natural ombrotrophic pocosins and partially drained pocosins that maintained typical pocosin vegetation (Richardson et al. 1981). The natural ombrotrophic pocosins consisted of areas that were undrained and received nutrients from rainfall only and lost water mainly through evapotranspiration. Wilson's 1962 data do not represent North Carolina's original pocosin acreage because the data do not include pocosins altered for cropland and forest plantations (Richardson et al. 1981). Richardson et al. (1981) does note, however, that based on Lilly (1981), pocosin conversion likely had not exceeded 10 percent of the original acreage by the date of Wilson's survey.

Pocosins occupied 2.24 million acres in North Carolina in the 1950's (Wilson 1962), at that time accounting for almost 70 percent of the nation's pocosins (Richardson et al. 1981). Based on an analysis of Wilson's data (1962) by the U.S. Fish and Wildlife Service (Patty Valentine, U.S. Fish and Wildlife Service, personal communication 1992), the A/P Study Area contained approximately 1.36 million acres of pocosins in the 1950's. At that time, the Albemarle-Pamlico counties with the greatest pocosin acreage, each with more than 100,000 acres, were: Hyde, Tyrrell, Dare, Jones, Craven, Beaufort, and Carteret.

Richardson et al. (1981) compared the data in Wilson's 1962 report (data actually collected in the 1950's by the USFWS) to 1979 Landsat imagery to estimate the amount of pocosin wetlands that had been converted over approximately 30 years. It was estimated that statewide nearly 33 percent (740,000 acres) of the natural wetlands reported by Wilson were, by 1979, totally developed, i.e., wetlands that had been "...drained and ditched, their natural vegetation removed, their soils prepared for agriculture, forestry, or industry, etc...", and that were clearly shown on Landsat imagery.

Approximately 1.5 million acres of natural or slightly altered pocosins existed in North Carolina in 1979 (Richardson et al. 1981). This number was further separated into two categories: 1) those pocosins that remained in a natural state; and 2) those pocosins that were "in transition," i.e., those pocosins that "...were either partially altered (drained, cleared, or cut), planned for development by their owners, and/or disturbed to the point where native vegetation and ecosystem processes were changed..." Thirty-six percent (808,000 acres) of the 2.24 million acres reported in 1962 were classified as "in transition," and 31 percent (695,000 acres) were considered natural. Of the statewide pocosin acreage that Richardson reported as natural in 1979 (695,000), approximately 398,000 acres were in the A/P Study Area (Richardson, Duke Wetland Center, Unpublished data 1992).

It would be beneficial to determine the acreage of "in transition" pocosins, identified by Richardson et al. (1981), that were ultimately developed, but this task would take significant additional effort and is beyond the scope of this Status and Trends document. Since the publication of Richardson et al. (1981), some large pocosin areas have moved out of the "in transition" category, while others have

moved into it. For instance, many of the pocosin wetlands that are now a part of the Alligator River NWR and the Pocosin Lakes NWR were in the "in transition" category at the time of the Richardson et al. (1981) report, but they were subsequently bought by or donated to the USFWS. Other large pocosin areas that were in the natural category in the 1981 report have since been converted.

In areas where drainage has been extensive, peatlands have been developed for agriculture and silviculture. There has been considerable commercial interest in these areas for peat mining, but actual mining has been limited to demonstration areas and small horticultural peat operations to date.

C. 4. Forested Wetlands

The acreage, ownership, and trends portions of each of the three forested wetlands which follow were obtained from data provided by the Forest Inventory and Analysis Unit (FIA) of the Southeastern Forest Experiment Station in Asheville, North Carolina. Although this periodic inventory of the forests of each of the southeastern states is not designed to identify jurisdictional wetlands, it does identify forested physiographic land forms which are wetland timberland forest. In addition, a screening of the data to isolate conditions when wetland vegetation dominates or standing water is evident produced estimates of areas and ownership of "possible wet" forestland throughout those counties or the Albemarle-Pamlico study area. A more detailed description of the FIA procedures and a number of tables descriptive of all the forests and of all the possible wet forests of the study area are contained in Appendix D.

C.4.a. Pocosin forests and related wetlands

C.4.a.1. Description. Pocosin forests are usually characterized by a canopy of evergreens (pond pine, loblolly bay, red bay, sweet bay), sometimes mixed with deciduous trees (red maple, bald cypress) and a dense, tangled understory of mostly evergreen shrubs (McDonald et al. 1983). An herbaceous layer is essentially absent, owing to a lack of adequate light. Herbaceous plants can sometimes be abundant in the ecological context of a pocosin--along old road cuts, powerline rights-of-way, and semipermanently flooded depressions within the forest. The water regime is saturated; soils are typically organic, though mineral pocosins are known, and fire is a regularly occurring (and controlling) factor.

Forests may be slow to develop due to several factors: low nutrient availability, prolonged soil saturation and deficiency of soil oxygen, a shallow root zone, an unstable substrate, and a location often near the coast where the probability is high for tree-toppling winds. Where expanses of suitable habitat exist, and outlying fringes of shrubs and low trees offer wind protection--much like the salt spray zone in maritime forests--a relatively tall stand of timber can develop. However, the common pocosin community consists of poor quality trees scarcely more than 20-30 feet high. Examples of this type of forest are located along US 264 between Engelhard and Long Shoal River in Hyde County, along NC 94 near the Alligator River in Tyrrell County, in Croatan National Forest, Carteret and Craven Counties, Great Dismal Swamp, Camden County; along the North Landing River just north of the Pungo Ferry Bridge in the City of Virginia Beach (L.C. Ludwig, Virginia Division of Natural Heritage, personal communication, 1991); and elsewhere.

Certain pond pine stands have a low diversity of pocosin shrubs and a luxuriant growth of giant cane. It is unclear whether this phenomenon is related to a mineral substrate or to an increased frequency of fire. Other pocosins may have pockets of bay forest, bald cypress, sweetgum, swamp

tupelo, Atlantic white cedar, red maple, or other species. These vegetative perturbations are not understood.

Pocosin forests are important natural refuges for black bear, bobcat, deer, and other wide-ranging species. Canals and drainage ditches, sluggish streams, and open bodies of water can maintain a diverse assemblage of fish, amphibians, reptiles, and other aquatic life when the pH of the water is not too acidic. Large areas of North Carolina pocosins, notably in Dare, Hyde, Tyrrell, and Camden Counties, are drained by ditches that contain very acidic water. Thus the faunal diversity is low.

Not infrequently in eastern North Carolina, an evergreen forest with dense evergreen shrubbery develops on longleaf pine savannas where fires have been excluded. These savannas may occur on relict sand ridges long ago weathered to only a few inches in elevation above the adjacent sloughs, as in western Carteret County. Although the vegetative cover may be much like that of a pocosin, periodic fires could rapidly suppress this shrub layer and promote the characteristic wiregrass savanna cover.

C.4.a.2. Acreage and ownership. FIA screened data for the Bays and Wet Pocosins classification is the best available match for the Pocosin and Related Wetland classification. The acreage by broad ownership category for the two most recent forest surveys are as follows:

| Survey Year | Ownership (Acres) | | | % Sampling Error |
|----------------|-------------------|---------|---------|---------------------|
| | Public | Private | Total | |
| 1984 | 138,137 | 419,151 | 557,288 | 1.27 |
| 1990 | 211,973 | 300,694 | 512,667 | 1.26 |

C.4.a.3. Trends. Thus there is an apparent decrease of 8.0 percent on this forested wetland category from 1984 to 1990. An unknown portion of this decrease is due to sampling error. The 53 percent increase in public ownership of bays and wet pocosins consists only of those which contain commercial timberland. The acreage in parks and preserves where timber harvesting is normally restricted by legislation is not included in the data. Such acres are usually in public ownership. Also not included are those bays and wet pocosins which contain so little current or recent volume or are of such low productivity that they do not meet the assigned requirements of productive timberland. Therefore, it is likely that the percentage of bays and wet pocosins which are in public ownership is greater than these data indicated. This should provide an increased level of protection of these unique wetlands. On the other hand, private land that is poorly stocked (ie. classed as unstocked) is also excluded from the survey and would not show up in the acres reported, thus, increasing the percentage of this timberland in public ownership.

C.4.b. Riparian/Alluvial forested wetlands

C.4.b.1. Description. The wetland classification system of Cowardin et al. (1979) identifies riparian/alluvial forested wetlands as palustrine forested and estuarine forested wetlands, with additional modifiers explicitly defining wetlands by vegetation type and hydrology. Commonly, these areas are referred to as "bottomlands" or "wooded wetlands". They occur along the Nottoway River in Virginia, along the Roanoke, the Tar and Pamlico, the Neuse in North Carolina, and along other large interior streams in both States. Tidewater rivers may have adjacent swamps but these wetlands lack strong alluvial processes.

Environmental factors that interact to create riparian forested wetlands include a complex inter-relationship among geomorphology, hydrology, energy distributions (primarily driven by hydraulic energy), and physio-chemical nutrient relationships. Much variation exists within and among riparian forested wetlands, but unifying characteristics also exist. These unifying characteristics include a linear form, the corridor for transport of water and erodible material, and a profound connection with ecosystems upstream and downstream (Brinson et al. 1981).

Riparian forested wetlands function as buffers which dissipate the physical energies of the riverine system. As the hydraulic energy is reduced, the velocity of the water slows and sediments are dropped from suspension. Within highly eroded floodways, a mosaic of sediment ridges and scoured swales provides water storage, and thus a reduction of depth of the water column. During the growing season, mineral nutrients from the water are fixed in plant tissues and later released as detritus, fueling the complex chemical energy pathways of the floodplain organisms and downstream ecosystems. The dendritic flow pattern during flood events permits mobile aquatic organisms to move out of the main stream and to return again as the water recedes. Timing of anadromous fish spawning runs may coincide with overbank flooding in the late winter and early spring months. Interaction of the riparian forested ecosystem with the geomorphologic, chemical, nutrient, and energy components of the riverine system yields a particularly high level of productivity (Wharton et al. 1982).

Plant community composition and distribution in riparian forested wetlands are influenced by the species' tolerance to anaerobic conditions. Other factors influencing the distribution of plant species include seed availability and dispersal sources upstream, soil characteristics, detrital decomposition rates, soil and water pH, nutrient availability and turnover rates, flood depth and water velocity, light intensity, and levels of human and natural disturbance (Wharton et al. 1982). The variability and interaction of these factors produces a very diverse assemblage of plants.

In the wettest habitats of the Albemarle-Pamlico area, muck forests are dominated by bald cypress and water-tupelo. According to the Cowardin et. al (1979) classification, they are semi-permanently flooded. The soil surface is covered by undecomposed leaves and is occasionally exposed during summer droughts when evapotranspiration is also intense. Emergent herbaceous plants have little opportunity for development. As the hydrology is modified somewhat by swifter flow, higher banks, narrower channels, coarser-grained sediments, or greater distance from the stream channel, a somewhat different group of plants may be present. Common trees include American elm, red maple, sycamore, sweetgum, green ash, laurel oak, swamp cottonwood, water hickory, water oak, sugarberry, river birch, Shumard oak, cherrybark oak, and others. Black willows and river birches may overhang the stream. Levees will often have seedlings and small trees of common pawpaw. Along smaller streams, particularly, riparian wetlands will contain American holly and a diverse shrub assemblage. These habitats are noteworthy sites for some of our most aggressive pest species--Chinese privet, Japanese honeysuckle, joint-head arthraxon, Nepal microstegium, and ground ivy. The disturbance factor, favoring the establishment of pest species, is often accentuated by small stream channelization, highway ditches, and an apparent propensity by the public to dump trash at isolated bottomland road crossings.

Riparian wetlands such as the Roanoke River bottomlands are highly regarded as wildlife habitat, especially for white-tailed deer and wild turkey. Some wetland wildlife species are perceived to be nuisances by some property owners. Within recent years, beavers have proliferated in the interior counties of the A/P study area. Allen (1982) suggests that in addition to adequate food species, suitable habitat for beavers must contain stable aquatic habitat and a channel gradient of less than 15 percent. The extent of timber loss that is a direct result of perennial inundation caused by beavers is

unknown. Field verification of National Wetlands Inventory maps reveals substantial conversions of forests to marshes and open water in the interior Coastal Plain counties of the A/P study area. In at least one county soil survey, soil scientists have found extensive beaver ponds in areas that the latest available photography depicts as bottomland forests [personal communication (1992), R.H. Ranson, Jr.].

Riparian wetlands support a variety of indigenous invertebrates, amphibians, reptiles, mammals, birds, and fish. The corridors of forest provide migratory paths for mammals and birds. Efforts to maintain streamside management zones of woodlands are evidenced by such policy documents as North Carolina's best management practices for forestry in wetlands (Department of Environment, Health, and Natural Resources 1990).

C.4.b.2. Acreage. The FIA physiographic "possible wet" classification which most nearly fit the wetlands described in this section are the broad flood plains, the narrow flood plains, deep swamps, and the miscellaneous hydric. The aggregate acres for these three classifications by the broad ownership categories for the two most recent forest surveys are as follows:

| Survey | Ownership (Acres) | | | % Sampling Error |
|--------|-------------------|-----------|-----------|------------------|
| | Public | Private | Total | |
| 1984 | 48,858 | 1,094,124 | 1,142,982 | 0.88 |
| 1990 | 71,709 | 1,032,924 | 1,104,636 | 0.90 |

C.4.b.3. Trends. The lack of consistent, comprehensive inventories complicates any valid assessment of historical acreage of riparian forested wetland types in the Albemarle-Pamlico study area. Wilson (1962) reported approximate acreage by county from data extracted from the Office of River Basin Studies (1954), but he used wetlands samples no smaller than 40 acres. In the North Carolina part of the Albemarle-Pamlico study area, "bottomlands" occupied 302,850 acres and "wooded swamps" occupied 501,250 acres. These figures represented 66% and 51%, respectively, of the state total for these forested wetland types, which were the best estimates at the time. Forested wetland conversions have occurred at a high rate on a national basis in recent years (Frayser et al. 1983). The US Department of Agriculture, Soil Conservation Service (1989) reported in its National Resource Inventory 1982-87 that 1244 miles of channels and dikes had been completed in North Carolina with 1459 miles planned. Drainage has accompanied land clearance for agriculture, improved silviculture, mosquito control, and flood control in and around municipalities.

Despite reports of extensive conversion of forested wetlands to other wetland and nonwetland types [Richardson et al. (1981); Tiner (1984); Hefner and Brown (1985); Cashin (1990); Dahl (1990); Dahl and Johnson (1991); Department of Environment, Health, and Natural Resources 1991]], the Roanoke River floodplain is one of the largest intact and least disturbed bottomland forest ecosystems remaining in the mid-Atlantic region. But even the Roanoke fails to flood as it one time did. From Roanoke Rapids upstream, a succession of dams impounds the river, and what one now sees developing on the floodplain downstream is a riparian forest that typifies an altered water regime.

C.4.c. Nonriparian forested wetlands

C.4.c.1. Description. Nonriverine swamp forests occur on broad flat areas, where poor drainage and high water tables keep them ponded for significant intervals during the year. These swamps frequently occur near the edge of large peatlands, grading into pocosins or related communities toward the interior of the peatland. They may grade to moist upland communities on the better drained periphery, or they may form a narrow fringe swamp along freshwater estuaries (Brinson et al. 1985).

Swamps that occur between small brackish marsh creeks and the freshwater zone at the mouths of streams may also have attributes of fringe swamps. They are located too far downstream to have pure riverine characteristics, and so, in part, are under sea-level control. At the present time these swamps are being overtaken by the upstream migration of brackish marshes of various combinations of plants associated with a general response to sea level rise. On a short-term basis, however, fringe swamps may be affected by excessive flooding during coastal "nor'easters" and hurricane events. Shoreline vegetation of the upper Alligator River in Dare and Tyrrell Counties allegedly changed after the construction of the Atlantic Intracoastal Waterway because this waterway opened a passage that allowed saltier water from the Pungo River to enter an oligohaline system.

Observed from the water, fringe swamps often give the impression that they consist primarily of bald cypress. According to Brinson et al. (1985), examination of several sites revealed, however, that bald cypress is more abundant at the estuarine edge than toward the swamp interior. Likely contributing factors are variations in species' flooding tolerances, resistance to decay, and lack of windfall of bald cypress relative to other species. Regardless, by the time erosion causes the shoreline to retreat into the swamp, the only tree species remaining in the permanently flooded condition is bald cypress. The extensive and complex root structure allows this species to remain standing and contribute to the complex aquatic habitat near the shoreline.

Another interesting forested swamp exists along the marshes of Beaufort, Hyde, Pamlico, and Carteret Counties (and perhaps elsewhere). This forest consists predominately of loblolly pine, occasionally with a scattering of bald cypress and a typical subcanopy of red cedar, bays, red maple, eastern false-willow, southern bayberry, and other coastal species. An excellent example is in the vicinity of Rose Bay and US Highway 264 in Hyde County. Purer pine stands can be found on the southwest side of Pantego Creek near Belhaven (Beaufort Co.) and in Cedar Island National Wildlife Refuge, Carteret Co. At other sites, pond pine may predominate, and should be expected since the soils are clearly saturated for long periods of time. While this forest type is in clear proximity to brackish marshes, it would appear that lateral flow of freshwater through the root zone is sufficient to allow non-halophytes to grow.

Nonriverine swamp forests are communities dominated by species similar to those on river floodplains, but occur on sites not associated with present-day river or tidal flooding. Schafale and Weakley (1985) recognize two community types within this category: the cypress-and-gum dominated nonriverine swamp forest type on the wetter sites, and the oak dominated nonriverine wet hardwood forest type on slightly drier sites. The latter seems to correlate with broad flats of silt, silty loam, and loamy clay. Until recently, some of these clay flats were mapped as Roanoke loam by soils scientists, who recognized that first terraces and second terraces in the Roanoke Valley contained slightly different soils. The newer soils mapping (as in Hyde and Beaufort Counties, NC) shows these poorly draining flats series other than Roanoke loam.

The nonriverine swamp forest type, in its primary state, was thought to be dominated by bald cypress and swamp tupelo, with infrequent loblolly pine and Atlantic white cedar. After early logging, bald cypress seldom regenerated, and the logged areas generally became dominated by a low canopy of black gum, red maple, or loblolly pine. The shrub layer, initially fairly open, often became dense and pocosin-like.

The nonriverine wet hardwood forest type in natural condition was dominated by bottomland hardwood species (sweetgum, laurel oak, cherrybark oak, swamp chestnut oak, willow oak, swamp tupelo, American elm, and red maple) with occasional moist slope species (American beech, American hornbeam, flowering dogwood, sourwood). Shrub species tended to be sparse. Once logged, areas that formerly had canebrakes became dense thicket stands of giant cane, coast pepper-bush, catbrier, and overstory trees of loblolly pine.

Prior to widespread ditching, water would have entered nonriverine swamps by rainfall, shallow groundwater flow, and possibly by sheet flow from adjacent pocosins. In most places the water would have fed into the heads of small drainages, connecting to better developed streams and ultimately to the estuaries. In a few places, such as the Great Dismal Swamp, water would have left as sheet flow onto adjacent peatlands. Like all large wetlands, these communities would have stored fresh water, and released it gradually into the streams and estuaries, thereby reducing peak flows. By their position at the margin of large pocosin areas, these communities may have mediated the flow of water out of them.

Nonriverine swamps have received little study in comparison to marshes, pocosins, and bottomlands. No quantitative studies are known. Lynch and Peacock (1982b) and Peacock and Lynch (1982a) gave qualitative descriptions of remnant areas included in county natural areas inventories. Greater attention has focused on the more extensive nonriverine swamp forest type, particularly the Great Dismal Swamp (Carter and Gammon 1976; Musselman et al. 1977; Kirk 1979), but information is largely lacking on most other examples of nonriverine swamp forest. Limited information on natural conditions, dynamics, endangered species, fire regime, and hydrology complicate management plans when they are proposed.

C.4.c.2. Acreage and ownership. These low lying flat areas, not associated with rivers and free flowing drainage, are the most extensive physiographic type within the A/P study area. In the FIA data, these areas are identified as wet flats and dry pocosin. The "Possible Wet" screened data for the wet flat and dry pocosin type in the A/P study area resulted in the following estimates of non-riparian forested wetland acreage and ownership for the most recent two surveys:

| Survey Year | Ownership (Acres) | | | % Sampling Error |
|----------------|-------------------|-----------|-----------|---------------------|
| | Public | Private | Total | |
| 1984 | 24,464 | 1,005,654 | 1,030,118 | 0.93 |
| 1990 | 28,981 | 1,184,565 | 1,213,546 | 0.86 |

C.4.c.3. Trends. Nonriverine hardwood forests were once a common community type in the Albemarle-Pamlico region. Ashe and Pinchot (1897) reported that oak flats once covered 1000 square miles of the coastal plain, one-fourth of the swamp area (apparently not including river floodplains which they discussed separately). Based on soils, Peacock and Lynch (1982b) estimated that this type of community was once the most common in Pamlico County and that the same was undoubtedly true

in other counties in the region. Because these sites are fertile and easily drained, most have been converted to agriculture. Additional acreage has been partially drained and put into timber plantations. [We make a distinction between drainage systems which are routinely maintained and those which were constructed primarily to facilitate timber harvest and reforestation, and which are not maintained as often.] These activities continue to reduce the few known remnants.

The wetter nonriverine swamp forest type also occupied vast areas on the Outer Coastal Plain. They, too, have been much reduced by conversion to agriculture and timber plantations. Of the substantial acreage remaining, most of it has an altered hydrology and its trees have been harvested repeatedly.

D. SPECIAL FISHERIES HABITATS

D. 1. Bay Scallop Beds

D.1.a. Description. In North Carolina, bay scallop (*Argopecten irradians concentricus*) beds occur only in seagrass beds (Gutsell 1930; Thayer and Stuart 1974) in waters of year-round high salinity (> 26 ppt). Three seagrasses (*Zostera marina*, *Halodule wrightii*, and *Ruppia maritima*) provide a substrate for attachment of newly recruited bay scallops, which spend their first 2-4 months of life attached by byssal threads to blades of seagrass (Thayer et al. 1984b). This attachment holds the juvenile scallops above the bottom, thereby preventing them from being buried under sediments, helping to maintain lower turbidity in the scallops' immediate vicinity, and allowing for greater flux of foods than would occur on the bottom (Eckman et al. 1989). The food supplies of bay scallops may also be enhanced by the production of microalgae and bacteria on blades of seagrass. Predation rates on juvenile scallops are reduced by the structural complexity of emergent substrate (seagrass shoots and blades), known to inhibit several sorts of predators (Heck and Thoman 1981; Summerson and Peterson 1984).

Even after the age of 2-4 months, bay scallops remain within seagrass beds despite their ability to swim (Peterson et al. 1982). When displaced from seagrass meadows, adult bay scallops tend to migrate rapidly back to the meadow; this tendency maintains the scallop population within the meadow (Peterson et al. 1989). Adult bay scallops outside seagrass suffer much greater predation from whelks (*Busycon* spp.) than those that remain inside seagrass beds (Peterson et al. 1989; Prescott 1990). Experimental reduction of seagrass cover resulted in proportionate declines in resident bay scallop abundance (Peterson et al. 1987).

Bay scallop habitat is controlled by all the factors affecting seagrass abundance (turbidity, bottom disturbance -- especially that resulting from fishing practices, disease, temperature, etc.). Scallop habitat is also controlled by factors affecting bay scallop survival (turbidity [Duggan 1973] and salinity [Mercaldo and Rhodes 1982] primarily). There appears to be planktonic food in excess for suspension feeders in North Carolina estuaries (Peterson and Beal 1989). In the Albemarle Sound, no bay scallops exist because of depressed salinities. Low salinity in Pamlico Sound constrains the bay scallop distribution to a narrow eastern fringe close to Atlantic Ocean inlets. If an inlet were to break through into Currituck Sound during a hurricane, for example, substantial bay scallop habitat could form in that sound.

In Pamlico Sound, bay scallop beds are distributed in a narrow band along the Outer Banks from north of Oregon Inlet to Cedar Island. Farther south, bay scallop habitat widens to include the full breadth of Core Sound, Back Sound, and Bogue Sound. Some substantial pockets of suitable and productive bay scallop habitat occur in large, highly saline rivers such as the North River, Newport River, White Oak River, and New River. Some bay scallop habitat occurs south of Bogue Inlet (notably in Stump Sound and New River Inlet), but is limited in these areas.

Historically, 60% of the bay scallop harvest in North Carolina has come from western Bogue Sound (Salter Path to Bogue Inlet), 35% from Back and Core sounds, and only 5% from all other water bodies (catch statistics from NC Division of Marine Fisheries).

The bay scallop is the most physiologically sensitive of all of North Carolina's shellfish and so can act as the fisheries "canary" to indicate the onset of problems with the health of estuarine systems. Similarly, the seagrass beds themselves serve as an indicator of ecosystem health, as shown by history of the Chesapeake Bay (Orth and Moore 1983).

Bay scallops are of great importance to local fishing communities (Fricke 1980). The bay scallop is harvested and brings income during the winter season, when few alternatives exist for North Carolina fishermen. Furthermore, local shucking and processing of bay scallops, often by the family members of fishermen, add substantially to the economic value of the bay scallop to North Carolina.

D.1.b. Status of Information. The functions of bay scallop habitat are reasonably well understood. Among the least understood phenomena, however, is the role of recruitment in determining bay scallop abundance. Bay scallop recruitment appears to be limited, in part, because vagaries of larval transport determine where the population will be concentrated in any given year. Understanding the role of recruitment will require much more research.

The distribution of suitable seagrass habitat in Pamlico Sound is reasonably well known (Section II. B. 2.), but the year-to-year dynamics of seagrass bed distribution have not been sufficiently studied.

D.1.c. Trends. The trends in abundance and distribution of bay scallop habitat are not known. The bay scallop resource is fully utilized by commercial fishermen every year. The SAV habitat is potentially threatened by lack of controls on freshwater runoff and turbidity, both of which may be expected to increase as development increases.

D.1.d. Management/Regulatory Status and Trends. Most scallop habitat is included in two areas (Core Sound and western Bogue Sound) that have been nominated by the NC Division of Marine Fisheries for designation as Outstanding Resource Waters (ORWs). The habitat for bay scallops is managed only to the degree that bullraking, clam "kicking", and dredging for clams and oysters are prohibited in seagrass beds by Marine Fisheries Commission (MFC) regulations and to the degree that Environmental Management Commission (EMC) stormwater runoff regulations reduce freshwater influx and turbidity-enhancing erosion. Increasingly intense hand raking for clams uproots large amounts of seagrass (Peterson et al. 1983) and thereby diminishes the quantity and quality of bay scallop habitat. In addition, stormwater runoff regulations are not designed to protect maintain high salinity regimes.

D. 2. Hard Clam Beds

D. 2. a. Description. Hard clams (*Mercenaria mercenaria*) live in a wide range of sediment types from shell hash (oyster rocks), to sands, to muds (Pratt 1953; Pratt and Campbell 1956). They generally reach their highest abundances in muddy sands and sandy muds (Wells 1957), although shell hash is the best of all bottom types (Castagna and Kraeuter 1977). Water temperature is suitable for hard clams everywhere in the North Carolina's estuaries. The habitat for hard clams in the Albemarle and Pamlico sounds is limited almost solely by salinity. Hard clams require waters of relatively high salinity (permanently above about 12.5 ppt), but are tolerant of a lower salinity than bay scallops; therefore, so the hard clam habitat includes all the bay scallop habitat plus a large area of lower salinity and reduced or absent seagrass. Only a few beds exist in Pamlico Sound in a relatively narrow band along the Outer Banks (from Cedar Island to Buxton, including the area from Oregon Inlet westward to mid-Pamlico Sound on Bluff Shoal). This limited area of hard clam habitat in Pamlico Sound continues, however, to support a significant commercial clam catch. No hard clam beds exist in the very low salinity Albemarle Sound.

Sediments serve as a substrate in which hard clams bury themselves. The sediment buffers the clams from the physiological effects of rapid changes in the temperature or salinity of the overlying water column (Johnson 1965, 1967) and protects the clams from predators. Shell hash (Castagna and Kraeuter 1977) and seagrass roots and rhizomes (Peterson 1982, 1986a) offer even better protection from predators.

The sediments and the water column provide food resources for hard clams. These food resources, mostly phytoplankton, are extremely abundant in North Carolina estuaries (Peterson and Beal 1989). Nevertheless, clams need to live in areas of appreciable horizontal advection to avoid possible depletion of foods in benthic boundary layers (Wildish and Kristmanson 1979).

Hard clams are often limited in abundance and distribution by predation. Whelks probably limit hard clam abundance in clean sand and high salinity near Ocracoke, Hatteras, and Oregon Inlets (Peterson 1982). Blue crabs are an even more important enemy in many areas (Arnold 1984), but probably do not restrict hard clam distribution in Pamlico Sound. Hard clams are not afflicted by any significant disease problems in North Carolina.

Because hard clams live in excess of 40 years in North Carolina (Peterson 1983, 1986b), they are a fishery resource that, if not over-harvested, can be conserved and harvested sustainably year after year. The maintenance of a healthy hard clam resource will provide an economic safety factor for fishermen. The economic value of hard clams has risen high enough (\$6.2 million in 1988) to make this fishery extremely significant to the economy of North Carolina. This high value can justify aquaculture of hard clams, now economically feasible over large portions of southern and eastern Pamlico Sound.

D.2.b. Status of Information. The abiotic and biotic components that define hard clam habitat are reasonably well known (Pratt 1953; Pratt and Campbell 1956; Wells 1957; Carriker 1959). The degree to which larval events and settlement phenomena influence hard clam distribution is, however, still being researched (Butman et al. 1988).

The role of shell hash and seagrass cover in inhibiting predation is well established (Castagna and Kraeuter 1977; Peterson 1982). The physiological effects of low salinity are also clear. Less obvious is the importance of substrate (sediment grade) relative to flow regime, because these two factors are complexly inter-related (Grizzle and Morin 1989).

Fishing pressure is intense enough on hard clams that collectively fishermen have an excellent knowledge of the distribution of hard clam habitat everywhere in North Carolina. However, no quantitative chart of hard clam habitat exists. The NC Division of Marine Fisheries (DMF) is now engaged in preparing such a map.

Knowledge of the critical roles that high salinity, seagrass cover, and intact shell bottoms play helps dictate the means of preserving hard clam habitat in the Pamlico Sound. Fortunately, measures taken to avoid increasing freshwater runoff from storms will not only maintain high salinities but will also limit fecal coliform pollution, the primary cause of the closure of clam beds to shellfishing.

D.2.c. Trends. No data exist concerning the temporal pattern of change in hard clam habitat in North Carolina. Habitat distribution probably changes most due to variation in salinity regimes. Such variation occurs on a large scale for 3 reasons. First, the degree of infilling of ocean inlets can radically affect the tidal water exchange and thus the extent of high-salinity habitat inside Pamlico Sound. Because of shoaling of key inlets, especially Oregon Inlet, hard clam habitat in Pamlico Sound may have been reduced over the past 10-20 years, but no distributional data exist to assess this hypothesis. Second, the clearing and paving of land in the watershed act to increase freshwater runoff and reduce estuarine salinity. This may have restricted the hard clam habitat in the recent past. Third, variation in rainfall variation causes variation in salinity regimes. The drought period between 1985 and 1989 increased clam habitat. In fact, clams were caught incidental to oyster dredging around the mouth of West Bay, which is not known as a clam-producing area.

The habitat quality for hard clams in Pamlico Sound remains high, except where declining salinities, due to inlet shoaling and stormwater runoff, are restricting the extent of the habitat. The full extent of restriction or devaluation of hard clam habitat due to increased stormwater runoff and drainage has yet to be experienced because the last few years have been unusually dry. Clam kicking and over-fishing, however, are jeopardizing the sustained yield of hard clams in most habitats.

Use of the hard clam resource in North Carolina has increased greatly in recent decades, with an approximately 8-fold increase in landings from the 1960s and early 1970s to 1985. In the past two or three years, catch declined to the level of the late 1970s despite continued high fishing effort.

D.2.d. Management/Regulatory Status and Trends. Hard clam habitat is protected in North Carolina by stormwater runoff regulations promulgated by the EMC and by management of bottom-disturbing practices by the MFC. Mechanical harvesting of hard clams is prohibited in seagrass beds by MFC regulation in an effort to protect the seagrasses from being uprooted. Unfortunately, some illegal harvest by the mechanical harvesters has occurred in seagrass beds, especially in southern Pamlico Sound just north of the Wainwright Islands. Inlet management is complicated by the need for federal cooperation to provide financial support for maintenance and dredging. It is not clear whether existing stormwater runoff regulations are providing adequate protection for hard clam habitat. A number of the major hard clam beds in the state are included in an area that has been nominated for designation as Outstanding Resource Waters.

D. 3. American Oyster Beds

D.3.a. Description. American oysters (*Crassostrea virginica*) require a hard substrate for larval attachment and subsequent growth to adulthood. The hard substrate, biotic or abiotic, provides a hard surface for larval attachment up above the sediments. This allows the newly metamorphosed oysters to feed without suffocating under sediment cover. Oyster reefs also provide important habitat for several commercially and recreationally significant fishes. This hard substrate is ordinarily provided by biogenic calcium carbonate, namely, the shells of dead or living oysters. Oyster habitat also includes abiotic hard substrates, such as seawalls, bulkheads, and pilings (Ortega 1981). Oysters can tolerate lower salinities than can hard clams or bay scallops, but they are limited to salinities within a range of 5-30 ppt (Chanley 1957; Galtsoff 1964; Burrell 1977).

Oysters are widely distributed in relatively discrete beds throughout Pamlico Sound. Although the locations of some oyster beds are relatively fixed, many oyster beds are transient. Several of these beds have been created by planting mollusc shells through DMF's oyster management program. Oyster beds are absent from deeper depositional basins in Pamlico Sound, where summer anoxia is a routine event (Tenore 1972). Oysters are not found in Albemarle Sound, except in the extreme lower portions of the sound around northern Roanoke Island for short periods during drought years.

Intertidal oysters in the Albemarle and Pamlico Sounds occasionally experience massive winter kills from intense freezes, but these events only temporarily restrict the oyster habitat, in part because there are such limited intertidal zones in these bodies of water. Intense summer heat may enhance the propagation of protozoan diseases, MSX and "Dermo", (see Chapter IV.G.) and so contribute to oyster mortality. Such diseases, however, probably do not limit oyster habitat in Pamlico or Albemarle Sounds to the extent that high summer water temperatures do. Summer anoxia in the deeper basins of the Albemarle and Pamlico Sounds greatly limits oyster habitat (Tenore 1972).

Oyster habitat is devalued by the increasing extent and intensity of anoxia events in Pamlico Sound. These events are a reflection of increased eutrophication of the Pamlico Sound tributaries caused by excessive nutrient inputs by farm runoff, municipal sewerage discharges, and industrial sources of nutrients and organics. Oyster habitat may also be affected adversely by the use of heavy oyster dredges. Heavy dredges destroy, scatter, and bury the shell material necessary for larval settlement and perpetuation of the oyster bed. Oyster habitat may also be negatively affected by other fishing practices, such as clam kicking and trawling, that suspend sediments and cause sediment deposition on shell surfaces in the oyster bed. This can suffocate live oysters and make potential settlement surfaces unacceptable to oyster larvae.

Oysters feed largely on suspended phytoplankton and suspended benthic microalgae (Haines and Montague 1979). These types of food sources for suspension-feeding invertebrates do not appear to be limited in North Carolina's estuaries (Peterson and Beal 1989). The presence of suitable hard substrate, usually provided by oyster shells, is the greatest limitation to the abundance and distribution of commercially harvestable oyster beds. In areas of high salinity (in excess of about 30 ppt) predators such as the oyster drill (*Urosalpinx cinerea*) greatly limit the abundance of adult oysters (Wells 1961). Such high salinities, however, occur only in close proximity to Ocracoke, Hatteras, and Oregon Inlets in Pamlico and Albemarle Sounds.

D.3.b. Status of Information. The physical and biological factors that define oyster habitat are reasonably well known (Carriger 1959; Galtsoff 1964; Loosanoff 1965). Perhaps the most serious omission in our knowledge is an appreciation of the factors that influence oyster recruitment patterns. Some research is being conducted now in Pamlico Sound to help fill this void in our knowledge.

Perhaps the least understood process affecting oyster habitat is the epidemiology of the two oyster diseases, "MSX" and "Dermo". Other functions of oyster habitat variables are reasonably well appreciated.

The DMF is now involved in a shellfish mapping survey that should provide quantitative information of oyster habitat in Pamlico and Albemarle Sounds. Presently, no comprehensive map of the distribution of productive oyster beds exists.

D.3.c. Trends. With recent drought years, oyster populations have tended to move substantially upriver in many Pamlico Sound tributaries, presumably in response to increasing salinity. The incidence of "MSX" and "Dermo" was especially great in the summer of 1988, but whether this represents the beginning of a trend of increasing disease occurrence or whether it was simply a consequence of the extreme heat and drought, remains unclear.

D.3.d. Management/Regulatory Status and Trends. The most significant management activity affecting oysters in Pamlico Sound is the DMF shell planting program. New mounds of shell material are introduced at various locations in the sounds to provide surfaces for larval attachment. This program has been extremely successful, suggesting that suitable settlement substrate indeed limits oyster abundance and production in North Carolina. A current research program is assessing how shell planting success varies with key habitat variables to improve the siting of the shell mounds.

D. 4. Nursery Areas

D.4.a. Description. Nursery areas are those portions of estuarine waters most critical to the early life stages of marine and estuarine organisms. Initial development of the postlarval stages of many fish and shellfish species occurs in primary nursery areas (Type I) located in the uppermost areas of estuaries and their tributaries. As these organisms develop, they move seaward into secondary nursery areas (Type II) in the mid-portions of estuaries. In the lower portions of estuaries, young-of-the-year become mixed in temporary or transport nursery areas (Type III) prior to or during migration (Purvis 1976).

Low salinities and shallow depths characterize primary nursery areas. The substrate is usually soft mud and/or mud-grass; fish populations consist uniformly of very young juveniles (Purvis 1976). Moderate depths and salinities are characteristic of secondary nursery areas in the lower and/or deeper portions of creeks and bays (Phalen 1989). Bottoms may be sand or sand-grass; fish populations consist generally of developing juveniles of similar size (Purvis 1976). The greatest estuarine depths and highest salinities are found in the temporary nurseries or transport areas (Purvis 1976). These gathering areas and migration routes are located in the lower portions of major estuaries nearest to the inlets (Purvis 1976).

Although the classification of nursery areas given above is commonly used, Ross and Epperly (1985) divided Pamlico Sound nursery areas into five groups on the basis of Morisita's and Czekanowski's indices, catch-per-unit-effort (CPUE) data, and a discriminant model using 11 abiotic variables. They were able to ascertain correlations between associated environmental factors, CPUE, and groups of estuarine fish species (Ross and Epperly 1985).

From 1979 to 1984, 128 species were taken in the DMF's estuarine trawl survey (the entire program includes 119 stations from Pamlico Sound to the Cape Fear River). Despite the apparent

species diversity, each year only 10 species comprised over 97% of the individuals taken, and 7 -- spot (Leiostomus xanthurus), croaker (Micropogonias undulatus), menhaden (Brevoortia tyrannus), brown shrimp (Penaeus aztecus), blue crabs (Callinectes sapidus), southern flounder (Paralichthys lethostigma), and silver perch (Bairdiella chrysoura) - were among the 10 most abundant each year in samples taken by 3.2 m trawls. Spot was by far the most common species, comprising roughly 60% of all individuals taken, and croaker was the second most common species, representing 15 to 25% of all individuals (DeVries 1985). Nursery areas are designated for management purposes based on the CPUE in trawl samples of juveniles and the proportion of juveniles in the catch (Purvis 1976).

Different species enter the nursery areas at different times of the year, and remain for varying periods. Juvenile spot begin entering in February, and the species is present in large numbers during every month except December (Purvis 1976). Postlarval croakers arrive over a prolonged period from August through May but peak recruitment takes place during winter and early spring (Purvis 1976). Postlarval menhaden are recruited during February through June (Purvis 1976). Brown shrimp are found from July through October and from April through June. They begin entering the commercial fishery in April and continue doing so until July (Purvis 1976). Blue crabs are present in primary nursery areas throughout the year (Purvis 1976).

Primary nursery areas (Type I) have been delineated in most of the tributary bays and estuarine streams along the north shore of Pamlico Sound (Epperly 1984). The more diffuse secondary nursery areas and temporary or transport nursery areas are recognized as a matter of policy but have not been delineated geographically.

Because primary nursery areas are located in the upper reaches of estuaries and are characterized by low salinity, they are very sensitive to activities on adjacent uplands. Variations in freshwater inflow resulting from drainage or an increase in the area of impermeable surface can alter the velocity and magnitude of salinity changes. Sediment coming from agriculture, land clearing, and development activities can reduce light penetration and suffocate benthic organisms. Nutrients and other pollutants originating from septic tanks or industrial or municipal discharges can increase the production of unwanted plankton or, alternatively, can poison and disrupt the desirable balance of estuarine organisms (Epperly 1984). Because of the complexity of the estuarine system and the synergy among environmental factors, it is difficult to demonstrate the degree to which any one factor is limiting estuarine productivity at any particular time. Any or all may have a profound impact upon environmental conditions in primary nursery areas and their continued contributions to estuarine and marine fisheries.

D.4.b. Status of Information. The NC Wildlife Resources Commission and the DMF have been the most active agencies collecting information concerning nursery areas in the Albemarle/Pamlico region. As part of its surveys of inland fishing waters, DMF personnel surveyed waters off the Albemarle/Pamlico peninsula during the summer of 1964 (Bayless and Shannon 1965; Smith and Baker 1965) and Lake Phelps in 1965, 1976, and 1978 (Kornegay and Dineen 1979). The DMF conducts routine fisheries surveys in the area. They began in 1972 with anadromous fisheries investigations in Albemarle and Croatan Sounds and their tributaries. In 1974, and continuing until the fall of 1975, DMF conducted monthly trawl sampling in northern Pamlico Sound nursery areas. Effort was reduced between late 1975 and 1978, when the Division began a statewide juvenile stock assessment (Epperly 1984). As part of this program, DMF sampled 51 stations in designated primary nursery areas on a monthly basis from March through November in 1981 and 1982, with much reduced efforts during the winter (when few fish were in the area). In addition to the trawl samples of juvenile fish, surface and bottom salinities and water temperatures were measured (Ross and Epperly

1985). Supplementing this broad-based survey were more intensive studies of Rose and Swanquarter Bays from 1977 to 1980, directed toward determining the effects of freshwater drainage upon the nursery areas (Pate and Jones 1981; Jones and Sholar 1981). North Carolina State University sampled in the same area between 1979 and 1983 (Gerry 1981; Woodward 1981; Currin 1984; Epperly 1984).

Although questions have been raised from time to time concerning the adequacy of gear and sampling design used in the DMF surveys, (Epperly 1984; Phalen et al. 1989), the data base provided is generally adequate for defining the location and areal extent of primary and secondary nursery areas and changes in fish populations. The DMF plans to continue sampling nursery areas as part of their juvenile stock assessment program (Spence et al. 1988). Data from the surveys may be used to predict subsequent commercial landings of brown shrimp and Atlantic croaker (DeVries 1985), and to document year-to-year fluctuations in species abundance.

D.4.c. Trends. General statements regarding the sensitivity of primary nursery areas to environmental alterations and impending threats to such areas exist (Purvis 1976; Epperly 1984), however, no definitive analysis of environmental or fish population trends in nursery areas was found.

D.4.d. Management/Regulatory Status and Trends. Designated primary nursery areas are protected against damaging fishing practices through regulations of the MFC enforced by the DMF. Trawling, oyster and clam dredging, and clam "kicking" (using propeller wash to excavate clams) are prohibited in primary nursery areas. Impacts from land use activities are less well controlled and may make a greater impact upon the long-term health of nursery areas.

Point discharges of waste materials are regulated through National Pollutant Discharge Elimination System permits issued by the NC Division of Environmental Management. Deposition of dredged and fill material in the waters and adjacent wetlands is governed by Clean Water Act Section 404 permits issued by the US Army Corps of Engineers. Development in estuarine waters, coastal wetlands, and estuarine shoreline Areas of Environmental Concern (AECs) is regulated by permits from the NC Division of Coastal Management.

Probably the greatest weakness in existing programs lies in controlling non-point sources of water pollution and in regulating development landward of existing AECs within the zone directly affecting primary nursery areas. The former is addressed in Sections 208 and 319 of the Federal Water Pollution Control Act and its amendments; the latter is under consideration by the NC Environmental Management Commission and Coastal Resources Commission. At the present time, however, no definitive action has been taken in either area.

D. 5. Anadromous Species Spawning Habitats

D.5.a. Description. Anadromous fish species spend their adult lives in the ocean but return to freshwater or brackish water habitats to reproduce. North Carolina has three families of anadromous fish represented by seven species: striped bass (Morone saxatilis), American shad (Alosa sapidissima), hickory shad (Alosa mediocris), blueback herring (Alosa aestivalis), alewife (Alosa pseudoharengus), Atlantic sturgeon (Acipenser oxyrinchus), and shortnose sturgeon (Acipenser brevirostrum). The status of these populations was determined by a 1980 survey (Rulifson et al. 1982), results of which were summarized for the Albemarle-Pamlico Estuarine Study area in Table II-3. The shortnose

sturgeon remains on the US Fish and Wildlife Service Endangered Species List and is believed to be extirpated in the Albemarle-Pamlico Estuarine area.

Spawning habitats of anadromous species are located upstream of tidal influence and saltwater intrusion in several primary rivers and many tributaries throughout the Albemarle-Pamlico Estuarine Study area. Exact locations are species specific and dictated by abiotic factors including water velocity, water depth, and substrate type. Spawning generally occurs over a rather broad reach within a particular river due to the fact that water velocity and depth can fluctuate daily. Biotic factors associated with spawning grounds vary depending on the species in question; habitats range from swiftly flowing mainstream waters low in aquatic fauna to floodplain habitats and slow-currented oxbows containing abundant submerged and emergent flora (Tables II-4, II-5, II-6, II-7, II-8, and II-9).

These riverine areas provide the combination of physical and chemical aspects required by anadromous species for completion of their life cycles. The eggs of all species require flowing waters to prevent suffocation and provide specific ranges of temperature, pH, turbidity, and water hardness to ensure optimal hatching success and minimal larval deformation. Several species (e.g., striped bass and shad) have eggs that must be in constant motion for proper embryo development; thus, the eggs are transported downstream as they develop. Larvae of these species tend to be active predatory foragers and are found in the more open-water habitats. The eggs of other species (e.g., alewife) develop best in slowly-flowing waters and tend to produce larvae that commonly inhabit heavily vegetated or floodplain habitats.

The distribution of anadromous spawning habitat is species specific and varies temporally and spatially. The primary rivers utilized by striped bass and American shad include the Roanoke River of Albemarle Sound and the Neuse and Tar rivers of Pamlico Sound. Hickory shad spawn in these rivers as well as in the Chowan River of Albemarle Sound. River herring (blueback herring and alewife) spawn in many of the smaller tributaries bordering Albemarle Sound. Spawning of sturgeon species within the Albemarle-Pamlico Estuarine Study area is not documented. Specific spawning locations within these river systems are presented in Tables II-4 to II-9. Spawning is limited to those areas possessing at least minimal water quality parameters and sufficient water flow for survival of eggs and larvae. All species spawn during the spring. The primary trigger for spawning activity is water temperature. During the spawning migration anadromous fish actively avoid waters of low dissolved oxygen concentrations and extremely high turbidity (Manooch and Manooch 1986). If present, these adverse conditions may shift spawning habitats for days or for the entire season. Dams, dikes, roadways requiring culverts, and other barriers also restrict access to traditional spawning grounds (Collier 1989).

D.5.b. Status of Information. Field work in the 1970s and 1980s delineated the spawning grounds for most anadromous fish species within the A/P Study area. The bulk of this information is available from state fishery agency reports, although locating some of it is difficult. Information from most of these reports is presented in Tables II-4 through II-9. Of the seven anadromous species documented in these waters, spawning areas of three are not well known: hickory shad, Atlantic sturgeon, and shortnose sturgeon (if still present at all). An important document by Ries Collier of the US Fish and Wildlife Service in Raleigh (Collier 1989), has identified man-made and natural limitations to historical spawning grounds. Still lacking, however, is a good understanding of how these species are affected by present-day resource management; primarily hydropower generation, floodplain lumbering and agriculture, and water withdrawal and waste discharge by municipalities and industry. Some of this work is currently underway for the lower Roanoke watershed by the Roanoke River Waterflow Committee and the Striped Bass Management Board (Manooch and Rulifson 1989;

Rulifson and Manooch 1990a, 1990b; and Zincone and Rulifson 1991). In summary, the information available provides a good base for establishing management options, but detailed information on downstream users and uses and how they affect the young after spawning is still lacking.

Table II-3. Results of a 1980 Survey Indicating Status of Anadromous Fish Populations within the A/P Study Area (Rulifson et al. 1982)

| Anadromous species | | | | | | | |
|------------------------|-----|----|-----|-----|-----|-----|-----|
| Watershed | SB | AS | HS | BH | AW | AS | SS |
| <u>Currituck Sound</u> | - | - | - | D | D | - | E |
| <u>Albemarle Sound</u> | D | D | D | D | D | D | E/T |
| North R. | - | - | - | D | D | - | E |
| Pasquotank R. | - | - | - | D | D | - | E |
| Little R. | - | - | - | D | D | - | E |
| Perquimans R. | - | - | - | D | D | - | E |
| Yeopim R. | - | - | - | D | D | - | E |
| Chowan R. | D | D | D | D | D | D | E/T |
| Meherrin R. | S/D | D | S/D | D | D | - | E |
| Roanoke R. | D | D | D | D | D | D | E/T |
| Cashie R. | - | D | S/D | D | D | - | E |
| Scuppermong R. | - | - | - | D | D | - | E |
| Alligator R. | - | - | - | D | D | - | E |
| <u>Pamlico Sound</u> | | | | | | | |
| Pungo R. | - | - | - | N | N | - | E |
| Pamlico R. | I | - | - | N | N | S/D | E |
| Tar R. | I | D | D | D | D | D | E/T |
| Neuse R. | S/D | D | D | D | D | D | E/T |
| Trent R. | - | D | S/D | S/D | S/D | - | E |

Species key: SB = striped bass; AS = American shad; HS = hickory shad; BH = blueback herring; AW = alewife; AS = Atlantic sturgeon; SS = shortnose sturgeon. Status key: I = increasing; S = stable; D = declining; T = threatened; E = extirpated; dash (-) = no response; N = not known.

D.5.c. Trends. In general, populations of all anadromous species continue to decline throughout the A/P Study area (Table II-3). Overharvest is one cause for decline of these populations, but degradation of available spawning habitat has contributed as well. The historical spawning grounds in a number of river systems have been blocked by construction of dams and reservoirs, and access to other areas has been limited by road construction using culverts rather than bridges to span smaller streams. In some cases, the manner in which river systems are managed for flood control, hydropower generation, and recreation has changed since the 1950s (Manooch and Rulifson 1989, Rulifson and Manooch 1990b).

Historically, stock restoration efforts have concentrated on rearing eggs and larvae of the species, then returning the progeny to streams or to the sounds. Recently, attention has been given to dwindling available spawning habitats, causes for their degradation, and possible alternatives for reversing the process. Only two species in North Carolina have undergone extensive stock restoration efforts by culturing: striped bass and American shad.

Even in the late 1800s, concern for preservation of striped bass stocks in the Albemarle Sound area was expressed in federal documents (Smith 1907). In 1873, under the direction of US Fish Commissioner Baird, 100,000 striped bass were hatched at Weldon and planted in local waters. From 1879 to 1884, the State Superintendent of Fisheries, Mr. S.G. Worth, performed experimental work on hatching and rearing Roanoke striped bass near Weldon. In 1884, financial aid by the US Fish Commissioner ensured collection of large numbers of eggs and the continued operation of temporary hatching stations on the Roanoke River near Weldon (Smith 1907). Even at the present time, annual stocking programs to restore Roanoke/Albemarle striped bass are continued by both the US Fish and Wildlife Service and the North Carolina Wildlife Resources Commission. Other striped bass populations within the A/P Study area are stocked on an irregular basis; however, all populations continue to decline (Table II-3).

During the late 1800s, the North Carolina shad fishery reached its peak in importance, and at one time exceeded the production of any other state (Smith 1907). In 1896, the Neuse River was regarded as the most important shad-producing stream between the James River, Virginia, and the St. Johns River, Florida. After 1900, decline in numbers was attributed to overharvest and the welfare of these populations was in serious jeopardy. In 1904, the North Carolina Legislature designed a law to protect shad from overharvest.

Realizing the importance of shad as a natural resource, North Carolina became one of the first states to attempt artificial propagation. In 1873, under the direction of US Fish Commissioner Baird, about 45,000 shad were hatched at New Bern and planted in local waters. In 1875, shad-hatching efforts at New Bern were unsuccessful. In 1877, North Carolina began shad-hatching efforts in its own behalf with an operation on the Neuse River, which was not successful. Joint efforts for shad restoration were undertaken by the US Fish Commission and the states of Virginia, North Carolina, and Maryland in 1878. The operation was located on Salmon Creek at the head of Albemarle Sound. By 1880, shad-hatching efforts proved successful and the state maintained a shad hatchery at Avoca until 1884. In 1885, North Carolina discontinued all shad culture work; however, the federal government continued its efforts until the turn of the century (Smith 1907).

D.5.d. Management/Regulatory Status and Trends. Commercial harvest of anadromous species in North Carolina is regulated at both the state and federal levels. Regional fisheries councils, such as the Atlantic States Marine Fisheries Commission (ASMFC), have implemented coast-wide fishery management plans for ocean harvest of anadromous alosids (shad and river herring) and striped

bass. The shortnose sturgeon is protected by federal law as an endangered species. A management plan for Atlantic sturgeon harvest is currently in preparation by ASMFC. At the state level, the DMF is responsible for commercial and recreational harvest regulations within 3 miles of the coast, and within the sounds and estuaries. The North Carolina Wildlife Resources Commission regulates harvest of these species in inland waters. No commercial fishing for anadromous species is allowed in inland waters; however, spawning areas are not protected from recreational fishing pressure. North Carolina is the only Atlantic coast state that allows recreational harvest of striped bass from within the spawning grounds. A summary of striped bass harvest regulations was presented by Rulifson and Manooch (1990a). At the present time, there are no regulations in place that regulate harvest of anadromous species in all phases of their complex life histories, although a cooperative agreement was negotiated in 1990 between the US Fish and Wildlife Service and the two state agencies that manage striped bass in North Carolina was negotiated in 1990 (W.C. Cole, US Fish and Wildlife Service, personal communication).

Table II-4. Spawning Criteria of Striped Bass within the A/P Study Area

Location:

ROANOKE RIVER - River Mile (RM) 78-137, centered at Weldon (RM 130) at Fall Line (Hassler et al. 1981).

TAR RIVER - 55.6 to 148.2 km upstream from river mouth; 75% within a 37-km area (Humphries 1966); RM 50 to RM 85 (Humphries 1966; Kornegay and Humphries 1975); Falkland bridge upstream for 80 km (Miller 1975). Falkland to above Tarboro, with most between Falkland and Tarboro in 1988 (dry spring) (K. Nelson, pers. comm.).

NEUSE RIVER - Middle Neuse from NC HWY 55 bridge near Kinston (RM 80) to the SR 1224 bridge above Goldsboro (RM 145). Major area: NC HWY 55 bridge to SR 1915 bridge near Goldsboro (Hawkins 1979). Spawning in 1989 from Seven Springs (RM 105) to above Goldsboro (RM 145+) with most above Goldsboro; 1989 was a wet spring (K. Nelson, pers. comm.).

Season:

ROANOKE RIVER - April 15 to June 5; peak May 10-20 (Hassler et al. 1981).

TAR RIVER - April 15 - May 15 (Humphries 1965); mid-April to mid-May; peak late April to early May (Miller 1975). In 1973, April 21- May 14; in 1974, April 28-May 17 (Kornegay and Humphries 1975).

NEUSE RIVER - Late March to late May (Hawkins 1979); April through mid-May (Baker 1968).

Temperature:

ROANOKE RIVER - 13°C to 21.7°C; peak 16.7°C-19.4°C; 90% of spawning between 15.4°C and 20.3°C (Shannon and Smith 1968; Shannon 1970; Street 1975; Hassler et al. 1981).

TAR RIVER - 15.0°C-22.2°C, peak 18.0°C-21.0°C (Humphries 1965); 19°C-21°C, peak at 19°C-19.5°C (Miller 1975).

NEUSE RIVER - 13.5°C-24°C; peak 20°C-21.5°C (Hawkins 1979).

Habitat:

ROANOKE RIVER - main open water area of river up to the Roanoke Rapids dam in wet years, water highly sedimented and turbulent (Rulifson).

TAR RIVER - main river channel, primarily sand substrates (K. Nelson, pers. com.)

NEUSE RIVER - main river channel, primarily sand substrates (K. Nelson, pers. com.).

Nursery Area:

Postlarvae and Juveniles:

ROANOKE RIVER - Roanoke delta, primarily Cashie River, and western Albemarle Sound in salinities zero to 7 ppt (Hassler et al. 1981; Rulifson et al. 1988).

TAR-PAMLICO RIVER - Hardee Creek above Washington in Tar River stretching to Pungo Creek in the Pungo River at salinities zero to 4.5 ppt. Major areas: Broad Creek and South Creek (Hawkins 1979).

NEUSE RIVER - Downstream from New Bern (Hawkins 1979).

Table II-4 (striped bass continued)

Fertilization:

Striped bass eggs are released in open waters of rivers where they are fertilized. Require current for suspension in water column.

Hatching:

Incubation period ranges from 29 hours at 23.9°C to 80 hours at 12.2°C (Hardy 1978). Percent hatching success is correlated with substrate composition: coarse sand, 35.7%; clastic, 36.4%; silt, 13.1%, silty- clay, 3.2%, and muck detritus, 0.0% (Bayless 1968).

Feeding:

Active feeding initiated 4 to 10 days post-hatch; non-feeding larvae may exhibit reduced function of certain organs and tissues as early as 4.5 days post-hatch (Rulifson et al. 1986). Prey for Roanoke River larvae are small zooplankton crustaceans, primarily copepodid copepods and *Bosmina.

Water Quality:

Salinity tolerance of eggs ranges from zero to 10 ppt (Setzler et al. 1980). Eggs will hatch in waters of pH values above 5.5 and below 10.0 but fry survival is best within 6.5-9.5 (Shannon 1967). Sudden shifts in pH is lethal (Mehrle et al. 1986). Eggs and larvae are particularly sensitive to residual chlorine even at levels as low as 0.04 to 0.5 ppm (Morgan and Prince 1977, Middaugh et al. 1977). Striped bass larvae are classified as "sensitive" to suspended sediments (Morgan et al. 1973) and exhibit reduced survival at concentrations of 500 - 1,000 mg/l (Auld and Schubel 1978).

Swimming Ability:

Yolksac larvae attempt to swim toward the surface but sink between efforts. Newly-hatched larvae require sufficient turbulence to keep them from settling to the bottom and smothering (Setzler et al. 1980).

Chemical Tolerances:

Extensive information on chemical tolerances can be found in Rehwoldt et al. (1971) and Setzler et al. (1980).

Table II-5. Spawning Criteria of American Shad within the A/P Study Area

Location:

CHOWAN RIVER -

Blackwater River: US HWY 258 bridge and below (Winslow et al. 1985).

Nottoway River: Virginia State HWY 645 bridge and below (Winslow et al. 1985).

Meherrin River: Eggs and larvae were collected at the SR 1339 bridge and below (Winslow et al. 1983).

ROANOKE RIVER - Conine Creek near US HWY 17 bridge (RM 37.5) at Williamston upstream to US HWY 258 bridge (RM 102). Concentrated at Conoho Creek downstream from NC HWY 125 at Williamston (Johnson et al. 1978). May often concentrate below the Roanoke Rapids Dam (RM 137) in April and May (Mullis, pers. comm.).

TAR RIVER - from Bear Creek above Washington to Rocky Mount and tributaries (Marshall 1976).

PAMLICO RIVER - tributaries including Durham Creek, Chocowinity Creek, Herring Run, Broad Creek, and Nevil Creek (Marshall 1976).

NEUSE RIVER -

Neuse: Usually upstream from Trenton; from US HWY 70 Business (RM 85) in Kinston to SR 1224 bridge upstream from Goldsboro (RM 145), upstream from Quaker Neck Dam (Marshall 1977, Hawkins 1979).

Contentnea Creek: SR 1225 bridge to creek mouth (Hawkins 1979).

Little River: NC HWY 581 bridge to river mouth (Hawkins 1979).

Trent River: from mouth to a point near Pleasant Hill (Baker 1968).

Season:

CHOWAN RIVER -

Nottoway River: May (Winslow et al. 1985).

Blackwater River: May (Winslow et al. 1985).

ROANOKE RIVER - April (Johnson et al. 1978).

TAR RIVER - March 31 - May 14 (Marshall 1976).

NEUSE RIVER - Late April to early May (Hawkins 1979).

Temperature:

CHOWAN RIVER - Between 18°C and 22.5°C in the Blackwater and Nottoway Rivers (Winslow et al. 1985).

ROANOKE RIVER - no information.

TAR RIVER - no information.

NEUSE RIVER -

Neuse: 15°C to 24°C (Hawkins 1979).

Trent: 16°C (Marshall 1977).

Habitat:

ROANOKE RIVER - no information.

TAR RIVER - primarily main channel of river and larger tributaries (K. Nelson, pers. comm.).

NEUSE RIVER - limited primarily to main section (Hawkins 1979).

Table II-5 (American shad continued)

Nursery Area:

Postlarvae and Juveniles:

ROANOKE RIVER - no information.

TAR-PAMLICO RIVER - 91% of young of year caught from Hardee Creek to the Cannon Swamp area in July (Hawkins 1979).

NEUSE RIVER -

Neuse: SR 1224 bridge upstream from Goldsboro (RM 145) to Duck Creek downstream from New Bern (RM 35). Highest concentrations near the SR 1224 bridge above Quaker Neck Dam and also SR 1152 bridge upstream from Kinston near Taylor Creek (Hawkins 1979). Remain in fresh/brackish waters until October-November.

Trent: Pollocksville downstream to the mouth of Island Creek (Marshall 1977).

Fertilization:

American shad eggs are released in open waters of rivers and fertilized (Cheek 1968). Eggs are non-adhesive and slightly heavier than water; require currents for successful development and transport downstream (Sholar 1977a; Ulrich et al. 1979).

Hatching:

Incubation period depends on water temperature and is limited to a range of 12°C to 19°C (Leach 1925a). Temperatures of 7°C to 9°C are usually lethal (Leim 1924). Maximum hatch and survival is between 15.5°C and 26.6°C (Leggett and Whitney 1972), but temperatures of 20.0°C to 23.4°C result in extensive larval abnormalities (Leim 1924). No viable eggs develop above 29°C (Bradford et al. 1968).

Feeding:

Larval shad consume aquatic crustaceans and tendipedid larvae and pupae (Levesque and Reed 1972).

Water Quality:

Shad eggs in the Neuse River were found in waters of pH ranging from 6.4 to 6.9 and oxygen content of 6 to 10 ppm (Hawkins 1979). Egg hatching success not affected by suspended sediments less than 100 mg/l, but larvae exposed to levels above 100 mg/l for 96 hours showed reduced survival (Auld and Schubel 1978).

Swimming Ability:

No information available.

Chemical Tolerances:

Shad eggs are not significantly affected by lead levels below 15 mg/l (Whitworth 1969).

Table II-6. Spawning Criteria of Atlantic Sturgeon within the A/P Study Area

Location:

ROANOKE WATERSHED - no spawning documented

TAR WATERSHED - no spawning documented; adult fish are occasionally caught by fishermen,
2 at Falkland in 1988 (K. Nelson, pers. comm.)

NEUSE WATERSHED - no spawning documented

Season:

Spring (if applicable)

Temperature:

unknown

Habitat:

General - open waters of rivers in brackish or fresh waters over hard bottoms of clay, gravel, or shell in shallow water up to 5 fathoms deep (Vladykov and Greeley 1963; Leland 1968)

Nursery Areas:

Postlarvae and Juveniles:

None documented

Fertilization:

Atlantic sturgeon eggs are adhesive and demersal; require attachment sites in flowing water.

Hatching:

Incubation period ranges from 94 hours at 20°C to 168 hours at 17.8°C (Murawski and Pacheco 1977).

Water Quality:

No specific information available.

Swimming Ability:

Sac fry less than 10 days posthatch are active swimmers; after day 10 they assume a more benthic existence (Smith et al. 1980).

Table II-7. Spawning Criteria of Hickory Shad within the A/P Study Area

Location:

ROANOKE RIVER - mouth upstream to RM 105 above US HWY 258 bridge at Scotland Neck (Marshall 1977). During low water years, adult hickory shad are commonly caught below the rapids at Weldon by sport fishermen in late April and early May (Mullis, pers. comm.).

CHOWAN RIVER - Upper Chowan into the Nottoway and Meherrin Rivers above the Virginia border (Marshall 1977)

TAR RIVER - Between Greenville (RM 60) and Rocky Mount (RM 121) (Marshall 1977)

NEUSE RIVER - RM 80 to RM 97 and entire tributaries: Turkey Quarter Creek; Pitchkettle Creek; Taylor Creek; Halfmoon Creek; Contentnea Creek; Grindle Creek (Hawkins 1979)

Season:

ROANOKE RIVER - not documented

CHOWAN RIVER - not documented

TAR RIVER - late March to early April (Marshall 1976).

NEUSE RIVER - late March to early May (Pate 1972; Hawkins 1979).

Temperature:

ALBEMARLE AREA - 13°C to 21°C (Street et al. 1975)

TAR RIVER - 14°C to 19°C (Marshall 1976)

NEUSE RIVER - lowest at 9.5°C (Pate 1972); range between 13°C and 18.5°C (Hawkins 1979)

Habitat:

Not documented. Generally, river swamp areas, lakes and large tributaries may be used (Godwin and Adams 1969; Street 1970).

Nursery Area:

Postlarvae and Juveniles:

ALBEMARLE AREA - not documented

TAR RIVER - Juveniles spend short time in upstream areas before migrating downstream to high salinity tributaries of the Pamlico River (Pate 1975). Specific locations not documented.

NEUSE RIVER - Juveniles spend short time in upstream areas before migrating to high salinity tributaries of Neuse River during summer months (Pate 1972; Spitsbergen and Wolff 1973; Marshall 1977; Hawkins 1979).

Fertilization:

Hickory shad eggs are released in open water areas of rivers where they are fertilized; typically demersal and somewhat adhesive, but easily dislodged and transported by currents (Mansueti and Hardy 1967).

Hatching:

Incubation time ranges from 48 to 70 hours at 16°C to 31° C (Mansueti and Hardy 1967).

Feeding:

Not documented

Table II-7 (Hickory Shad continued)

Water Quality:

In the Neuse River, hickory shad eggs were collected in waters of pH 6.4 to 6.5 and dissolved oxygen between 5 and 10 mg/l (Hawkins 1979). Hardiness to other water quality factors has not been documented.

Swimming Ability:

Not documented

Chemical Tolerances:

Egg and larval tolerances not documented

Table II-8. Spawning Criteria of Blueback Herring within the A/P Study Area

Location:

Albemarle Area -

- CHOWAN RIVER** - Rocky Hock Creek; Salmon Creek; Warwick Creek; Dillard Creek; Bennetts Creek; Sarem Creek; Barnes Creek; Wiccacon River (Winslow et al. 1985)
- ALLIGATOR RIVER** - Northwest fork; Frying Pan; Cherry Ridge Landing; Gum Neck Landing (pumping station); East Lake (lower); South Lake (upper); Second Creek (Loesch et al. 1977)
- ROANOKE RIVER** - Gardners Creek (SR 1511); Conoho Creek mouth (RM 37.5); Conine Creek mouth (RM 102); Cow Creek (Johnson et al. 1978)
- CASHIE RIVER** - SR 1225; SR 1514 (Johnson et al. 1978)
- SCUPPERNONG RIVER** - no specific location (Winslow et al. 1985)

Pamlico Area -

- TAR RIVER** - from Bear Creek above Washington to Town Creek above Old Sparta and tributaries (Marshall 1976)

Neuse Area -

- NEUSE RIVER** - SR 1008 bridge downstream to New Bern
- SWIFT CREEK** - SR 1440 bridge to mouth
- LITTLE SWIFT CREEK** - SR 1627 bridge to mouth
- BACHELOR CREEK** - US HWY 70 bridge to mouth
- CONTENTEA CREEK** - NC HWY 13 bridge (Snow Hill) to mouth
- LITTLE RIVER** - NC HWY 581 bridge to mouth
- TRENT RIVER** - Pleasant Hill to SR 1121 (Marshall 1977)
- Entire creeks:** Pinetree Creek, Turkey Quarter Creek, Pitchkettle Creek, Taylor Creek, Halfmoon Creek, Kitten Creek, Village Creek (Hawkins 1979)

Season:

- Albemarle area** - mid-March to late May (Winslow et al. 1985)
- TAR RIVER** - March 25 - May 7 (Marshall 1976)
- PAMLICO RIVER tributaries** - April 7 - May 3 (Marshall 1976)
- NEUSE RIVER** - late March to late May (Hawkins 1979)

Temperature:

- Albemarle Area** - 13°C to 22°C for "river herring" (Winslow et al. 1985)
- TAR RIVER** - 12°C to 19°C (Marshall 1976)
- PAMLICO RIVER tributaries** - 13°C to 25°C (Marshall 1976)
- NEUSE RIVER** - 13°C to 26°C (Hawkins 1979)

Habitats:

No specific information available. In general, prefer spawning sites with fast current and associated hard substrates (Loesch and Lund 1977). Brackish water or standing water rarely used.

Nursery Areas:

Postlarvae and Juveniles:

- ALBEMARLE SOUND** - Pasquotank River, Little River, Perquimans River, Chowan River, lower Roanoke River, Scuppernong River, Alligator River, and periphery of Albemarle Sound (Loesch et al. 1977; Winslow et al. 1985)

Table II-8 (Blueback Herring continued)

Nursery Areas:

Postlarvae and Juveniles (continued):

CROATAN SOUND - used as secondary nursery area from October through March (Street et al. 1975)

TAR-PAMLICO - Hardee Creek area to Washington, and Goose, Broad, and Blounts Creeks (Hawkins 1979)

PAMLICO SOUND - western and northern ends as secondary nursery areas from October through March (Spitsbergen and Wolff 1974; Marshall 1976)

NEUSE RIVER - mouth of Cove Creek downstream to mouth of Bachelor Creek (21 km) (Marshall 1977)

TRENT RIVER - Pollocksville downstream to mouth of Island Creek (Marshall 1977)

Fertilization:

Blueback herring eggs are essentially pelagic, but are demersal in still water and are somewhat adhesive (Lippson and Moran 1974; Loesch and Lund 1977). Eggs are released in grasses or vegetation and are fertilized (Frankensteen 1976).

Hatching:

Incubation period is dependent on water temperature; hatching time ranges from 80 to 94 hours at 20°C to 21°C, and 36 to 38 hours at 22°C (Morgan and Prince 1976; Street and Adams 1969).

Feeding:

Larvae begin feeding on zooplankton immediately after mouth becomes functional, primarily small cladocerans and copepods (Norden 1968; Nigro and Ney 1982).

Water Quality:

Blueback herring eggs and larvae exhibit high mortality when exposed to pH waters below 6 and 0.20 mg/l total aluminum (Klauda and Palmer 1987). Suspended sediments 100 ppm or less did not significantly affect the hatchability of blueback herring eggs (Auld and Schubel 1978).

Swimming Ability:

Prolarvae are positively phototropic (Mansueti 1956) and swim in spasms to the surface, sink to the bottom to rest for several seconds, then repeat the process (Cianci 1969).

Chemical Tolerances:

Monomeric aluminum concentrations of 0.1 mg/l during episodic pH events is highly toxic to eggs and larvae (Klauda and Palmer 1987). The LC₅₀ of total residual chlorine for eggs ranges from 0.20-0.32 ppm; sublethal concentrations resulted in deformed larvae (Morgan and Prince 1977). (Note: LC = lethal concentration, the concentration at which 50% of the test organisms die).

Table II-9. Spawning Criteria of Alewife within the A/P Study Area

Location:

- CHOWAN RIVER** - Dillard Creek at SSR 1226 bridge and below (Winslow et al. 1985)
ALLIGATOR RIVER - Gum Neck Landing; Alligator River, Southwest and Northwest forks; Alligator Creek; East Lake (lower); Second Creek; Frying Pan; South Lake (middle and upper); Kilkenny Landing; Swan Lake; Cherry Ridge Landing (Loesch et al. 1977)
CASHIE RIVER - Hoggard Mill Creek (SR 1301); Wading Place Creek (SR 1514) (Johnson et al. 1978)
NEUSE RIVER - Not known; probably use the river as far upstream as Contentnea Creek (Hawkins 1979)

Season:

- CHOWAN RIVER** - mid-March through late May (Winslow et al. 1985)
ALLIGATOR RIVER - no information available
CASHIE RIVER - no information available
NEUSE RIVER - mid-March to mid-April (Marshall 1977)

Temperature:

- CHOWAN RIVER** - 13°C to 22°C (Winslow et al. 1985)
ALLIGATOR RIVER - no information available
CASHIE RIVER - no information available
NEUSE RIVER - 15°C to 20.5°C (Marshall 1977)

Habitat:

General - eggs and milt are released over detritus-covered bottom of attached vegetation, sticks, or other organic matter and occasionally over a hard sand bottom (Cooper 1961) in ponds and sluggish stretches of rivers and streams (Bigelow and Schroeder 1953, Kissil 1974).

Nursery Area:

Postlarvae and Juveniles:

- General** - Alewife larvae generally remain in the vicinity of the spawning grounds (Hildebrand 1963). Juveniles remain in tidal creek nursery areas and move seaward in late summer and fall (Bigelow and Schroeder 1953).
ALBEMARLE AREA - Pasquotank River; Little River; Perquimans River; Chowan River; lower Roanoke River; Scuppernong River; Alligator River, and periphery of Albemarle Sound (Winslow et al. 1985)
CURRITUCK SOUND - all (Winslow et al. 1985)

Fertilization:

Alewife eggs are broadcast at random, are demersal and adhesive initially; within several hours the adhesive property is lost and eggs enter the water column (Mansueti 1956; Cooper 1961).

Hatching:

Incubation period for alewife eggs ranges from 2.1 days at 28.9°C to 15 days at 7.2°C (Edsall 1970)

Feeding:

Larvae begin feeding on zooplankton immediately after mouth becomes functional, primarily on small cladocerans and copepods (Norden 1968; Nigro and Ney 1982).

Table II-9 (Alewife continued)

Water Quality:

Hatching success of alewife eggs is not affected by suspended sediments in concentrations of 100 mg/l or less (Auld and Schubel 1978).

Swimming Ability:

Prolarvae are positively phototrophic (Mansueti 1956) and swim in spasms toward the surface (Cianci 1969).

Chemical Tolerances:

No information available

E. BARRIER ISLANDS: BEACHES, DUNES, FLATS, THICKETS, WOODLANDS, MARSHES, IMPOUNDMENTS, INLETS, DREDGED ISLANDS, AND AQUIFERS

E. 1. Description

The North Carolina Outer Banks extend from the Virginia-North Carolina border to the southern end of Cape Lookout National Seashore -- a distance of almost 200 miles. The communities of Corolla, Duck, Southern Shores, Kitty Hawk, Kill Devil Hills, Nag's Head, Whalebone, and South Nag's Head are located on Currituck Banks; Rodanthe, Waves, Salvo, Avon, Buxton, Frisco, and Hatteras on Hatteras Island; and Ocracoke and Portsmouth on islands of the same names.

The Outer Banks are a chain of long, narrow, sandy barrier islands, from one-quarter mile to 3 miles wide (mostly less than 1 mile wide), forming the seaward boundary of Currituck, Albemarle, Roanoke, Pamlico, and Core Sounds. Oregon, Hatteras, Ocracoke, Swash, Drum, and Bardens inlets separate the islands. Between the Outer Banks and the mainland, waters of the Roanoke, Chowan, Tar-Pamlico, Neuse, and other rivers mix with the salt waters of the ocean to form the brackish waters of our estuarine sounds (Dunbar and Kniffen 1956; Stick 1958).

The Outer Banks are exposed to the effects of salt-spray laden wind (Boyce 1954). Prevailing summer winds are from the southwest, and the pruning effects of the salt spray produce the "wind-form" of the woody vegetation. Northeastern storms in winter make a lesser wind form. Winter "northeasters" are often severe and prolonged (the Ash Wednesday storm of 1962 opened up a wide inlet at Buxton and caused major beach erosion). Hurricanes sweep the Outer Banks at irregular intervals, overwashing the islands as floodwaters surging out of the sounds break through the barrier islands (Engels 1942).

Moving water also affects the Banks. The average rate of beach erosion varies from 2 to 6 ft per year (Benton 1981). These forces are more evident near the inlets, which can migrate at rates of up to 25 feet per year (Benton 1981). Thus the physical forces of nature--wind and wave, storm and erosion, tides and salt spray--are a profound, continuous, and varying component of the Outer Banks (Brower and Frankenberg 1976; Dolan et al. 1973; Godfrey and Godfrey 1975, 1976).

The vegetation and natural communities of the Outer Banks extend from beach to sound in narrow, sometimes inter-weaving, more or less parallel strips, with each community or habitat type composed of a few dominant and distinctive plant species (Oosting 1954; Brown 1959; Quay 1959; Milne and Quay 1966).

The herbaceous beaches, dunes, and flats, exposed to the greatest salt spray, are characterized by northern beach grass (*Ammophila breviligulata*), sea oats (*Uniola paniculata*), saltmeadow cordgrass (*Spartina patens*), sand rush (*Fimbristylis castanea*), broom-sedge (*Andropogon scoparius* var. *littoralis*), seaside goldenrod (*Solidago sempervirens*), wild bean (*Strophostyles helvola*), and other salt-tolerant species (Schafale and Weakley 1985).

Landward (soundward) herb-shrub habitats become increasingly dominated by wax myrtle (*Myrica cerifera*), yaupon (*Ilex vomitoria*), marsh elder (*Iva frutescens*), and young and/or stunted live oak (*Quercus virginiana*). Farther into the dune and flats system, herb-shrub communities are replaced by taller and denser shrub thickets, which in turn may grade into thicket woodlands. Progressing soundward, the thicket woodlands increasingly become dominated by red cedar (*Juniperis virginiana*).

red bay (Persea borbonia), Hercules club (Zanthoxylum clava-herculis), live oak, and loblolly pine (Pinus taeda), with much greenbriar (Smilax) and grape (Vitus).

The oldest, tallest, and most stable vegetation on the Outer Banks is maritime forest, with live oak, laurel oak (Quercus laurifolia), red cedar, American holly (Ilex opaca), and ironwood (Carpinus caroliniana) forming the canopy and a distinctive understory of red cedar, wild olive (Osmanthus americanus), red bay, flowering dogwood (Cornus florida), willow (Salix nigra), wax myrtle, yaupon, groundsel-tree (Baccharis halimifolia), French Mullberry (Callicarpa americana), grape, greenbriar, and other vines, small trees, and shrubs (Lopazanski et al. 1988).

Sloping toward the sounds are first the irregularly flooded high marsh and then the low inter-tidal marsh, each with its characteristic biota. (These habitats are discussed in Section C of this chapter.) Fresh marsh vegetation exists along roadsides, in the two fresh-water impoundments of Pea Island National Wildlife Refuge; in ponds and swales in Buxton Woods, Nag's Head Woods, Kitty Hawk Woods; and scattered along the sound side on Currituck Banks, in roadside borrow pits on Bodie Island, and in the Bodie Island Lighthouse Pond (Parnell and Quay 1962).

An adequate source of fresh water has always been a problem on the Outer Banks. Original settlers made do with shallow wells and cisterns. Increasing populations have rendered these systems inadequate. Visitation to the Cape Hatteras National Seashore in 1957, before the Oregon Inlet Bridge, was about one-third of a million per year; in 193 it was 1,707,000 (Quay 1980). In 1988, the annual visitation was 2.1 million for Cape Hatteras National Seashore alone, and nearly 3 million for Cape Hatteras National Seashore, Wright Memorial, and Fort Raleigh (Roanoke Island) combined (R. Wood, Cape Hatteras National Seashore, pers. comm. 1989).

Since 1969, the freshwater supply for the Hatteras Island region from Avon to Hatteras Village has been secured from a number of wells 40-feet deep located within Buxton Woods; this well field is now due to be expanded but will remain within the single freshwater aquifer of the Buxton Maritime Forest. The present set of 20-year-old wells at Buxton is now pumping at nearly full capacity. At Ocracoke, the freshwater supply is primarily from a reverse osmosis desalinization plant built in 1977, with wells at 600 feet deep. The freshwater supply from shallow wells for the three upper villages of Hatteras Island has become limiting and a desalinization plant at Rodanthe, from deep wells, is now being planned with the hope of becoming functional by 1990-91.

The freshwater supplies for the Roanoke Island, Nags Head, and upper Currituck Banks regions have been from wells of various depths in the different locations, but, more recently, are primarily from deep wells in the Skyco region of Roanoke Island. Beginning three years ago, Dare County, Nags Head, and Kill Devil Hills joined in a united effort to build the second desalinization plant for the Outer Banks and Roanoke Island. This new plant, another using the reverse osmosis method, which became functional in the summer of 1989, uses brackish water from deep wells and has a capacity of 3-million gallons-per-day. Consideration is already being given to expansion of this new source, located at Kill Devil Hills.

The freshwater available for all of Currituck County is relatively poor in both quantity and quality, with little prospect of water for the Currituck County Banks coming by pipeline from the mainland of either North Carolina or Virginia.

About two-thirds of the NC Outer Banks in the A/P Study area is in some kind of state, federal, or public land trust ownership. Such areas include Cape Hatteras National Seashore, Cape Lookout

National Seashore, Pea Island National Wildlife Refuge, Pine Island National Audubon Society Refuge, 720 acres of maritime woods owned by Nag's Head and the Nature Conservancy, Jockey's Ridge State Park, Wright Brothers National Memorial Monument, Currituck National Wildlife Refuge, the North Carolina National Estuarine Research Reserve, the NC Coastal Reserve, and the North Carolina Nature Conservancy in the Swan Island-Monkey Island region (US Fish and Wildlife Service 1980; Taggart and Henderson 1988). All of these lands are held and managed as natural areas and are protected from development. In Cape Hatteras National Seashore, the 8 villages (totaling about 6,000 acres) are separate enclaves, each functioning the same as any other town or community within the county government system.

The 6,000 acres of Pea Island National Wildlife Refuge are now enclosed within the Cape Hatteras National Seashore but are managed by the US Fish and Wildlife Service and have been since the refuge was established and the freshwater impoundments were constructed in brackish marshes during the late 1930s. Waterfowl and other wildlife are more abundant at Pea Island than in the rest of the Cape Hatteras National Seashore. Vegetation on Pea Island is managed intensively for waterfowl by cutting, burning, discing, plowing, the use of water-control structures on the sound side, and formerly herbiciding to keep the natural communities more open, wetter, and in the earlier stages of plant succession.

The Park Service management, in contrast, practices the classical "protect and leave alone" system. Park Service lands have been protected from cutting, burning, plowing, and four-wheel vehicles, but have been subjected to road and dune building and other human-induced perturbations. They have not experienced a devastating hurricane for the past 35 years. As a result, these areas have become much more heavily vegetated, moving into the later stages of succession, with major loss of openness, edge habitat, and standing fresh and brackish waters. Between 1958 and 1978, the 6,000 acres of Bodie Island moved into later stages of succession; the vegetation became taller, denser, and more woody -- 43% of the area underwent a change in habitat types. The comparative change at Pea Island was 14% (Quay 1980). The changes in stages of succession were from fresh pond and/or marsh, tidal marsh, or herbaceous beach or dune to herb-shrub thicket, or thicket woodland. These changes were measured by aerial photography and verified by ground studies.

Dredge spoil islands created and maintained by the US Army Corps of Engineers (Corps) have been an ecological feature of the Outer Banks region and A/P estuaries since the 1930s. They are common and widespread and are increasing in size and number along the inner lips of inlets, within the sounds, and bordering the Atlantic Intracoastal Waterway. Management of these islands has become a cooperative venture of the Corps, the National Park Service, the US Fish and Wildlife Service, the National Audubon Society, scientists from the University of North Carolina at Wilmington, the NC Nature Conservancy, the NC Wildlife Resources Commission, and the NC Division of Marine Fisheries. Personnel from these agencies combine to form management teams for the islands, brought together by their interests in channel maintenance, fisheries resources, wildlife management, and ecological ornithology. Twenty-three species of colonial-nesting waterbirds nest almost exclusively in dredge island habitats -from freshly-dumped bare sand and muck to thicket woodlands (Parnell and Soots 1979). 18 of the 23 are on "threatened" or "of special concerns" lists (Cooper et al. 1977; Parnell 1985).

Plant succession on dredge material islands progresses from bare sand to shrub thicket and on to thicket woodland in about 20 to 30 years and is thus very much amenable to regional management in conformation with dredging cycles (Parnell and Soots 1975).

E. 2. Status of Information

There is a vast and pertinent literature on all aspects of interest, concern, and needs of the A/P Study on the Outer Banks. The 1987 Cape Hatteras National Seashore Bibliography alone has 1080 references (National Park Service 1987). While some additional research might be desirable in specific areas, more than enough knowledge exists upon which to base definitive management plans and decisions (Owens 1985; US Fish and Wildlife Service 1980).

E. 3. Trends

In summary: human populations and intensity of land use are increasing. Urbanization is proceeding rapidly on privately owned lands. Waste disposal and fresh-water supply problems and needs are increasing rapidly and are near the critical point. Maritime forests continue to be degraded (Lopazanski et al. 1988). The engineering and management of sand is increasingly pressing and controversial; engineers, elected government officials, business people, and residents find themselves in basic and operational difference with ecologists, geologists, and other scientists (Pilkey 1989; Pilkey et al. 1978).

When the towns and villages of the Outer Banks were being developed in the 18th and 19th centuries, the barrier islands were wooded, with unique, salt-spray resistant maritime forests. All the villages were built on the sound side, under the protection of the canopy of live oaks. When Oregon and Hatteras inlets were torn out by the same hurricane in 1846, eye-witness accounts attest that the maritime woods was solid at least from Avon to Ocracoke and presumably in the Oregon Inlet region also (Engels 1942). Over the past 300 years, residents of the North Carolina Outer Banks have reduced the original extensive cover of woods, shrubbery, herbaceous dunes, and sound-side marshes to remnants in the earlier stages of succession. This reduction has been accomplished by cutting, logging, burning, and fragmenting the protective vegetation and thus exposing openings and edges to the necrotic effects of the salt spray. De-vegetation was intensified by grazing of pigs, goats, sheep, horses, and cattle (until the late 1930s); by roads, increasing urbanization, and their accompanying dredging and filling; by off-road vehicles in recent years; by the construction of hardened structures on beaches and at inlets; and (until recently) by the construction of dwellings atop and in front of the frontal dunes (Pilkey et al. 1978).

Urbanization is going on rapidly on all of Currituck Banks, from Nag's Head to Corolla, and in all 8 villages of the Cape Hatteras National Seashore -- from Rodanthe to Ocracoke, except for the refuges and land-trust areas. In the process, virtually all maritime forest and herb-shrub communities and some high marsh areas are being converted to developed land. NC State Highway 12 generally lies just behind (soundward of) the frontal dunes, extending into the herb-shrub and shrub-thicket communities. It frequently overwashes, and reconstruction of washed out and threatened sections will increasingly be into herb-shrub, woods, and high marsh areas.

With denser human populations and more intense urbanization, the ground water resources of the Outer Banks are being sorely taxed. The well field in Buxton Woods is now being expanded. This aquifer is maintained by the presence and function of the 3,000-acre Buxton Maritime Woods; any destruction of the woods will also endanger this finite lens of fresh water (Lopazanski et al. 1989; Heath 1988).

The acreage in public trust ownership and jurisdiction on the Outer Banks is increasing, with the US Fish and Wildlife Service, National Park Service, NC Wildlife Resources Commission, NC Division of Coastal Management, NC Division of Parks and Recreation, NC Nature Conservancy, NC National Estuarine Research Reserve, and NC Division of Marine Fisheries all involved. Urbanization is increasing rapidly in cities and villages and on the remaining private lands.

The condition of the ocean beach will continue to degrade as development continues, bringing increasing pressure for remedial measures. Beach replenishment, stabilization, and management are and will increasingly become questionable, expensive, and controversial subjects (Pilkey et al. 1978).

If, as predicted, sea level rises 5 feet by the year 2100, the ocean shoreline would be far inland of its present location and much of Currituck (over half), Dare (87%), and Hyde (more than 66%) counties would be under ocean water (Wilms 1988). With sea level rising 3-7 feet by 2030 (Benton 1981; Wilms 1988) the impending changes in the coastal zone are sobering.

E. 4. Management/Regulatory Status and Trends

A welter of laws, regulations, and standards administered by state, federal, and local agencies affect activities on the Outer Banks. The final Environmental Impact Statement for the proposed Currituck National Wildlife Refuge (US Fish and Wildlife Service 1980) lists, identifies, and explains 21 sets of North Carolina state environmental laws and regulations (legislation), and 17 sets of federal legislation which apply to the Outer Banks (US Fish and Wildlife Service 1980). While many of these management efforts may need to be more strict, and some may need to be added, better monitoring and enforcement of existing controls could be effected immediately.

F. RARE SPECIES AND NATURAL COMMUNITIES

F.1. Introduction

This section of the chapter: 1) provides basic information on both Federally-listed and State-listed endangered and threatened species in the A/P Study Area; 2) provides a listing of natural communities in the study area; and 3) discusses completed, ongoing, and planned work to inventory natural areas in the study area, including both North Carolina and Virginia.

F.2. Federally-listed Endangered, Threatened, and Candidate Species

The "U.S. List of Endangered and Threatened Wildlife and Plants" lists species that are Federally endangered or threatened. An "endangered" species is one that is in danger of extinction throughout all or a significant portion of its range. A "threatened" species is one that is likely to become endangered in the foreseeable future. A species is listed when a determination is made that its existence is threatened by at least one of five factors: the existing or threatened loss of the species' habitat; overuse of the species for commercial, sporting, scientific, or educational purposes; disease or predation; the nonexistence of regulatory means to prevent the decline of a species or the degradation

of its habitat; and other natural or manmade factors affecting the species' continued existence. Areas essential to a species' survival or conservation, known as "critical habitat," can also be protected.

In addition to being listed as endangered or threatened, plant and animal species may be categorized as "candidates". Candidate 1 (C1) species are those species for which the U.S. Fish and Wildlife Service has enough substantial information to list the species as endangered or threatened. Listing is "warranted but precluded by other pending proposals of higher priority." The U.S. Fish and Wildlife Service, however, can use emergency listing procedures "if the wellbeing of any such species is at significant risk." A candidate 2 (C2) species is one for which there is some evidence of vulnerability, but for which there are not enough data to support listing as endangered or threatened at that time. Again, listing is "warranted but precluded by other pending proposals of higher priority". Candidate species are not legally protected under the Endangered Species Act, and are not subject to any of its provisions until they are formally proposed or listed as endangered or threatened.

The Endangered Species Act of 1973, as amended, is carried out primarily by the U.S. Fish and Wildlife Service, in cooperation with States and other Federal agencies. The Fish and Wildlife Service and the National Marine Fisheries Service, for marine species, are responsible for administering the Act; regulations governing the import and export of endangered and threatened plants are enforced by the Animal and Plant Health Inspection Service of the U.S. Department of Agriculture. The U.S. Fish and Wildlife Service's involvement, beyond listing of a species, includes development of a recovery plan, Section 7 consultation responsibilities, law enforcement activities, research, and land management, with the purpose of increasing the species' chances for recovery and survival. The ultimate goal of the U.S. Fish and Wildlife Service's Endangered Species Program is to restore animal and plant populations to a level that would allow their delisting.

In the entire study area of North Carolina and Virginia, there are 14 Federally-listed endangered species, 5 Federally-listed threatened species, 2 species proposed-endangered, and 1 species proposed-threatened. In the North Carolina portion of the study area, there are 13 endangered species and 5 threatened species. In the Virginia portion of the study area, there are 4 endangered species and 1 threatened species. Two species, the Roanoke log perch (endangered) and American chaffseed (proposed endangered), are known to occur in the study area in Virginia but not in North Carolina. Table II-10 on the following page lists these Federally-endangered and -threatened species, as well as the counties in which they are documented to occur. Details on each species are beyond the scope of this report and will not be given; for more specific information on a given species, consult the appropriate Recovery Plan developed by the U.S. Fish and Wildlife Service. Recovery Plans exist for the following species: West Indian manatee, Dismal Swamp southeastern shrew, red wolf, roseate tern, bald eagle, red-cockaded woodpecker, piping plover, peregrine falcon, green sea turtle, Kemp's ridley sea turtle, loggerhead sea turtle, leatherback sea turtle, American alligator, and Tar River spiny mussel.

As previously mentioned, candidate species are those that are not now listed or officially proposed for listing as endangered or threatened but are under status review by the U.S. Fish and Wildlife Service. At the time of this writing, there were 30 candidate species in the North Carolina portion of the study area (listing dated 10-1-91, from U.S. Fish and Wildlife Service), and 20 candidate species in the Virginia portion of the study area (listing dated 1-24-92, from Virginia Department of Conservation and Recreation, Division of Natural Heritage). The U.S. Fish and Wildlife Service reviews and updates its lists of species on a regular basis. As more information becomes available on given species, the lists are subject to change.

Table II-10. Federally-listed endangered and threatened species in the Albemarle-Pamlico Study Area.

| SPECIES | FEDERAL STATUS | NORTH CAROLINA COUNTIES IN WHICH SPECIES IS KNOWN TO OCCUR* | VIRGINIA COUNTIES IN WHICH SPECIES IS KNOWN TO OCCUR** |
|---------------------------------|----------------|--|--|
| MAMMALS | | | |
| West Indian (Florida) manatee | E | Hyde | |
| Dismal Swamp southeastern shrew | T | Camden, Currituck, Gates, Pasquotank, Perquimans | Chesapeake, Suffolk, Virginia Beach |
| Red wolf | E | Dare, Tyrrell | |
| BIRDS | | | |
| Roseate tern | E | Offshore Migrant: Carteret, Dare | |
| Bald eagle | E | Beaufort, Carteret, Chowan, Craven, Dare, Durham, Hyde, Vance, Wake, Washington | Isle of Wight, Prince George, Suffolk, Surry |
| Red-cockaded woodpecker | E | Beaufort, Bertie, Camden, Carteret, Craven, Dare, Gates, Halifax, Hertford, Hyde, Johnston, Jones, Lenoir, Nash, Northhampton, Orange, Pamlico, Perquimans, Pitt, Tyrrell, Wake, Wayne, Wilson | Sussex |
| Piping plover | T | Carteret, Currituck, Dare, Hyde | |
| Arctic peregrine falcon | E | Carteret, Dare, Hyde | |
| REPTILES | | | |
| Green sea turtle | T | Beaufort, Bertie, Camden, Carteret, Chowan, Craven, Currituck, Dare, Hyde, Pamlico, Pasquotank, Perquimans | |
| Kemp's ridley sea turtle | E | Beaufort, Bertie, Camden, Carteret, Chowan, Craven, Currituck, Dare, Hyde, Pamlico, Perquimans, Tyrrell, Washington | |
| Leatherback sea turtle | E | Carteret, Currituck, Hyde | |
| Loggerhead sea turtle | T | Beaufort, Bertie, Camden, Carteret, Chowan, Craven, Currituck, Dare, Hyde, Pamlico, Pasquotank, Perquimans, Tyrrell, Washington | |
| American alligator | T S/A | Camden, Darteret, Craven, Dare, Hyde, Jones, Pamlico, Tyrrell | |
| FISH | | | |
| Roanoke log perch | E | | Dinwiddie, Franklin City, Sussex, Sussex/Greenville |

Table II-10. (continued)

| SPECIES | FEDERAL STATUS | NORTH CAROLINA COUNTIES IN WHICH SPECIES IS KNOWN TO OCCUR | VIRGINIA COUNTIES IN WHICH SPECIES IS KNOWN TO OCCUR |
|--------------------------|----------------|--|--|
| MUSSELS | | | |
| Tar River spiny mussel | E | Edgecombe, Franklin, Nash, Pitt | |
| Dwarf wedge mussel | E | Edgecombe, Franklin, Granville, Johnston, Nash, Wake | Nottoway/Lunenburg |
| PLANTS | | | |
| Rough-leaved loosestrife | E | Beaufort, Carteret, Pamlico | |
| Harperella | E | Granville | |
| Michaux's sumac | E | Durham, Franklin, Johnston, Orange, Wake, Wilson | |
| Sensitive joint-vetch | T | Beaufort, Craven, Hyde | Prince George |
| Smooth coneflower | PE | Granville, Durham, Orange | Franklin, Nottoway |
| American chaffseed | PE | | Greensville |
| Seabeach amaranth | PT | | |

* information provided by U.S. Fish and Wildlife Service

** information provided by Virginia Division of Natural Heritage

F.3. State-listed Endangered, Threatened, and Special Concern Species

In North Carolina, species are designated by two different State agencies. The N.C. Wildlife Resources Commission designates animal species and the North Carolina Plant Conservation Program lists and protects plants. The State defines an endangered animal species as any native or once-native species of wild animal whose continued existence as a viable component of the State's fauna is determined to be in jeopardy, or any species of animal listed as endangered pursuant to the Endangered Species Act (North Carolina Natural Heritage Program 1990a). A threatened animal species is defined as a native or once-native species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range, or one that is designated as a threatened species according to the Endangered Species Act. A special concern animal species is a species that is native or once-native to North Carolina which is determined to require population monitoring; individuals of the species may be taken in accordance with regulations (Article 25 of Chapter 113 of the North Carolina General Statutes) (North Carolina Natural Heritage Program 1990a).

The North Carolina Department of Agriculture's Plant Conservation Program lists State-endangered, -threatened, and -special concern plants. A State-listed endangered plant is defined as any plant species whose continued existence as a viable component of the State's flora is determined to be in jeopardy (North Carolina Natural Heritage Program 1990b). Endangered species cannot be removed

from the wild unless a permit is obtained for purposes of research, propagation, or rescue which will enhance the survival of the species. Wild-collected endangered species may not be sold or distributed (North Carolina Natural Heritage Program 1990b). A threatened plant species is defined by the State as any plant species likely to become an endangered species within the foreseeable future (North Carolina Natural Heritage Program 1990b). The State's regulations for threatened plants are identical to those for endangered plants. A special concern plant is defined by the State as any plant species which requires population monitoring, but which may be collected and sold under specific regulations (North Carolina Natural Heritage Program 1990b). Special concern plants which are not also listed as endangered or threatened can be wild-collected and sold under specified regulations. If a special concern plant is also listed as endangered or threatened, only propagated material may be sold or traded under specific regulations.

The definitions and regulations concerning State-listed endangered, threatened, and special concern species may differ slightly between North Carolina and Virginia; however, the Virginia definitions and any differences will not be discussed. As is the case in North Carolina, two Virginia agencies list endangered and threatened species in that state. Animals, except for insects, are listed by the Department of Game and Inland Fisheries, and plants and insects are listed by the Department of Agriculture and Consumer Services, Plant Protection Bureau.

In the North Carolina portion of the A/P Study Area, there are 28 State-listed endangered species (11 animals and 17 plants), 25 threatened species (14 animals and 11 plants), and 20 special concern animals. In the Virginia portion of the study area, there are 9 endangered species (8 animals and 1 plant), 10 threatened species (all animals), and 1 candidate species (there are no species designated as special concern). In addition to the agencies that are responsible for listing and protecting species, the Natural Heritage Program for each state maintains species lists. Updates occur on a regular basis, at least once a year (North Carolina Natural Heritage Program 1990a).

In addition to designating species as endangered, threatened, or special concern, plants, animals, and natural communities can be designated according to their Global status and their State status. However, no legal protection exists for these latter categories. The Nature Conservancy, scientific experts, and the various natural heritage programs together assign species a Global rank (North Carolina Natural Heritage Program 1990 a,b). Global rank 1 (G1) species are defined as being critically imperiled globally because of extreme rarity, meaning that they occur in 5 or fewer places worldwide, or because of some factor(s) making the species especially vulnerable to extinction. Global rank 2 (G2) species are imperiled globally because of rarity, 6 to 20 occurrences or few remaining individuals, or because of some factor(s) making it very vulnerable to extinction throughout its range. In the North Carolina portion of the study area, 13 animals are designated as G1 or G2 species and 31 plants are designated G1 or G2. In the Virginia portion of the study area, 9 animals are designated as G1 or G2 and 16 plants are so designated. In both states, most of these Globally-ranked species are also Federally-listed, State-listed, or State-ranked as S1 or S2.

State ranks are based on The Nature Conservancy's system of measuring rarity and threat status (North Carolina Natural Heritage Program 1990 a,b). In North Carolina, for instance, S1 species are defined as critically imperiled in the state because of extreme rarity, 5 or fewer occurrences or very few remaining individuals, or because of some factor(s) that make the species especially vulnerable to extirpation from the state. S2 species are imperiled in the state because of rarity, 6 to 20 occurrences or few remaining individuals, or because of some factor(s) that make the species very vulnerable to extirpation from the state. In the North Carolina portion of the study area, there are 155 S1 species. In the Virginia portion of the study area, there are 127 S1 species.

F.4. Natural Communities

A natural community is defined as "a distinct and reoccurring assemblage of populations of plants, animals, bacteria, and fungi naturally associated with each other and their physical environment" (Schafale and Weakley 1990). The North Carolina Natural Heritage Program has identified over 100 natural communities in the state; these are described in Schafale and Weakley (1990). As with plant and animal species, natural communities are ranked on Global and State scales; the definitions of G1, G2, S1, and S2 are found in the two previous paragraphs. Of the more than 100 North Carolina natural communities, 65 have been identified in the A/P Study Area. Of these 65 natural communities, 27 are ranked as G1, G2, S1, or S2. Table II-11 lists the natural communities, and their ranks, occurring in the North Carolina portion of the study area. The state of Virginia is currently in the process of classifying and ranking its natural communities.

F.5. Natural Area Inventories

The North Carolina Natural Heritage Program is responsible for maintaining a statewide inventory of important natural areas and rare species habitats, in accordance with the North Carolina Nature Preserves Act (Frost et al. 1990). The Albemarle-Pamlico Estuarine Study is funding the Natural Heritage Program to conduct an inventory to identify, describe, map, prioritize and make protection recommendations for special natural areas and endangered and rare species habitats in the North Carolina portion of the study area (Frost et al. 1990). Typically, the identified natural areas contain one to several natural communities, including those discussed in the previous section (Harry LeGrand, North Carolina Natural Heritage, personal communication 1992). The inventory data are being recorded in the Natural Heritage Program's inventory management system, as well as reproduced in reports.

The North Carolina inventories are being conducted in three phases. The first phase has been completed and the report is available. The field work for the second phase has been completed, but the report has not yet been produced, and the field work for the third phase is currently underway. The counties surveyed for the first report are: Currituck, Camden, Pasquotank, Perquimans, Chowan, Gates, Hertford, Bertie, Martin, and Washington. Those surveyed for the second report are: Hyde, Beaufort, Pitt, Pamlico, Craven, Jones, and Carteret. The third phase of the inventory covers the following counties: Lenoir, Greene, Wayne, Johnston, Wilson, Edgecombe, Northampton, Halifax, Nash, Wake, Franklin, Warren, Vance, Granville, Person, Orange, and Durham. Barrier islands, estuarine islands, and Dare and Tyrrell Counties were not inventoried (Harry LeGrand, North Carolina Natural Heritage, personal communication 1992). The mainlands of Dare and Tyrrell Counties were inventoried for CEIP reports (Coastal Energy Impact Program) in 1982 and 1981, respectively.

Phase 1 of the North Carolina natural areas inventory also identified especially significant wetland ecosystems, or "wetland complexes," in the ten study area counties covered by the survey (Frost et al. 1990). The Natural Heritage Program listed the following as significant wetland complexes: Roanoke River floodplain forests; Northwest River/North Landing River marshes, forests, and pocosins; Great Dismal Swamp forests and pocosins; Chowan River floodplain forests and marshes; North River/Great Swamp floodplain forests and marshes; Lake Phelps and Pungo Lake shoreline forests, marshes, and pocosins; Perquimans/Pasquotank hardwood forests on terrace flats; Merchants Millpond aquatic communities and forests; Maple Swamp and Church Island forests and marshes; Chowan County

Carolina bays; Cashie River floodplain forests; and East Dismal Swamp and Van Swamp forests. Information on individual sites can be found in Frost et al. (1990).

A natural areas inventory is also being conducted for the A/P Study Area in Virginia. The Virginia Department of Conservation and Recreation's Division of Natural Heritage is inventorying natural areas, exemplary wetlands, and endangered species in 16 of the 19 municipalities in the Virginia portion of the study area. The project is being conducted in two phases. The first phase inventoried 6 municipalities: Prince George County; Surry County; Isle of Wight County; Chesapeake City; Suffolk City; and Virginia Beach City (Tom Rawinski, Virginia Division of Natural Heritage, personal communication 1992). The inventory report includes information on 24 natural areas of special significance. The second phase of the Virginia inventory will focus on 10 of the remaining municipalities in the study area. The Division of Natural Heritage plans to have the second phase report completed in the Fall of 1992.

Table II.11. Natural communities in the Albemarle-Pamlico Study Area listed as G1, G2, S1, or S2. North Carolina listing from the N.C. Natural Heritage Program (listing dated 10-91)

| COMMUNITY NAME | STATE RANK | GLOBAL RANK |
|--|------------|-------------|
| Basic Mesic Forest (Coastal Plain subtype) | S1 | G5 T3 |
| Basic Mesic Forest (Piedmont subtype) | S2 | G5 T3 |
| Basic Oak-Hickory Forest | S2 S3 ? | G3 G4? |
| Coastal Fringe Evergreen Forest | S1 | G3? |
| Coastal Fringe Sandhill | S1 | G3 |
| Coastal Plain Marl Outcrop | S1 | G2 |
| Diabase Glade | S1 | G1 |
| Floodplain Pool | S1? | G? |
| Granitic Flatrock | S2 | G3 |
| Interdune Pond | S1 | G3 |
| Maritime Deciduous Forest | S1 | G1 |
| Maritime Dry Grassland | S2 | G3 |
| Maritime Evergreen Forest | S1 | G2 |
| Maritime Shrub Swamp | S1 | G1 |
| Maritime Swamp Forest | S1 | G1 |
| Maritime Wet Grassland | S2? | G3? |
| Nonriverine Swamp Forest | S2 | G2 |
| Nonriverine Wet Hardwood Forest | S1 | G1 |
| Peatland Atlantic White Cedar Forest | S2 | G2 |
| Piedmont/Mountain Swamp Forest | S1 | G2 G3 |
| Pine Savanna | S2 | G3 |
| Small Depression Pocosin | S1 | G2? |
| Small Depression Pond | S2 | G3 |
| Tidal Cypress-Gum Swamp | S2? | G3 |
| Tidal Freshwater Marsh | S2? | G4 |
| Ultramafic Outcrop Barren | S1 | G1 |
| Upland Depression Swamp Forest | S2 | G3 |

"?" indicates community rank uncertain or unranked

"T" indicates the rank of a community subtype

G. SUMMARY

G. 1. Introduction

Critical areas are composed of those biophysical systems which have the greatest impact upon estuarine waters or are otherwise unique or noteworthy. In this study, they have been grouped for convenience under five major headings: submerged aquatic vegetation, emergent vegetation under sea level influence, riparian/alluvial forested wetlands, special fisheries habitats, and other critical areas.

G. 2. Description

Beds of submerged aquatic vegetation (SAV) occupy the shallow water habitat immediately behind the barrier islands and some of the tributaries along the mainland side. SAV distribution varies greatly in space and through time. Near the inlets, in higher salinity water, SAV is composed largely of eelgrass and Cuban shoalgrass. In waters of somewhat lower salinity, widgeongrass may predominate; and in slightly brackish to fresh areas, wild celery, Eurasian watermilfoil, or a mixture of pondweeds and other species may occur. Currituck Sound once contained dense growths of native SAV which were largely replaced by Eurasian watermilfoil during the 1960s and 1970s. The milfoil decreased dramatically during the latter 1970s and was replaced in turn by the native widgeongrass. Similarly, SAV was common in the Pamlico River until the mid-1970s, decreased to about 1% of its former volume by 1985, and has since recovered to some degree.

Emergent wetlands under the influence of sea level (progressing generally from the ocean or inlet landward or upstream) include tidal salt marshes, nontidal brackish marshes, fringe swamps, and nontidal freshwater marsh. Tidal salt marshes, under the direct effect of periodic lunar tides and high salinity water, constitute a rich but severe environment. Few vertebrate species and only one higher plant, salt marsh cordgrass, occur along the lower border of these systems. In terms of fixing solar energy and supporting biomass, however, tidal salt marshes rank among the most productive biotic communities. At slightly higher elevations, where inundation is more irregular, other species of grasses, sedges, and rushes occur and more terrestrial animals may be found. Along major freshwater estuarine tributaries, a fringe of cypress-tupelo swamp separates the aquatic environment from the upland, and pockets of freshwater marsh may be found. In contrast to the few species of plants in salt marshes, this last community contains a rich assemblage of flowering plants. These wetland systems represent the transition area (ecotone) between upland communities and estuarine waters.

Farther up estuarine tributaries, where riverine conditions predominate, ecotones consist of swamps and bottomland hardwood communities. Bald cypress and water tupelo characterize the former, whereas the latter contain many flood-tolerant species. In these systems, riverine flooding replaces the lunar and wind-driven components characteristic of emergent wetlands.

A number of special fisheries habitats overlap with some of the other critical areas. Bay scallops make their homes in beds of eelgrass. Hard clams and oysters are found in relatively stable sediments on vegetated or un-vegetated bottoms. Estuarine nursery areas may include areas of SAV and marsh streams. Anadromous species may spawn in the waters of fringe and riverine swamps.

While their specific functions differ, all the preceding ecosystems are essential to the continued production of estuarine systems and organisms. These wetlands filter sediment and excess nutrients

from overland runoff, provide detritus and other nutrient to the estuaries, serve as water retention areas during floods, and shelter juvenile estuarine and marine organisms within their internal streams and drainageways. Without their continued services, the Albemarle/Pamlico region would cease to be what we cherish today.

Several types of critical areas with less direct ties to the estuaries occur in the region. The beaches, flats, and maritime forests of the barrier islands are essential features of the coastal landscape. The poorly drained peat soils of many of the inter-stream areas support broad-leaved evergreen shrub vegetation. These pocosins are a unique and valuable natural resource, as are the small isolated swamps found in depressions without obvious connections to other surface waters.

G. 3. Status and Trends of Information

While scientists always desire additional and more precise information, a critical area information base sufficient to support an effective management program probably already exists. Critical areas' biotic and abiotic components have been described, their distributions defined, and their relationships to the larger estuarine and marine ecosystems generally ascertained. Most of the descriptive work has been done, and it makes a strong case for preservation of these areas.

The work remaining is largely quantitative and explanatory. Important questions include: What causes the distribution of SAV to vary so widely? What can be done about it? Can the environmental factors limiting the distribution and functioning of these systems be characterized quantitatively? How are riparian and alluvial systems affected by off-site events such as the application of fertilizers and pesticides, flood-control and drainage programs, channelization, and other man-caused and natural phenomena? Perhaps the most important question is: how will all these systems be affected by the various sea-level rise scenarios that have been proposed?

G. 4. Management/Regulatory Status and Trends

As one passes from Navigable Waters of the United States upstream and inland, he encounters a continuum from strong federal involvement and generally effective overall regulation to almost exclusive local control and few restrictions. Construction on lands beneath Navigable Waters of the United States, extending inland to the mean high water line in tidal waters or the ordinary high water line in nontidal areas and including contiguous wetlands, is regulated by the US Army Corps of Engineers under the provisions of the River and Harbor Act of 1899 (33 U.S.C. 401, 403). Dredging in coastal waters also requires a state permit (NCGS 113-22). Upland and inland from this zone, deposition of dredged and fill material in other waters and wetlands without a Corps permit is prohibited by section 404 of the Clean Water Act (33 U.S.C. 1344). Much of the same area is included within Areas of Environmental Concern (AECs) identified by the NC Coastal Resources Commission under the provisions of North Carolina's Coastal Area Management Act (CAMA) (N.C.G.S. 113A-101 et seq.). Development in such areas requires a permit from the NC Division of Coastal Management. Discharge of pollutants into these areas is similarly regulated by a combination of federal and state laws, generally implemented through permits issued by the NC Division of Environmental Management.

However, a number of factors and activities which may have a profound effect on critical areas escape this regulatory matrix. Nutrients, pesticides, and other pollutants currently enter these systems

through diffuse overland flow or other nonpoint sources without regulation (note, however, that section 208 of the Clean Water Act [33 U.S.C. 1288] and section 319 of the Water Quality Act of 1987 address the subject of nonpoint source pollution). Increased runoff from development on upland areas outside of AECs may affect both quantity and quality of waters entering critical areas. Many interior wetlands are not protected against destruction other than direct filling, and neither the state nor the nation has enacted legislation directly addressing the issue of wetland protection.

Laws, regulations, and institutional organizations do not by themselves constitute effective resource management systems. They must have the support of knowledgeable and active citizens, the backing of concerned elected and appointed government officials, staffs of competent public servants, and adequate budgetary support. These may be the most important factors in determining the future of the Albemarle/Pamlico region.

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Appendix A Definitions of Wetlands

The information in items 1,2, and 3 is found in USEPA et al, 1991:

Several definitions of wetlands have been formulated by the U.S. Environmental Protection Agency (USEPA), the U.S. Army Corps of Engineers (USACE), the Soil Conservation Service (SCS), and the U.S. Fish and Wildlife Service (USFWS) in order to carry out their statutory, regulatory, and non-regulatory responsibilities related to wetland protection. The USEPA, USACE, and SCS have adopted regulatory definitions of wetlands (see 40 CFR part 110, 40 CFR part 116, 40 CFR part 117, 40 CFR part 122, 40 CFR part 230, 40 CFR part 232, 40 CFR part 435, 33 CFR part 328, and 7 CFR part 12). USFWS defines wetlands for the purposes of conducting an inventory of the nation's wetland, but this definition is not regulatory.

1. Section 404 of the Clean Water Act - USEPA and USACE Definition

The term wetlands means those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas (USEPA - 40 CFR 230.3; December 24, 1989; USACE - 33 CFR 328.3, November 13, 1986).

2. Food Security Act of 1985 - SCS Definition

Wetlands are defined as areas that have a predominance of hydric soils and that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and under normal circumstances do support a prevalence of hydrophytic vegetation typically adapted for life in saturated soil conditions, except for lands in Alaska identified as having a high potential for agricultural development and a predominance of permafrost soils (7 CFR 12.2 (a)(28)).

3. USFWS Definition - This definition was published in the USFWS publication, "Classification of Wetlands and Deepwater Habitats of the United States" (Cowardin, et al. 1979).

Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification wetlands must have one or more of the following three attributes: (1) At least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil, and (3) the substrate is nonsoil and is saturated with water at some time during the growing season of each year.

An important point to remember is that USEPA, USACE, and SCS definition of wetlands centers on the presence of all three parameters: hydrology, hydrophytic vegetation, and hydric soils, whereas USFWS requires the presence of only one of the three parameters.

4. Definition of Pocosin, as used by Richardson et al. (1981)

Pocosin covered "...a number of subclasses of wetlands found on the coastal plain of the southeastern United States. Specifically, the dominant subclasses from the 1954 classification of the United States Fish and Wildlife Service (USFWS) that were included under the term bog were pond pine wetlands, and scrub/shrub wetlands, along with Atlantic white cedar stands, savannas, and loblolly pine stands on hydric soils." (Richardson 1992)

From Richardson et al. (1981): "...the typical pocosin ecosystem in North Carolina is characterized by the vegetation..." ti-ti, sweetbay magnolia, red bay, ink-berry, greenbrier, and pond pine "...growing on waterlogged, acid, nutrient poor, sandy or peaty soils located on broad, flat topographic plateaus, usually removed from large streams and subject to periodic burning."

Appendix B

Scientific Names of Plants and Animals Referenced in the Wetlands Section and Rare Species and Natural Communities Section of the Status and Trends Report

PART 1. PLANTS

| | |
|-----------------------------|--|
| American beech | <u><i>Fagus grandifolia</i></u> |
| American chaffseed | <u><i>Schwalbea americana</i></u> * |
| American elm | <u><i>Ulmus americana</i></u> |
| American hornbeam | <u><i>Carpinus caroliniana</i></u> |
| Arrowhead | <u><i>Sagittaria</i> spp.</u> |
| Atlantic white cedar | <u><i>Chamaecyparis thyoides</i></u> |
| Bald cypress | <u><i>Taxodium distichum</i></u> |
| Bitter gallberry, ink-berry | <u><i>Ilex glabra</i></u> |
| Black gum | <u><i>Nyssa sylvatica</i></u> |
| Black needlerush | <u><i>Juncus roemerianus</i></u> |
| Broad-leaf cattail | <u><i>Typha latifolia</i></u> |
| Bulrush | <u><i>Scirpus</i> spp.</u> |
| Catbrier | <u><i>Smilax</i> spp.</u> |
| Cattail | <u><i>Typha</i> spp.</u> |
| Chair-maker's rush | <u><i>Scirpus americanus</i></u> |
| Cherrybark oak | <u><i>Quercus falcata</i> var. <i>pagodaefolia</i></u> |
| Chinese privet | <u><i>Ligustrum sinense</i></u> |
| Common pawpaw | <u><i>Asimina triloba</i></u> |
| Fetter-bush | <u><i>Lyonia lucida</i></u> |
| Flowering dogwood | <u><i>Cornus florida</i></u> |
| Giant bulrush | <u><i>Scirpus robustus</i></u> |
| Giant cane | <u><i>Arundinaria gigantea</i></u> |
| Green ash | <u><i>Fraxinus pennsylvanica</i></u> |
| Ground ivy | <u><i>Glechoma hederacea</i></u> |
| Groundsel-tree | <u><i>Baccharis halimifolia</i></u> |
| Harperella | <u><i>Ptilimnium nodosom</i></u> * |
| Hollies | <u><i>Ilex</i> spp.</u> |
| Honeycup | <u><i>Zenobia pulverulenta</i></u> |
| Japanese honeysuckle | <u><i>Lonicera japonica</i></u> |
| Joint-head arthraxon | <u><i>Arthraxon hispidus</i></u> |
| Laurel oak | <u><i>Quercus laurifolia</i></u> |
| Loblolly bay | <u><i>Gordonia lasianthus</i></u> |
| Loblolly pine | <u><i>Pinus taeda</i></u> |
| Longleaf pine | <u><i>Pinus palustris</i></u> |
| Marsh elder | <u><i>Iva frutescens</i></u> |
| Michaux's sumac | <u><i>Rhus michauxii</i></u> * |
| Nepal microstegium | <u><i>Eulalia viminea</i></u> |
| Olney's three square | <u><i>Scirpus olnevi</i></u> |
| Pennywort | <u><i>Hydrocotyle umbellata</i></u> |
| Pond pine | <u><i>Pinus serotina</i></u> |
| Red bay | <u><i>Persea borbonia</i></u> |
| Red maple | <u><i>Acer rubrum</i></u> |
| Riverbirch | <u><i>Betula nigra</i></u> |
| Rough-leaved loosestrife | <u><i>Lysimachia asperulaefolia</i></u> * |
| Salt grass | <u><i>Distichlis spicata</i></u> |
| Salt meadowgrass | <u><i>Spartina patens</i></u> |
| Saw grass | <u><i>Cladium jamaicense</i></u> |
| Sea ox-eye | <u><i>Borrchia frutescens</i></u> |

| | |
|--|--|
| * Federally - listed endangered and threatened species | |
| Seashore mallow | <u><i>Kosteletzkya virginica</i></u> |
| Sensitive joint-vetch | <u><i>Aeschynomene virginica</i></u> * |
| Smooth coneflower | <u><i>Echinacea laevigata</i></u> * |
| Shumard oak | <u><i>Quercus shumardii</i></u> |
| Smartweeds | <u><i>Polygonum spp.</i></u> |
| Smooth cordgrass | <u><i>Spartina alterniflora</i></u> |
| Soft-stem bulrush | <u><i>Scirpus validus</i></u> |
| Sourwood | <u><i>Oxydendron arboreum</i></u> |
| Southern cattail | <u><i>Typha domingensis</i></u> |
| Spikerush | <u><i>Eleocharis spp.</i></u> |
| Sugarcane plumegrass | <u><i>Eriarthus giganteus</i></u> |
| Sugar-berry | <u><i>Celtis laevigata</i></u> |
| Swamp chestnut oak | <u><i>Quercus michauxii</i></u> |
| Swamp cottonwood | <u><i>Populus heterophylla</i></u> |
| Swamp tupelo | <u><i>Nyssa sylvatica var. biflora</i></u> |
| Sweet gallberry, ball-gall holly | <u><i>Ilex coriacea</i></u> |
| Sweetbay magnolia | <u><i>Magnolia virginiana</i></u> |
| Sweetgum | <u><i>Liquidambar styraciflua</i></u> |
| Switch grass | <u><i>Panicum virgatum</i></u> |
| Sycamore | <u><i>Platanus occidentalis</i></u> |
| Ti-ti, swamp cyrilla | <u><i>Cyrilla racemiflora</i></u> |
| Umbrella-sedge | <u><i>Cyperus spp.</i></u> |
| Water hickory | <u><i>Carya aquatica</i></u> |
| Water oak | <u><i>Quercus nigra</i></u> |
| Wax myrtle | <u><i>Myrica cerifera</i></u> |
| Wiregrass | <u><i>Aristida stricta</i></u> |

PART 2. ANIMALS

MAMMALS

| | |
|---------------------------------|--|
| Beaver | <u><i>Castor canadensis</i></u> |
| Black bear | <u><i>Ursus americanus</i></u> |
| Bobcat | <u><i>Lynx rufus</i></u> |
| Dismal Swamp southeastern shrew | <u><i>Sorex longirostris fisheri</i></u> * |
| Hispid cotton rat | <u><i>Sigmodon hispidus</i></u> |
| Marsh rice rat | <u><i>Oryzomys palustris</i></u> |
| Mink | <u><i>Mustela vison</i></u> |
| Muskrat | <u><i>Ondatra zibethicus</i></u> |
| Nutria | <u><i>Myocastor coypus</i></u> |
| Otter | <u><i>Lutra canadensis</i></u> |
| Raccoon | <u><i>Procyon lotor</i></u> |
| Red wolf | <u><i>Canis rufus</i></u> * |
| West indian (Florida) manatee | <u><i>Trichechus manatus</i></u> * |
| White-tailed deer | <u><i>Odocoileus virginianus</i></u> |

BIRDS

| | |
|--------------------------|--|
| Arctic peregrine falcon | <u><i>Falco peregrinus tundrius</i></u> * |
| Bald eagle | <u><i>Haliaeetus leucocephalus</i></u> * |
| Great crested flycatcher | <u><i>Myiarchus crinitus</i></u> |
| Hooded warbler | <u><i>Wilsonia citrina</i></u> |
| Piping plover | <u><i>Charadrius melodus</i></u> * |
| Prothonotary warbler | <u><i>Protonotaria citrea</i></u> |
| Red-cockaded woodpecker | <u><i>Picoides borealis</i></u> * |
| Roseate tern | <u><i>Sterna dougallii dougallii</i></u> * |

* Federally - listed endangered and threatened species

Swainson's warbler *Limnothlypis swainsonii*
Worm-eating warbler *Helmitheros vermivorus*
Wild turkey *Meleagris gallopavo*

REPTILES

American Alligator *Alligator mississippiensis**
Diamondback terrapin *Malaclemys terrapin*
Green sea turtle *Chelonia mydas**
Kemp's ridley sea turtle *Lepidochelys kempii**
Leatherback sea turtle *Dermochelys coriacea**
Loggerhead sea turtle *Caretta caretta**

FISH

Mosquito fish *Gambusia affinis*
Mummichog *Fundulus heteroclitus*
Roanoke log perch *Percina rex**
Sheepshead minnow *Cyprinodon variegatus*
Striped killifish *Fundulus luciae*

INVERTEBRATES

Dwarf wedge mussel *Alasmidonta heterodon**
Fiddler crabs *Uca spp.*
Periwinkle *Littorina irrorata*
Tar River spiny mussel *Elliptio (Canthyria) steinstansana**

* Federally - listed endangered and threatened species

Appendix C

Discussion On Land Use/Land Cover Data For the Entire Albemarle-Pamlico Estuary Study Area, Landsat Data (1988)

The following summary and conclusions were taken from Khorram et al, 1992:

Five Landsat Thematic Mapper (TM) scenes covering 97% of the Albemarle-Pamlico drainage basin were used to classify land use and land cover. Digital TM data were physiographically stratified, converted to a Lambert Conformal Conic projection and classified into 18 classes using a supervised approach and statistics from TM bands 3, 4, and 5 (red, near infrared and middle infrared). Classification accuracies were determined based on 1,931 verification sample sites. Leaf-off conditions and, near the coast, excessive soil moisture limited differentiation of certain vegetation types particularly within the Tidewater region. Mapping accuracies were relatively low for Urban and Built-up land (46%) and ranged from 73% to 97% for five other Level 1 categories (Water, Agriculture, Forestland, Wetlands and Barren Land).

Image data were processed and classified into land use and land cover classes at the Computer Graphics Center (CGC) at North Carolina State University and then transferred to the North Carolina Center for Geographic Information & Analysis (CGIA). At the CGIA, image data were filtered using a standard 5x5 mode filter, converted to the ARC/INFO data format and partitioned by USGS 1:100,000 scale map boundaries. Land use/land cover data and products can be obtained from CGIA by USGS 1:100,000 map windows or by county in a variety of formats. Prospective users need to be aware that these data require large amounts of disk storage. Data are georeferenced to the N.C. State Plan Coordinate System, but, because of their deviation, mapping discrepancies may exist between this data layer and data layers derived from different mapping methodologies.

Overall, Landsat TM data appeared to be a good source of information for large area inventories of land use/land cover patterns. The resultant map products provide the level of detail and accuracy required regional/basin-level analyses for management and research needs.

Recommendations

The following recommendations should be considered during use of the current (1988) land use/land cover inventory:

1. Data are applicable to inventory and research efforts designed to characterize large geographic areas such as the entire Albemarle-Pamlico estuarine system, groups of counties, or basins, but are not appropriate for site-specific evaluations such as characterization of urban infrastructures.
2. Because of the low classification accuracies for developed areas and underestimation of forested wetlands, the estimates of these areas should be considered with great caution. Data on road networks or municipal boundaries can be obtained from alternative sources (USGS DLG files, Bureau of Census TIGER files or CGIA databases can be overlaid with the inventory data to provide quality assurance for developed areas.
3. Users should be aware that data require large amounts of disk storage due to large file sizes. Identification of appropriate hardware needs is recommended before acquisition and manipulation of digital data files.

4. Efficient map production equipment, preferably an electrostatic plotter, is required to produce hard-copy output.

5. In order to adequately monitor land use/land cover activities within the A/P basin, an inventory from satellite data should be conducted every five years. The next database should be developed for 1993 conditions.

The following information was taken from Table 5, Classification Accuracy Estimates, found on page 33 of Khorram et al, 1992. Standard errors, which are indicated within the parentheses (+/-) were calculated for Level 1 categories using a 95% confidence level. The Level I Total column is the standard error for all the categories found in that particular class.

| LEVEL I CLASS | CLASS NAME & NUMBER | LEVEL 1 TOTAL A* | LEVEL 1 TOTAL B** |
|------------------------|---|------------------|-------------------|
| Water | Water / 2 | 99 (+/- 1.24) | 97 (+/- 2.11) |
| Urban or Built-up Land | Low Dev / 3 Med Dev / 4 High Dev / 5 | 76 (+/- 7.35) | 46 (+/- 7.90) |
| Agriculture | Agriculture / 6 Disturbed / 12 | 86 (+/- 3.01) | 93 (+/- 2.30) |
| Shrub/Scrub | Low Vegetation / 7 | 84 (+/- 6.21) | 90 (+/- 5.25) |
| Forest Land | Pine / 8 Hardwood / 10 Mixed / 11 | 89 (+/- 2.51) | 93 (+/- 2.10) |
| Wetland | Bottom HDWD / 9 Riverine / 14 Evergreen / 15 White Cedar / 16 Low Pocosin / 17 Low Marsh / 18 High Marsh / 19 | 89 (+/- 3.15) | 88 (+/- 3.25) |
| Barren Land | Sand / 20 | 100 (-) | 73 (+/- 29.5) |

A* - Percent probability that an area which is actually in class N has been classified as class N on the image; "Producers accuracy".

B** - Percent probability that an area which has been classified as class N on the image actually is class N; "User's accuracy".

Appendix D

Albemarle-Pamlico Study Area Forest Land Information - Forest Inventory and Analysis Data

The following tables and data depicting the status and recent trends of the forested wetlands of the A/P Study Area were drawn from data taken in the 5th and 6th surveys conducted by the Forest Inventory and Analysis Research Unit (FIA). This Research Unit, based in Asheville, North Carolina is a part of the Southeastern Forest Experiment Station of the US Forest Service. The primary objective of the FIA survey is to periodically inventory and evaluate all forest and related resources for the Southeastern States (VA, NC, SC, GA, and FL). Similar units working out of other Experiment Stations are responsible for the rest of the country.

This activity began in 1933 and has been repeated roughly each decade until 1984 when the cycle was reduced to 6 years. Basically the data are drawn from 24,658 forest and 24,807 non-forest permanent ground cluster plots. Since the beginning each successive survey has increased in statistical sophistication, and in the quantity and kind of data taken. Today data are taken on not only the merchantable volume of timber species but upon total biomass of all vegetated strata by species and frequency, and wildlife habitat data. Many non-timber attributes are collected at each sample location.

The 1990 or Sixth Survey for North Carolina was based upon the classification of 128,322 sample clusters systemically spaced and superimposed upon the latest available aerial photographs. Each sample is a systematic grid of 16 points, and each point is used for photo interpretation. A subsample of 9612 of the 16 point clusters was ground checked, and a linear regression was fitted to the data to develop the relationship between the photo and ground classification of the subsample. The procedure provides a means for adjusting the initial estimates of areas for change in land use since date of photography and for photo misclassification. Measurements of timber volume, classification of vegetation, and forest type, and other area attributes were recorded at 5692 on-site sample locations. Ownership information was collected from correspondence, public records, and local contacts. In those counties where the sample missed a particular ownership class, temporary samples plots were added.

All Timberlands, APES Area

Timberland as used herein means "lands at least 16.7 percent stocked by forest trees of any size, or formerly having had such tree cover, not currently developed for non forest use, capable of producing 20 cubic feet or industrial wood per acre per year and not withdrawn from timber production by legislative action."

Survey sample data, drawn from such timberland were processed for the 2870 plots which were located in the 47 county area of North Carolina and Virginia which comprise the APES region. Estimates of total timberland area in the APES area has a sampling error of 0.34 percent in terms of one standard error of estimate. Sampling error of course increases for estimates of area of each smaller subset of conditions. The following tabular information titled "Timberland Area" is drawn from analysis of these data.

Possible Wet Timberlands, APES Area

All timberlands are assigned to one of thirteen physiographic classes based upon soil moisture and drainage, topography, aspect, and soil characteristics. Of these classes in the APES area eight have the potential to include wetlands. The definition of these eight physiographic classes follows:

Flatwoods - Flat or fairly level sites outside the floodplains of rivers and streams. Excludes deep sands as well as wet, swampy sites.

Narrow Floodplains - Floodplains less than 1/4 mile in width along rivers and streams. Consider the floodplain on both sides of the stream in determining the width. These sites are normally well drained but are subject to occasional flooding during periods of heavy or extended precipitation. Includes associated levees, benches, and terraces within a 1/4 mile limit. Excludes swamps and sloughs with year-round water within the 1/4 mile limit.

Broad Floodplains - Floodplains 1/4 mile or wider along rivers and streams. These sites are normally well drained but are subject to occasional flooding during periods of heavy or extended precipitation. Includes associated levees, benches, and terraces. Excludes swamps and sloughs with year-round water.

Other Mesic - All moderately moist physiographic sites not described.

Deep Swamps - Low, wet, flat forested areas, usually quite large in extent, which are flooded for long periods of time except during periods of extended drought. Soil and moisture conditions are generally quite favorable for forest growth of selected species. Excludes cypress ponds and small drains.

Small Drains - Narrow, streamlike, wet strands of forest land often without a well-defined stream channel. These areas are poorly drained or flooded throughout most of the year except during periods of extended drought, and drain the adjacent, higher ground.

Bays and Wet Pocosins - Low, wet, boggy sites characterized by peaty or organic soils. May be somewhat dry during periods of extended drought.

Other Hydric - All other hydric physiographic sites. Includes cypress ponds and other hydric conditions not described by other classes.

Of these eight physiographic forest types four, Deep Swamps, Small Drains, Bays/Wet Pocosins, and other Hydric are clearly, by any rational definition, wetlands. They may or may not be "jurisdictional wetlands", but they are forest habitats wherein a surplus of water, surface or subsurface, plays a dominant role in the formation and perpetuation of the various layers of vegetation. The remaining physiographic classes Flatwoods, Broad Flood Plains, Narrow Flood Plains, and other Mesic are less clear cut. This is particularly true of the Flatwoods.

To estimate the portion of these timberland types which are likely to be wetlands a process was developed by the FIA Unit in Asheville to screen the plot data drawn from such types in the APES area. The screening process to identify the "possible wet" acres within these timber types is as follows:

1. All plots with the physiographic class of deep swamp, small drain, bay and wet pocosin, or other hydric were identified as "possible wet".

2. All North Carolina plots drawn from the physiographic classes of broad flood plain or narrow flood plain which had a forest type classification of loblolly pine, pond pine, oak-pine, oak-gum-cypress, elm-ash-cottonwood, or maple-beech-birch were identified as "possible wet".

3. Any flatwood or other mesic plot where:
 - (a) obligate wetland species exceed 50 percent of the stocking or,
 - (b) both facultative wet and obligate wet species together exceed 50 percent of the stocking or,
 - (c) facultative and wetter species accounted for more than 50 percent of the stocking and there was the presence of surface water or the site was judged to exhibit conditions which limited forest operations due to soil moisture; during sometime of the year, not necessarily the growing season, was identified as "possible wet".

Samples with a humus depth of greater than 9 in. were classified as hydric. Other soils data collected in FIA samples usually are inadequate to determine the presence of hydric soils and were disregarded in the screening process.

The estimates are conservative since small stand conditions less than 1 acre, narrow strands of trees less than 91 feet wide, and some forest such as National parks are not sampled.

While there is clearly opportunity for error in this approach the results are a reliable broad brush estimate of the status of forest land which may be functioning in a wetland role and their very recent trends in the APES area.

The tabular data entitled "Possible Wet" represent the results of this screening process. Complete print out of the FIA data for the APES area for all timberlands and "possible wet" for the 1984 and 1991 surveys, each consisting of 81 tables, are available at the APES Office, 225 North McDowell Street, Raleigh, North Carolina 27603. The telephone number is 919-733-0314.

Additional information on the FIA program may be obtained from Noel Cost of the FIA staff in Asheville at the Southeastern Forest Experiment Station, Forest Inventory and Analysis, 200 Weaver Boulevard, Asheville, NC 28804. The telephone number is 704-257-4350.

**POSSIBLE WET TIMBERLANDS
ALBEMARLE - PAMLICO STUDY AREA
PHYSIOGRAPHIC CLASS BY OWNERSHIP**

| PHYSGRAPH CLASS | PUBLIC | | FOREST IND. | | OTHER PRIVATE | | ALL OWNERSHIP | |
|---------------------------|----------------|----------------|----------------|----------------|------------------|------------------|------------------|------------------|
| | 1984 | 1990 | 1984 | 1990 | 1984 | 1990 | 1984 | 1990 |
| Deep Swamps | 27,198 | 20,903 | 33,119 | 29,964 | 165,807 | 142,379 | 226,124 | 193,246 |
| Broad Flood Plains | 5,568 | 24,064 | 44,984 | 52,728 | 134,305 | 135,218 | 184,857 | 212,010 |
| Narrow Flood Plains | 6,963 | 9,119 | 51,825 | 44,722 | 577,965 | 496,260 | 636,753 | 550,101 |
| Flatwood and Dry Pocosins | 24,464 | 28,981 | 314,063 | 365,971 | 691,591 | 818,594 | 1,030,118 | 1,213,546 |
| Bays and Wet Pocosins | 138,137 | 211,973 | 90,038 | 56,971 | 329,113 | 243,723 | 557,288 | 512,667 |
| Other Misc. Classes | 9,129 | 17,623 | 17,690 | 32,343 | 68,429 | 99,274 | 95,248 | 149,240 |
| TOTAL | 211,459 | 312,663 | 551,719 | 582,699 | 1,967,210 | 1,935,448 | 2,730,388 | 2,830,810 |

Note:

- (1) Although only 10.9 percent of the total is in public ownership over 41 percent of the bays and wet pocosins which support timberland are in public ownership.
- (2) The extremely large shifts of acreage both within and between classifications is probably due to sampling error and to changes in identification more than to actual increase or decrease in timberlands.
- (3) Descriptions of physiographic classes may be found on page ___ of this appendix.

**POSSIBLE WET TIMBERLANDS
BROAD MANAGEMENT CLASS BY OWNERSHIP
ALBEMARLE - PAMLICO ESTUARINE STUDY AREA**

Acres By Class By Survey Year

| OWNERSHIP | PINE PLANTATION | NATURAL PINE | OAK-PINE | UPLAND HRDWOOD | LOWLAND HRDWOOD | ALL MNGMENT CLASSES |
|----------------------|-----------------|--------------|----------|----------------|-----------------|---------------------|
| PUBLIC | | | | | | |
| 1984 | 5,369 | 80,318 | 33,937 | 4,520 | 87,315 | 211,459 |
| 1990 | 1,567 | 32,260 | 33,129 | 1,729 | 143,978 | 312,663 |
| FOR. INDUSTRY | | | | | | |
| 1984 | 146,058 | 117,615 | 33,677 | 31,144 | 223,225 | 551,719 |
| 1990 | 197,677 | 83,864 | 47,833 | 35,398 | 217,927 | 582,699 |
| OTHER PRIVATE | | | | | | |
| 1984 | 42,637 | 372,262 | 206,677 | 193,207 | 1,152,427 | 1,967,210 |
| 1990 | 96,399 | 287,796 | 238,140 | 214,662 | 1,098,451 | 1,935,448 |
| ALL OWNERSHIP | | | | | | |
| 1984 | 194,064 | 570,195 | 274,291 | 228,871 | 1,462,967 | 2,730,388 |
| 1990 | 295,643 | 403,920 | 319,102 | 251,789 | 1,460,356 | 2,830,810 |

**POSSIBLE WET TIMBERLANDS
ALBEMARLE - PAMLICO ESTUARINE STUDY AREA
OPERABILITY CLASS**

| OPERABILITY CLASS | TIMBERLAND AREA (acres) 1984 | TIMBERLAND AREA (acres) 1990 |
|-------------------------------|------------------------------|------------------------------|
| Seasonal Water ¹ | 1,065,178 | 1,118,410 |
| Mixed Wet & Dry ² | 52,174 | 48,229 |
| Year Round Water ³ | 312,736 | 315,704 |
| Total | 1,430,088 | 1,482,343 |

1. Limited to seasonal use due to water conditions in wet weather.
2. Mixed wet and dry areas within forest condition typical of multi-channeled streams with intermixed dry areas or islands.
3. Adverse operating conditions caused by year round water problems.

**POSSIBLE WET TIMBERLANDS
ALBEMARLE-PAMLICO SOUND STUDY AREA**

Acres* Treated or Disturbed Annually

| Treatment or Disturbance | 1984 Acres | 1990 Acres |
|---------------------------------|-------------------|-------------------|
| Final Harvest | 56,393 | 81,839 |
| Partial Harvest ** | 13,020 | 6,158 |
| Commercial Thinning | 2,755 | 4,811 |
| Other Stand Improvement | 3,170 | 1,524 |
| Site Preparation | 28,750 | 37,227 |
| Artificial *** Regeneration | 22,594 | 29,669 |
| Natural *** Regeneration | 21,677 | 43,488 |
| Other Treatment | 5,533 | 7,952 |
| Natural Disturbance | 37,899 | 33,235 |

* Many acres experience more than one treatment or disturbance during a remeasurement period, E.G., final harvest, site preparation, artificial regeneration, hence the individual treatments or disturbances are not totaled.

** Includes high grading and some selective cutting.

*** Includes establishment of trees for timber production on forest and nonforest land.

**POSSIBLE WET FIA DATA
ALBEMARLE-PAMLICO STUDY AREA
PERCENT SAMPLING ERROR**

| CATEGORY | 1984 | 1990 |
|----------------------------|-------------|-------------|
| Deep Swamps | 1.99 | 2.15 |
| Broad Flood Plains | 2.20 | 2.05 |
| Narrow Flood Plains | 1.19 | 1.27 |
| Flatwoods and Dry Pocosins | 0.87 | 0.86 |
| Bays and Wet Pocosins | 1.27 | 1.32 |
| Other Mesic and Hydric | 3.04 | 2.44 |
| | | |
| Softwood Plantations | 2.15 | 1.73 |
| Natural Pine | 1.25 | 1.33 |
| Oak Pine | 1.81 | 1.67 |
| Upland Hardwood | 1.98 | 1.88 |
| Lowland Hardwood | 0.78 | 0.78 |
| | | |
| Seasonal Water | 0.91 | 0.89 |
| Mixed Wet and Dry | 4.14 | 4.29 |
| Year Round Water | 1.69 | 1.68 |
| All of Above | 0.79 | 0.77 |

**ALBEMARLE-PAMLICO ESTUARINE STUDY AREA
SUMMARY STATISTICS**

| CATEGORY | 1984 | 1990 | % CHANGE 1984-1990 |
|-----------------------------------|-----------|-----------|-----------------------|
| All Timberlands | 7,739,628 | 7,697,488 | -0.5 |
| All Possible Wet Timberlands | 2,730,388 | 2,830,810 | +3.6 |
| All Pine Plantations | 1,072,442 | 1,422,340 | +32.6 |
| All Possible Wet Pine Plantations | 194,064 | 295,643 | +52.3 |
| All Natural Pine | 1,889,188 | 1,668,983 | -11.6 |
| All Possible Wet Natural Pine | 570,195 | 503,920 | -11.6 |
| All Oak-Pine | 1,045,537 | 1,086,923 | +3.9 |
| All Possible Wet Oak-Pine | 274,291 | 319,102 | +16.3 |
| All Upland Hardwood | 2,036,741 | 1,870,657 | -8.1 |
| All Possible Wet Upland Hardwood | 228,871 | 251,789 | +10.0 |
| All Lowland Hardwood | 1,695,720 | 1,648,585 | -2.8 |
| All Possible Wet Lowland Hardwood | 1,462,967 | 1,460,356 | -0.2 |

III. WATER QUALITY

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A. WATER QUALITY ISSUE IDENTIFICATION

A. 1. Freshwater Drainage and Estuarine Circulation

There are five major hydrologic pathways by which water and chemical constituents can enter the Albemarle-Pamlico (A/P) system. These pathways are (1) atmospheric deposition, (2) direct discharge of waste materials into the estuary, (3) inflow through tidal inlets, (4) groundwater discharge to the system, and (5) surface drainage via tributaries and runoff. Within the estuaries, physical and chemical transformations also occur that may effectively remove certain constituents from the water or may release substances which were previously biologically unavailable.

The primary focus of this section is surface drainage of freshwater into the Albemarle-Pamlico system. Riverine inflows and local, or nonpoint-source, inputs from lands surrounding the estuarine waters are discussed separately. Surface drainage processes are physically linked to hydrologic-transport mechanisms within the estuaries -- mechanisms which affect essentially all of the physical and chemical processes and many of the biological processes occurring in the sounds. Consequently, discussion of estuarine transport, particularly the mixing of fresh and brackish water, in the context of surface drainage, is also warranted.

Groundwater discharge directly into the estuaries and tidal exchange through inlets are important hydrologic processes affecting Albemarle-Pamlico water quality, however, there is essentially no available information on these processes for the system. A Sea Grant study currently underway in Oregon and Ocracoke Inlets may provide this information (Dr. L.J. Pietrafesa, NC State University, Personal Communication), however, the discussion of groundwater contributions to the Albemarle-Pamlico System and of tidal exchange through the inlets in this presentation is quite limited. Atmospheric deposition of chemical constituents is discussed in Section A.2. Metals and toxins are discussed in A.3. Sediments are discussed in A.4. Information on point source discharges is presented in Section A.5.

A. 1. a. Riverine Issues. Maintenance of an acceptable level of estuarine water quality is dependent, to a large extent, upon the quality of the inflowing rivers. Rivers supply the estuary with freshwater, nutrients, sediment, and other substances. The proper balance of riverine inputs and ocean water produces a setting which is favorable for living resources. Estuarine water quality management must involve knowledge and management of these riverine inputs.

Freshwater is the most important product that upland rivers supply to the estuary. Temporal variations in riverine inputs determine the spatial patterns of salinity and water density in the estuary. These, in turn, control the longitudinal patterns of distribution of plants and animals, the vertical patterns of dissolved oxygen, and other important characteristics of the estuary. Water transports, in solution, in suspension, and along the stream bed, a variety of substances that govern estuarine water quality. There are several important issues related to riverine freshwater inputs and sound water quality management. Some of these issues have been addressed to the extent that current information is useful for management decisions:

1. The seasonal and geographic distributions of freshwater inflows to the estuaries are important for determining constituent loadings, evaluating water budgets, estimating the duration and extent of salinity intrusion, managing the fishery resource, etc.
2. Information on the relation between upstream river flows and the potential for the occurrence of estuarine algal blooms may be used for variable-discharge permitting of point-source discharges.

3. An understanding of the relation between river flow and inputs of sediments and chemical constituents is important for managing upstream inputs and estuarine wasteload allocations. Infrequent, high-flow events, in particular, may remove large amounts of sediment and associated constituents from storage in the rivers and transport them into the estuaries. (Simmons 1988)
4. Flow diversion and management of reservoir releases are significant issues in the Roanoke and Neuse River basins. The existence of major reservoirs in those basins offers possibilities for flow regulation to enhance water quality and fishery resources if the relationship between flow and other processes are well established.
5. Watershed modeling has been attempted in the Chesapeake basin. This capability may allow the evaluation of the cumulative effects on the estuaries of upland land-use conversions and land management strategies. Physical and chemical modeling of rivers would also be required to link upland surface drainage processes to estuarine inputs.

A. 1. b. Local Drainage Issues. The Albemarle-Pamlico estuarine system has an extensive shoreline. Lands along this shoreline support a number of uses including agriculture, silviculture, residential and urban development, and marina operations. Investigations over the last 15 to 20 years have established that drainage from urban and agricultural lands can significantly contribute to the degradation of rivers and streams (Paerl 1983).

Tributary freshwater inflow rates can exert a direct influence on Albemarle-Pamlico water quality, apart from chemical constituents carried by the inflows. For example, the increase of low flows from the Roanoke River above natural conditions has apparently resulted in a decrease in the magnitude and frequency of saltwater intrusion into western Albemarle Sound (NC Division of Environmental Management 1982). The decrease in saltwater intrusion may, in turn, have resulted in an increase in nuisance algal blooms in the area (NC Division of Environmental Management 1982). This relation has been documented by Christian et al. (1986) who showed that the occurrence of blue-green algal blooms in the Neuse River estuary was directly related to Neuse River flow rates.

Much of the land surrounding the Albemarle-Pamlico estuary must be drained to accommodate agriculture, silviculture, and other types of development due to a naturally high water table, relatively high rainfall (between about 50 and 55 inches per year, depending upon location), and the flat terrain of the region. More than 20 miles of field ditches, collector canals and main canals are typically present in each square mile of agricultural land (Heath 1975; Daniel 1978). The ditches, designed to remove runoff from a 2 inch rainfall within 24 hours (Heath 1975), may increase the rate and volume of runoff (Skaggs et al. 1980; Daniel 1981).

There is some argument about long-term and undesirable decreases in salinity of the tidal creeks and bays resulting from the increased drainage. Sholar (1980), for example, estimated that salinity in northwestern Pamlico Sound decreased at an annual rate of about 0.2 ppt between 1948 and 1980. On the other hand, between 1968 and 1986, Stanley (1988b) detected a slight increase in surface salinity near the mouth of the Pamlico River and a decrease of about 0.13 ppt per year in the bottom salinity near the mouth. Most of these changes appear to have occurred between 1968 and 1975.

In contrast to the estuaries of Texas and California, in which hypersaline conditions often exist, parts of the Albemarle-Pamlico estuarine system appear to be affected by excessive rates of freshwater inflow, especially during the spring. For example, Pate and Jones (1981) linked the impairment of nursery area function to high freshwater inflow rates associated with artificial drainage ditches. Important issues concerning local drainage of freshwater into the estuaries include the following items:

1. Rate measurements, including temporal and spatial variations, of freshwater drainage from various land uses around Albemarle-Pamlico waters are required for many of the same reasons that riverine inflows are needed. The effect of land use, artificial drainage, channelization, and water-control practices on drainage to estuarine waters will allow better informed management of land use conversion activities and management of existing drainage systems.
2. Effects of freshwater drainage, from both altered and natural areas, on the salinity regime of receiving waters may be used to evaluate the effect of existing drainage outlets, to manage pumped-drainage systems and to better protect important nursery areas.
3. Identification of lands and nursery areas of significance and areas which would suffer major adverse effects from drainage activities, along with a solid basis from which to evaluate the effects of drainage on receiving waters, is also vital to the protection of aquatic living resources.
4. If areas of ecological or economic significance are found to be adversely affected by drainage activities, mitigation of the effects or restoration of altered lands may be an option. Information on expected benefits of such mitigation/restoration activities, plus the cost of mitigation/restoration, will allow more informed decisions to be made.
5. Effects of a single land use conversion or drainage activity within a small area on receiving waters are certainly difficult to quantify. Yet, management decisions require information on the net, or cumulative, effect of numerous small, individual changes on overall receiving water quality.
6. Global climate change and the related sea-level rise are topics of intense scientific speculation and discussion. Because of the low elevations and flat terrain of the Albemarle-Pamlico shoreline, sea-level rise would have a dramatic effect on the entire estuarine system, including freshwater drainage processes.

In Back Bay, Virginia, there has been concern over the local (and usually short-term) effects of the saltwater pumping operation at Little Island, a project that was designed to have counteracted the effects of the construction of a line of dunes (the dunes have successfully prevented overwash events from occurring for nearly 20 years, and so have altered the salinity of Back Bay). A significant saltwater plume, however, was produced, the adequate dispersion of which was dependent upon wind-driven tides, and the flushing regime of the Bay was altered. Operations of the station were recently brought to an end in the midst of much controversy over the desired character of the waterbody.

A. 1. c. Estuarine Transport Issues. Riverine inflows and local drainage waters are mixed by hydrodynamic and transport processes within the estuary. These processes also directly or indirectly affect, among other things, the re-suspension, transport, and deposition of sediments, advection and mixing of dissolved substances, exchange of oxygen and volatile organics across the air-water interface, the formation and movement of algal blooms, and the movement of the larval stages of several fish and shellfish species.

In general, estuarine transport rates cannot be determined directly except over a small area for a short period of time. The usual procedure is to measure tidal elevations, wind speed and direction, inflow rates, and the upstream and downstream salinity variation over time. These data are utilized, along with information about bathymetry, to compute transport rates throughout some region of interest. Short-term measurements of velocity fields may be used to insure that the computations provide reasonable results for the conditions under which the measurements were made.

A. 1. d. Availability of Information. Williams et al. (1973) stated, "Bits of information on currents, salinities, temperatures, effects of storms, and other events (including engineering projects) are scattered widely in the literature, from historical narratives to modern scientific papers, but effective physical description of these bodies of water has seldom been accomplished." This 18-year-old statement about the Albemarle-Pamlico system is still generally true. Most of the existing data for the Albemarle-Pamlico estuarine system is, by virtue of the objectives and methods of the data collection, more suited for analysis of processes occurring under a particular set of circumstances than for use in the assessment of temporal and spatial trends. Bales and Nelson (1988) compiled a bibliography of works concerning hydrology and water quality in the Albemarle-Pamlico region, which is useful for identifying available data.

Freshwater inflows to the Albemarle and Pamlico sounds are gaged by the US Geological Survey (USGS). Ragland et al. (1987) summarized the existing USGS stream-gaging network in North Carolina, however, most of the gaging stations are located well upstream of the mouths of the Albemarle-Pamlico tributary rivers. Flow from about 63% of the 4,940 square-mile Roanoke River basin is measured; flow from only about one-half of the 4,300 square-mile Tar-Pamlico River basin and the 5,600 square-mile Neuse River basin is gaged. In addition a few of the smaller tributaries to the sounds are gaged, but in general, freshwater inflow rates to the Albemarle-Pamlico system are not well defined.

Based on frequency curves for annual mean discharge (Wilder et al. 1978) of the Blackwater, Roanoke, Tar, and Neuse Rivers, there is a 50% chance that annual mean flow in any year will be 0.8 cfs/sq mi or less in the Blackwater and Roanoke Rivers. The comparable flows for the Neuse and Tar Rivers, on the other hand, are about 1.05 cfs/sq mi. Low flow frequency values were similar for all streams except the Roanoke (Wilder et al. 1978). Natural flows in the Roanoke are augmented by releases from Kerr and Gaston Reservoirs. During 30-day, 10-year low flow conditions (flows which are not exceeded for 30 consecutive days and occur, on the average, once every 10 years) about 75% of the total inflow to the Albemarle-Pamlico estuarine system consists of flow from the Roanoke River basin, which constitutes only about 48% of the total Albemarle-Pamlico drainage basin.

Historical tidal-elevation records exist for numerous sites around the Albemarle-Pamlico estuarine region. A synoptic array of tidal-elevation gages was installed along the Pamlico and Neuse Rivers during February 1988 by the US Geological Survey (Figure III-1) and in Albemarle Sound in 1990. US Army Corps of Engineers' (COE) needs are typically project-specific and, as a consequence, COE gages tend to be short-duration installations. Short-duration historical records also exist from numerous National Ocean Service (NOS) gages in North Carolina. Chronologies of COE and NOS tidal-elevation stations are available. About 6 years of record for eight sites located on the Chowan River are also available for the late 1970s and early 1980s (Daniel 1977). In addition, tidal-elevation data, with periods of record on the order of months, have been obtained by other researchers, such as Pietrafesa et al. (1986). Useful publications for tidal information include the following tide tables published annually by the US Department of Commerce: NOS publications "Index of Tide Stations, United States of America and Miscellaneous Other Locations", "Sea Level Variations for the United States 1985-1980 (Annual Revision)", "Products and Services Handbook", Ho and Tracey (1975), Harris (1981) and Ebersole (1982).

By contrast, there have been relatively few measurements of tidal velocity in Albemarle-Pamlico estuarine waters. One potential difficulty with utilizing much of the available velocity data is that important ancillary information, such as tidal stage, salinity, and wind field, were not obtained in conjunction with velocity measurements. Several sets of velocity measurements have been taken at Oregon Inlet and Ocracoke Inlet (Giese et al. 1985). These COE data typically were taken at various times throughout a single tidal cycle. One set of velocity data was collected at Hatteras Inlet during flood flow.

Dye releases for the measurement of time of travel have been made in the Chowan River (Daniel 1977), the Neuse River (Woods 1969; Christian et al. 1986), and the Pamlico River (Horton et al. 1967).

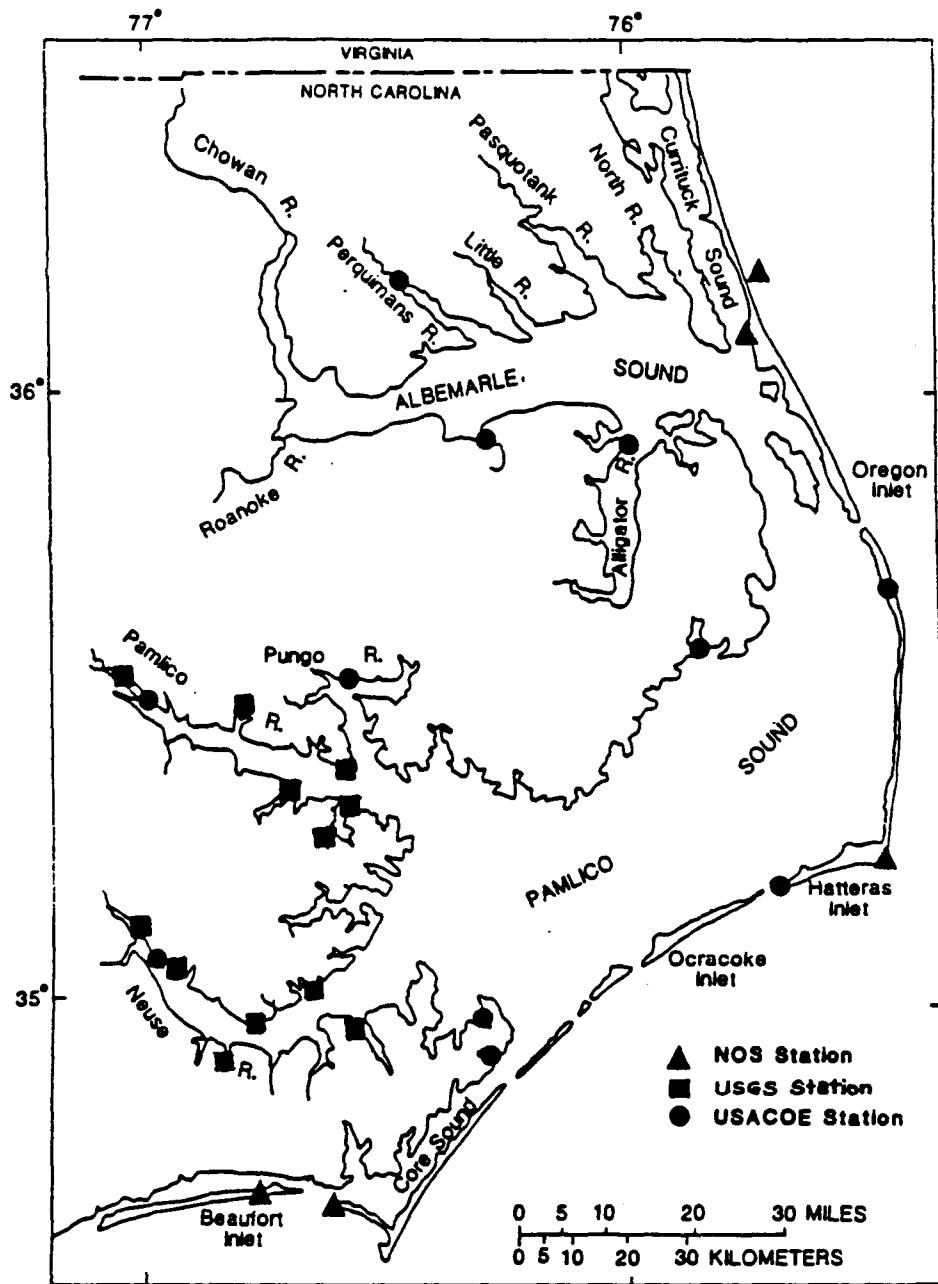


Fig. III-1. Tidal Elevation Gage Sites in the Albemarle-Pamlico Estuarine System, March 1989. From J.D. Bales, USGS, Personal Communication.

Instantaneous discharge measurements were made in the upper reaches of the tide-affected portion of the Chowan River (Jackson 1968). Longer term velocity data were obtained from seven recording velocity meters that were moored in the Neuse River for 38 days (Knowles 1975). Perhaps the most comprehensive set of hydrodynamic data were obtained from seven moored, recording velocity meters, two tidal-elevation gages, and five thermographs located near Oregon Inlet (Singer and Knowles 1975).

Salinity is physically linked to the flow field by the pressure gradients generated from the salt distributions, yet, salinity has typically been measured as a conservative tracer (i.e., without regard to flow conditions), which renders the data of little use for assessing transport processes. In addition, salinity fluctuations are so rapid, great, and erratic that samples collected at monthly, or even daily, frequencies may only be suitable for obtaining seasonal trends.

Giese et al. (1985) provided a detailed analysis of historical data on saltwater intrusion in Albemarle-Pamlico tributary rivers. Summaries of Albemarle-Pamlico estuarine system salinity data have been given by Marshall (1951), Roelofs and Bumpus (1953), Hobbie (1970b), Schwartz and Chestnut (1973), Williams et al. (1973), and Sholar (1980). Salinity distributions were observed in Albemarle Sound and the Chowan River for several months in 1981 and 1982 and have been reported, along with estimates of the frequency of occurrence of various salinities in Albemarle Sound (NC Division of Environmental Management 1982). Based on several years of observations, Wilder et al. (1978) developed cumulative frequency curves of specific conductance for sites on the Pasquotank, Perquimans, Chowan, Scuppernong, Pamlico and Neuse Rivers, and Albemarle Sound. Singer and Knowles (1975) obtained some vertical profiles of salinity with their velocity data measured near Oregon Inlet.

Despite the polymictic nature of the Albemarle-Pamlico estuarine system, periodic vertical salinity and/or thermal stratification occurs (on an hourly to daily basis) and occasionally persists for days or weeks in the central basins and main stems of tributaries and estuaries (Matson et al. 1983; Paerl et al. 1984). Significant hypoxia/anoxia can accompany stratification and salt wedges which may extend up into ordinarily highly productive meso- to oligohaline segments of slow-moving rivers (Chowan, Pamlico, Neuse). During these events deposited organic matter is entrained and rapidly decomposed and converted to inorganic nutrients (including phosphates and ammonia) in hypolimnetic, near-bottom, saline waters. Salt wedges are not permanent features; hence, regenerated inorganic nutrients are eventually redistributed and assimilated by photosynthetic primary producers throughout the shallow water column.

Giese et al. (1985) used long-term records at the downstream-most gaging stations and drainage-area ratios to develop a gross monthly water budget for Albemarle and Pamlico Sounds (Tables I-3 and I-4). Pietrafesa et al. (1986) also developed a gross monthly water budget for Pamlico Sound, which is similar to that of Giese et al. (1985). Likewise, a similar water budget was also developed for Albemarle Sound by the NC Division of Environmental Management (1982).

For the period 1970-1988 Harned and Davenport (1990) found a statistically significant increase in salinity in the upper Pamlico River, in the central portion region of Albemarle Sound, and in the Pasquotank River. A decline in salinity was found in the lower Pamlico River. No statistically significant trend in salinity was found elsewhere in the Albemarle or Pamlico sounds or tributaries. Data from National Weather Service meteorological stations are published monthly in the National Oceanographic and Atmospheric Administration (NOAA) report "Climatological Data -- North Carolina" and are stored at the National Climatological Data Center in Asheville, North Carolina. Meteorological data are also recorded at the Cherry Point Marine Corps Air Station (MCAS) and at several of the US Coast Guard stations in the region. USGS is measuring windspeed and direction at three open water sites in support of hydrodynamic modeling activities. Analysis of long-term meteorological data has been provided by, among others, Carney and Hardy (1967) and Pietrafesa et al. (1986).

A. 1. e. Extent and Status of Understanding. The hydrology of the Albemarle-Pamlico Estuary, particularly the wetlands and artificially drained lands, is quite complex. Moreover, the natural hydrology of much of the region has been altered by construction of vast networks of drainage ditches and canals (Heath 1975). It had been speculated that artificial drainage activities would not significantly alter the annual water budget (Heath 1975); the primary effect, it was assumed, would be a slight increase in surface runoff as a result of a lowering of the water table. Indeed, recent investigations reveal that annual surface runoff from drained agricultural lands in the Albemarle-Pamlico region exceeds runoff from undisturbed lands by about 10% (Skaggs et al. 1980; Daniel 1981; Gilliam et al. 1985). This increase in runoff was attributed to the difference in evapotranspiration rates between agricultural and natural lands (Gilliam et al. 1985).

The effect of artificially drained systems on runoff from individual events is apparently more pronounced than changes in the annual water budget (Skaggs et al. 1980; Daniel 1981; Gregory et al. 1984). Peak outflow rates tend to occur sooner and be of greater magnitude on lands with man-enhanced drainage than on natural lands (Skaggs et al. 1980; Gregory et al. 1984).

Some results from investigations in the Coastal Plain of the effects of stream channelization on flows and the lowering of water tables may be extrapolated to describe changes that might occur because of artificial drainage. Both maximum and minimum rates of flow are typically more extreme as a result of channelization (Figure III-2), but the total annual runoff volume appears to change very little from natural conditions (Winner and Simmons 1977; Gregory et al. 1984). Lowering natural water tables by artificial drainage also reduces recharge to the deep aquifers; thus, saltwater encroachment into the deep aquifer, which is a continuing process, may be increased (Heath 1975).

"Drainage density" is the ratio of total length of all stream segments in the basin to the basin area. Drainage density indicates the efficiency with which water is removed from an area by surface runoff. Drainage densities are about 2.5 miles per square mile for the Piedmont and about 1.5 miles per square mile for undisturbed Coastal Plain lands (Heath 1975). By comparison, artificial drainage systems in lands between Albemarle and Pamlico Sounds typically have about 20 miles of channel per square mile of basin. There is some argument about whether artificial drainage has resulted in long-term and undesirable decreases in salinity of receiving waters. It has been estimated that freshwater drainage from the Albemarle-Pamlico peninsula accounts for about 6% of the inflow to Albemarle Sound and about 8% of the inflow to Pamlico Sound (Heath 1975). Consequently, drainage activities probably do not significantly affect overall salinities in the sounds. Artificial drainage does, however, under certain meteorological conditions, result in changes to the salinity regime in small tidal creeks and bays (in many cases the end points for drainage canals) (Overton et al. 1988).

In addition to carrying fresh water to the sounds, drainage ditches and canals also act as conduits for the upstream movement of brackish water. Because the bottoms of many ditches and canals are below sea level, estuary water may move inland, particularly during periods of low freshwater runoff. Many low-lying areas, which were once agriculturally productive, have become contaminated by salt as a result of the movement of salt water inland through the canals. The onset of the anticipated increase in the rate of sea-level rise will likely focus greater attention on this process. Water control structures placed in drainage ditches allow the land user to exert some control over the level of the water table in fields. This process can result in more efficient drainage and may improve water quality draining to receiving waters. Two studies, currently underway, should result in better understanding of the effects of water-control structures on off-site water quality (Dr. Wayne Skaggs, NC State University; Dr. Jerad Bales, US Geological Survey).

There have been several efforts to investigate various aspects of artificial drainage and salinity changes in receiving waters. In a study of tributary tidal creeks to South River, Kirby-Smith and Barber (1979) found that drainage from Open Ground Farm sometimes decreased surface salinities, but that the bottom salinities were unaffected. Drainage from Mattamuskeet Canal lowered surface salinities in the

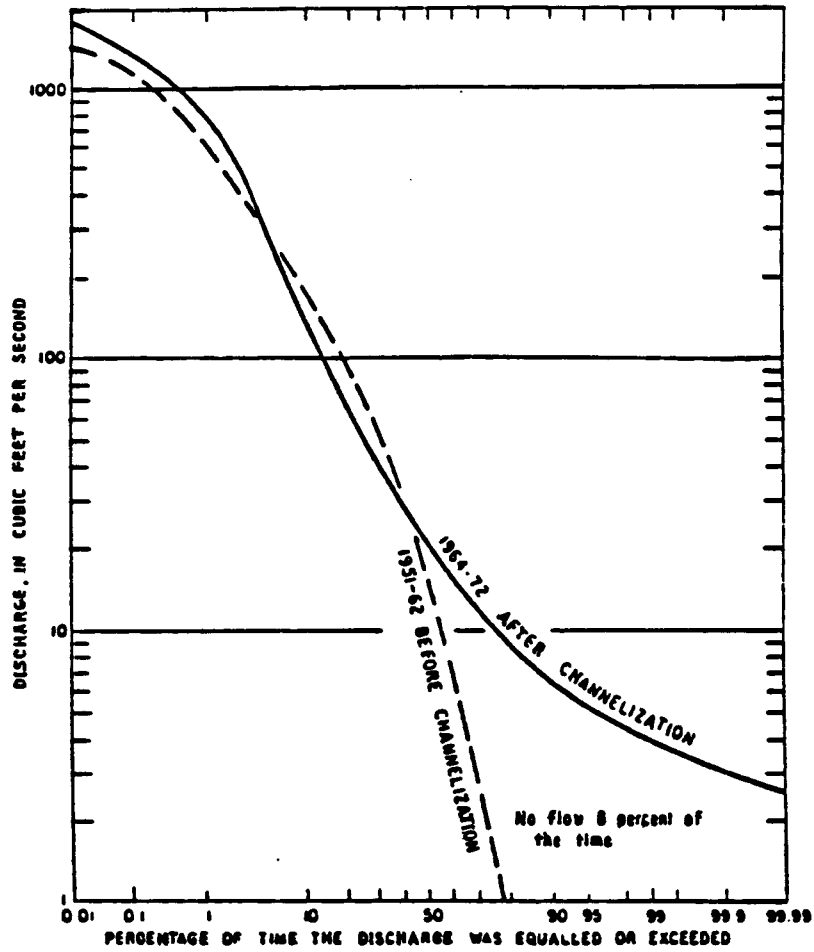


Fig. III-2. Flow Duration Curves for Ahoskie Creek at Ahoskie Before and After Channelization. From Winner and Simmons (1978).

upper portions of Rose Bay (Gilliam et al. 1985), but salinity at the mouth of Rose Bay appears to be controlled by wind-induced circulation and tidal exchange processes. Salinity in Broad Creek changed in response to the changing availability of freshwater, a product of winds pushing saltier water away from the canal (Overton et al. 1988). The effects of freshwater drainage and the associated salinity changes on the living resources of nursery areas are not entirely clear.

Controlled drainage affects both nitrate and phosphorus losses from agricultural fields. Nitrate export is reduced by as much as 50% when a high water table is maintained in the field by placing a control structure across the field ditch outlet. This reduction is due to a greater opportunity for denitrification (which occurs in anaerobic environments) in a saturated soil profile (Gilliam et al. 1978). While nitrate export may be decreased by controlled drainage, losses of organic nitrogen may be increased, and organic nitrogen is less biologically available than nitrate (Gilliam et al. 1985). On the other hand, because there is less water storage capacity in the more saturated soil, surface runoff and associated sediment and phosphate loads may be increased with the use of drainage control, especially in comparison to fields with well-drained soils or with good subsurface drainage systems.

Improved subsurface drainage may be the most effective method for reducing peak outflow rates in drainage ditches (Gilliam et al. 1985). Water is stored in the soil and is released slowly by evapotranspiration and/or lateral movement to drainage ditches. Recent results indicate that total nutrient export from agricultural fields is affected more by the drainage outflow volume than by the type of drainage system present in the field (Evans et al. 1987).

A cooperative investigation of the off-site effects of water control structures on the flow and water conditions of canals in Hyde County is currently being undertaken by the US Geological Survey and NC Division of Environmental Management (Dr. Jerad Bales, US Geological Survey; Personal Communications). Preliminary data indicate that fresh water may be released more slowly from ditches controlled by tidegates than from uncontrolled ditches (Figure III-3). Mean salinity in the tidegate controlled canal was 3 ppt. compared with a mean of roughly 5 ppt. of adjacent canals under uncontrolled conditions. Salinities of greater than 18 ppt. were observed in the uncontrolled Hyde County canals (Treece and Bales, 1990). There is widespread recognition that additional assessment of off-site effects of water control structures is needed. The Albemarle-Pamlico Estuarine Study Work Plan accorded high priority to the need to evaluate "best management practices" in coastal situations. Proper implementation of control strategies will depend on these types of evaluations. It is of equal priority to gain an understanding of the off-site effects of agricultural water management. "Research in this area [off site effects] needs to be significantly increased if we are to be successful in designing and managing systems to satisfy both agricultural and off site objectives" (Skaggs, 1987).

A. 2. Nutrients

A. 2. a. Eutrophication. Nutrient loading is the process that usually controls the rate at which primary production increases in water bodies. Eutrophication is the process by which excessive nutrient loading causes an array of symptomatic changes in a water body among which are high rates of primary production and high levels of algal biomass. From a management perspective, eutrophication is frequently equated with the rate at which fertility increases and the manifestation of such increases in terms of water quality. Primary production is the biochemical conversion of inorganic carbon (CO₂) into organic matter, a process mediated by photosynthetic and chemosynthetic microorganisms and higher plants in aquatic ecosystems. In essence, this process represents the initial input of organic matter at the base of the food chain, supporting all higher ranked consumers of organic matter, ranging from simple heterotrophic bacteria and fungi to invertebrates, fish and, ultimately, man.

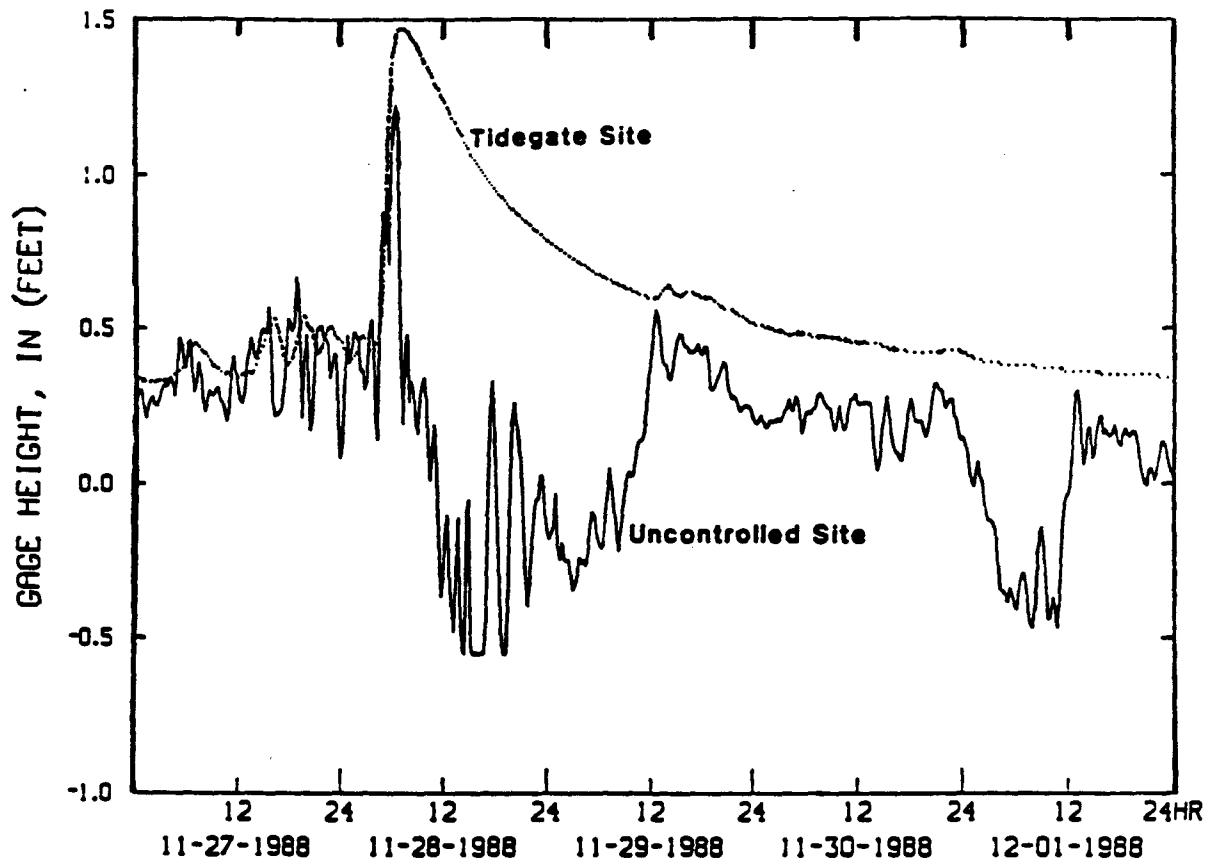


Fig. III-3. Water Level Response to Rainfall at a Tidegate Site versus an Uncontrolled Site. From J.D. Bales, USGS, Provisional Data.

Eutrophication in and of itself should not a priori be construed as an undesirable process. Limnologists, marine biologists and ecologists recognize this process as a natural phenomenon in aquatic ecosystems (Ruttner 1963; Vollenweider 1968; Likens 1972a; Wetzel 1975). Due largely to human interference with this process, events have led to undesirable (often termed "cultural") eutrophication. Eutrophication is the ominous process frequently associated with perceptible water quality degradation (Hasler 1947; Likens 1972b).

Primary production is regulated by the fundamentally important physical and chemical factors of: (1) photosynthetically available light, (2) water circulation, (3) temperature and (4) nutrients. A variety of secondary factors, including biological and geochemical nutrient regeneration, biological fixation, and conversion of essential nutrients, also play roles in mediating primary production rates. This secondary set acts on nutrients once they have already been discharged into a system and accordingly reflects the productive, or trophic, characteristics. It is the set of primary factors which most directly determine eutrophication trends. Of those factors nutrients are most critical, for it is the chronic (and, in the case of highly polluted systems, acute) nutrient loading characteristics that invariably determine eutrophication and trophic characteristics of receiving water bodies. Physical factors, such as light and temperature regimes, morphometry, water residence time, and vertical-horizontal circulation all reflect geological and climatological/latitudinal conditions which, over time, fluctuate slowly relative to nutrient inputs. A flow diagram depicting the diagrammatic relationships in an ecosystem is given in Figure III-4.

Eutrophication is a natural process of ecosystem "aging", where chronic nutrient loading results from combined erosional, hydrological, and terrestrial biogeochemical processes in a watershed, and leads to gradual accumulation of biologically-available nutrients in sediments and the water column. Human activities in watersheds have, in many cases, changed nutrient loading patterns and characteristics by altering the above-mentioned processes (Beeton 1965; Schelske and Stoermer 1971; Schindler 1974, 1977).

Specific problem areas involving anthropogenic nutrient/sediment inputs that contribute to accelerated eutrophication include:

1. **Land Use.** Activities which have, over the past two decades, been shown to be major nutrient contributors are: a) conversion of forests to agricultural, municipal, and industrial land, b) conversion of native forests to managed forests (silviculture), c) conversion of wetlands and marshes to agricultural, municipal, industrial, and recreational regions, d) agricultural clearing and tilling practices, and e) use and application of fertilizers. These alterations and uses constitute major nonpoint and point nutrient/sediment sources. Their relative contributions of nitrogen and phosphorus need to be quantified and considered in overall management strategies aimed at regulating eutrophication in the Albemarle-Pamlico estuarine system.
2. **Nutrient Discharge Patterns.** Both the magnitude and timing of nutrient discharges require careful consideration and appropriate controls. Based on the hypothesis that enhanced spring discharge of nutrients is instrumental in supporting subsequent summer nuisance algal blooms in oligohaline portions of several major tributaries (especially the Chowan and Neuse Estuaries), the timing of discharge events and their relative importance as nutrient sources are critical in controlling unwanted aspects of eutrophication. Allowable point and nonpoint discharges must exit the mesohaline portions of tributaries prior to the late-spring early-summer "slow down" (increased residence time) periods when initiation of nuisance blooms is most likely. This aspect of basin-wide nutrient management should accompany formulations for total annual nutrient input constraints in order to most effectively stem nuisance bloom potentials.
3. **Freshwater Runoff.** In addition to its role in mediating nutrient loadings (especially spring freshwater runoff events), freshwater dilution of seawater plays a critical role in determining

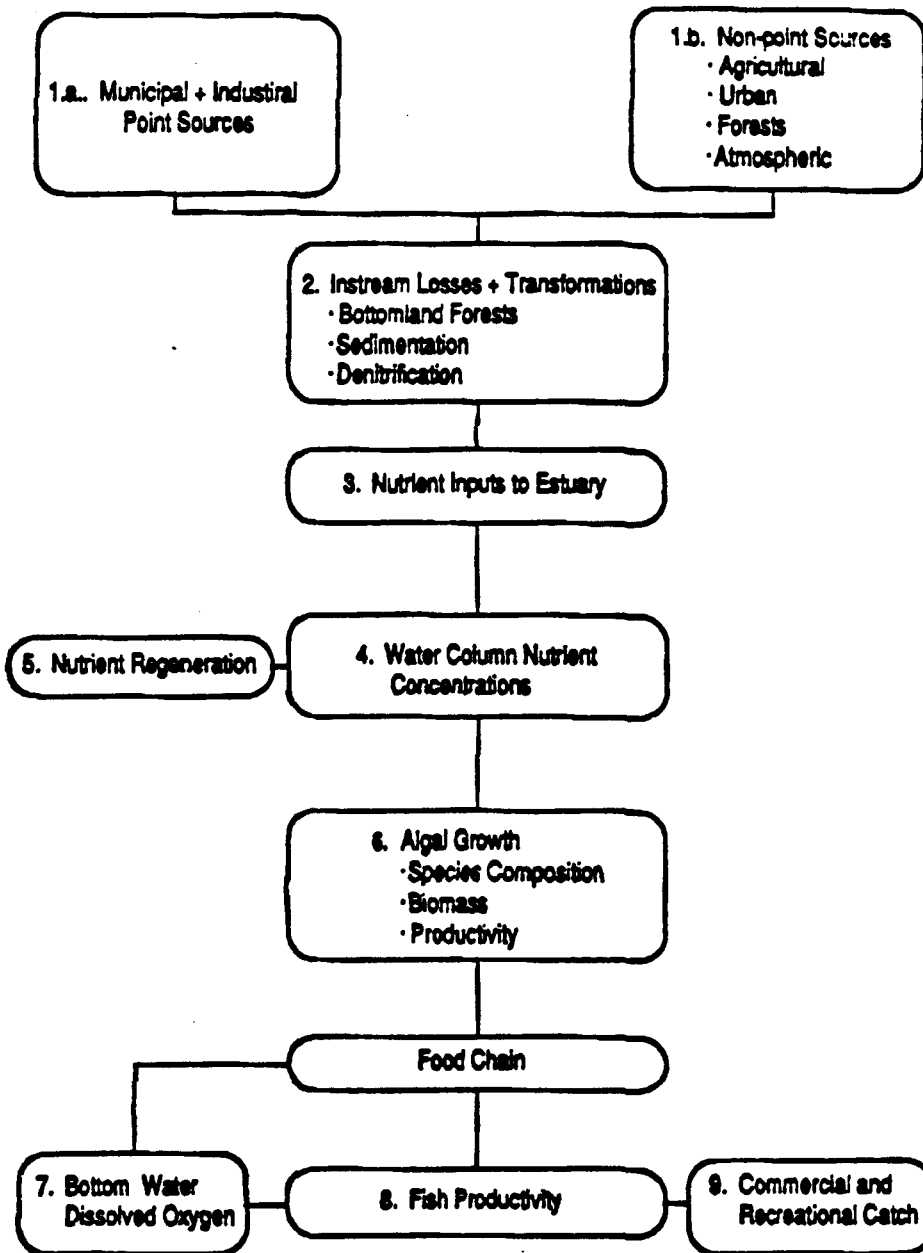


Figure III-4. Compartmentalized Model of Events leading to Consequences of Eutrophication. From D.W. Stanley, East Carolina University, Personal Communication.

the nature, extent, and duration of nuisance algal bloom events in receiving estuaries. Previous work (Witherspoon et al. 1979; Paerl 1982a, 1983; Paerl et al. 1984) has shown that the combined presence of high nutrient loading and low salinities (<5 ppt) greatly enhance nuisance bloom potentials in both the Chowan and Neuse River Estuaries. The blooms observed under these conditions have been dominated by cyanobacterial nitrogen fixing (Anabaena, Aphanizomenon) and non-nitrogen fixing (Microcystis, Oscillatoria) taxa. At salinities exceeding 5 ppt these taxa rapidly lose their dominance, and are generally replaced by mesohalophilic flagellates and dinoflagellates. In nutrient enriched waters, the latter can be responsible for chlorophyll *a* concentration frequently exceeding 50 ug/l (Paerl 1987; Stanley 1988b).

Impacts of freshwater salinity dilution on phytoplankton species composition and biomass have been examined further downstream at the meso-euhaline intersection of the Neuse Estuary-Pamlico Sound (Mallin et al. 1991), it can be stated with certainty that such dilution events in oligo- to mesohaline portions of certain Albemarle-Pamlico estuarine system tributaries are key determinants of both the nature and magnitude of algal blooms (Paerl 1982a, 1983, 1987 and Mallin et al. 1991). It can also be concluded that enhanced freshwater runoff and associated nutrient loads increase the risk of cyanobacterial blooms extending and proliferating further downstream in the estuaries (Paerl et al. 1984). Accordingly, freshwater runoff dynamics (magnitude and timing) will require careful scrutiny in future water quality management plans for the Albemarle-Pamlico estuarine system. It is predictable that alterations in freshwater runoff characteristics will yield profound impacts on rates of eutrophication in localized regions of the Albemarle-Pamlico estuarine system.

4. Erosion and Sedimentation. Sediment loading from the watersheds yields a diverse array of impacts on receiving estuarine-sound waters. The mineralogical and organic sediments periodically discharged into the estuaries represent a source of nutrients, both in adsorbed and subsequently desorbed, and particulate forms. The specific roles of sediments and soluble nutrients (non-sediment associated) in eutrophication mechanisms have not been adequately addressed and are the subject of proposed research. It is safe to assume, even at this early stage of investigation, that sediments will play a central role in the long-term nutrient transport and loading cycles. Sediment loading during spring runoff, when erosional products are transported significant distances into the lower estuaries and open sounds, is of particular concern with respect to long-term eutrophication trends. Such runoff events represent particularly effective means of dispersing nutrients which can subsequently be made soluble and available, during ensuing summer months and perhaps future years, as an algal nutrient source. Certainly, the well-mixed characteristics of the Albemarle-Pamlico estuarine system ensures the circulation of such released nutrients in the water column where effective algal assimilation seems certain.

It should be recognized that suspended sediments affect water column transparency, often decreasing it by factors of 2 to 3. In assessing the overall eutrophic effects of sedimentation, the positive effects of associated nutrient enrichment must be weighed against the potential negative impacts of decreased light availability on phytoplankton. Settling generally reduces sediment-related turbidity shortly after acute erosional-runoff events, but leaves soluble nutrient loads in the water column after sedimentation. Given the ability of phytoplankton to readily intercept such nutrients in euphotic well-mixed waters, it is likely that nutrient enrichment far outweighs reduced transparency in an overall consideration of eutrophic impacts of sediment loadings.

5. Precipitation (Acid Rain). While attention has focused on land-borne nutrient runoff as a main factor involved in estuarine and coastal eutrophication, virtually no attention has been paid to atmospheric sources of nutrients, specifically nitrogen-enhanced acid rain. As a source

of freshwater runoff and dilution, precipitation has historically been recognized as a factor qualitatively and quantitatively affecting eutrophication. Until recently, however, precipitation has not been considered a highly significant nutrient source. Even in the mid-1970s, precipitation-related nutrient inputs were thought to be only 9-10% for nitrogen and less than 5% for phosphorus (NC Division of Environmental Management 1989a). Our recent awareness of the magnitudes and frequencies of nitrogen-enriched acid rain altered our appreciation for and concern about this important nutrient source affecting the Albemarle-Pamlico estuarine system (Paerl 1985). Recent experimental work has shown that naturally-occurring amounts of rainfall can stimulate primary production in estuarine and coastal waters through the addition of nutrients (mainly nitrogen) contained in the rainwater (Paerl 1985, Paerl et al. 1990).

In the North Carolina shallow coastal habitats, much of the nitrogen loading is rapidly assimilated by oligohaline and mesohaline phytoplankton populations that typically reside in the upstream portions of estuaries. These populations act as biological "filters", stripping out biologically-available nitrogen before it enters the larger meso- to euhaline segments of the estuaries, sounds (Albemarle and Pamlico), and Atlantic coastal waters. As a result, these vast water bodies remain chronically nitrogen deficient. Because riverine nitrogen inputs are often stripped in upper portions of estuaries, direct nitrogen inputs from precipitation become an increasingly important source of biologically-available nitrogen downstream. While rainfall nitrogen accounts for about 10-20% of annual nitrogen inputs in the upper portions of estuaries, it may account for as much as 30-40% of the annual nitrogen supplied to the lower estuaries and sounds (Paerl 1985). These calculations are based on annual rainfall nitrogen loading originating from "non-acid" rain events. Typically NO_3^- , which is the largest nitrogen constituent in North Carolina rainfall, ranges in concentration from 5 to 10 umoles per liter during "non-acid" rain events ($\text{pH} > 4.5$). By contrast, during "acid" rain events ($\text{pH} < 4.5$) NO_3^- concentrations can exceed 100 umoles per liter (Paerl 1985). Considering acid rain derived NO_3^- loading values, direct nitrogen loading from precipitation could account for as much as 50% of the total annual nitrogen loading in the open sounds and coastal waters. This estimate may, in fact, be conservative since dry deposition of nitrogen has not been included in these calculations. This largely ignored source of nitrogen can, at times, account for a bulk of the nitrogen input into these waters.

A. 2. b. Impact of Nutrients. Of all the nutrients essential for primary production, nitrogen and phosphorus have been of most concern as "limiting factors" controlling eutrophication (Likens 1972a; Schindler 1977; Hecky and Kilham 1988). Both are frequently perceived to be the primary anthropogenic nutrient inputs. As constituents in key structural and functional molecules (including proteins, lipids, sugars and nucleic acids), nitrogen and phosphorus are in high demand by primary producers (Stewart 1974). This, along with the fact that availability of these nutrients is often restricted (compared to plentiful supplies of carbon, hydrogen, oxygen, sulfur, silicon, and a variety of trace metals), implies that nitrogen- and/or phosphorus-limited growth commonly characterizes aquatic ecosystems (Hecky and Kilham 1988). In general, nitrogen has been considered most limiting in marine and coastal waters (Ryther and Dunstan 1971; Carpenter and Capone 1983), while phosphorus is a dominant limiting nutrient in freshwater (Likens 1972b; Schindler 1977). In estuaries, both nitrogen and phosphorus play key roles in limiting growth (Neilson and Cronin 1981; D'Elia et al. 1986; Nixon 1986), and it is clear that the Albemarle-Pamlico estuarine system is no exception.

Accelerated eutrophication is of environmental and economic concern. Frequently, serious water quality degradation in the form of "runaway" or uncontrolled nuisance algal blooms, periphytic and/or macrophytic growths accompany accelerated eutrophication. Secondary effects of such unwanted growth may include:

1. Toxicity to members of resident food chains caused, for example, by blooms of cyanobacteria (blue-green alga) and/or dinoflagellates (red tide);
2. Toxicity of drinking water, fish, and shellfish affecting recreational users (including domesticated animals and humans) of degraded waters;
3. Hypoxia and/or anoxia of hypolimnetic (non-mixed subsurface) and near bottom waters, resulting from increased biological and chemical oxygen demands caused by decomposition of micro-algal blooms and macrophytic growth. Both forms of oxygen depletion lead to intolerable living conditions, toxicity and death of invertebrate, shellfish, and finfish species in affected waters and sediments;
4. Resultant alterations of planktonic and benthic food chains due to either poor food values (due to the shape or size of colonial nuisance algae) or avoidance of primary producers (due to toxicity or undesirable taste);
5. Increased incidence and stress-related promotion of fish and shellfish diseases; and
6. Foul smells, unacceptable tastes, and poor aesthetic values of affected waters.

To varying extents, symptoms as well as fully developed cases of the above-mentioned manifestations of accelerated eutrophication have affected some tributaries of the Albemarle-Pamlico estuarine system. In all cases, enhanced sediment and soluble nutrient loadings have been identified as causative agents for these forms of water quality degradation.

Coastal nutrient-related water quality problems, ranging from gradual eutrophication to massive algal blooms, represent serious short- and long-term threats to commercial, recreational, and aesthetic values of affected freshwater and estuarine habitats in eastern North Carolina (Paerl 1982a, 1983, 1987). It is clear that eutrophication-related problems have caused persistent negative impacts on the economic and environmental well-being of the Albemarle-Pamlico estuarine system. Technically, relevant questions of concern include:

1. Are inorganic nutrients limiting and hence regulating phytoplankton growth in the Albemarle-Pamlico system?
2. Which nutrients act as growth limiting factors?
3. Is anthropogenic nitrogen and/or phosphorus enrichment a detectable problem in the Albemarle-Pamlico system?
4. Is accelerated eutrophication, resulting from such enrichment, occurring in the Albemarle-Pamlico system?
5. What are the symptoms of eutrophication?
6. Does nutrient-related eutrophication represent a threat to fisheries, recreational and aesthetic resources in the Albemarle-Pamlico system?
7. If the above are true, can we properly manage a system of such size and scope and successfully arrest and reverse long-term water quality degradation?

A. 2. c. Availability of Information. It is intuitively obvious that increased estuarine nutrient loading ought to occur with increasing human population, increasing use of nitrogen and phosphorus fertilizers,

and continued conversion of forest lands to agriculture. Scores of annual nitrogen (N) and phosphorus (P) loading estimates have been made for various estuarine drainage basins, including the Neuse, Chowan, and Tar-Pamlico River estuaries. However, actual estuarine nutrient loadings have not increased at rates similar to those of population growth.

A study (Stanley 1988a) was conducted to use existing data to estimate N and P loading rates for the Neuse basin over the past 100 years. Trends in land use and nutrient loading in the Neuse River basin were estimated for the period 1880 through 1985 by summing computed estimates of annual point and nonpoint source loadings for each county in the basin. The procedure was a modification of that used by Craig and Kuenzler (1983). Nonpoint sources considered included: (1) six categories of farm animals, (2) agricultural cropland, (3) idle cropland, (4) forestland, (5) pastureland, and (6) urban land area. Data on harvested acreage of individual crops were tallied and summed to give the total cropland acreage. Results of this study are given in Section C.1.b.

Harned and Davenport (1990) used seasonal Kendall test to evaluate trends in Water Quality data, including nutrients, collected at 296 locations in the Albemarle-Pamlico system in 1945 and 1988.

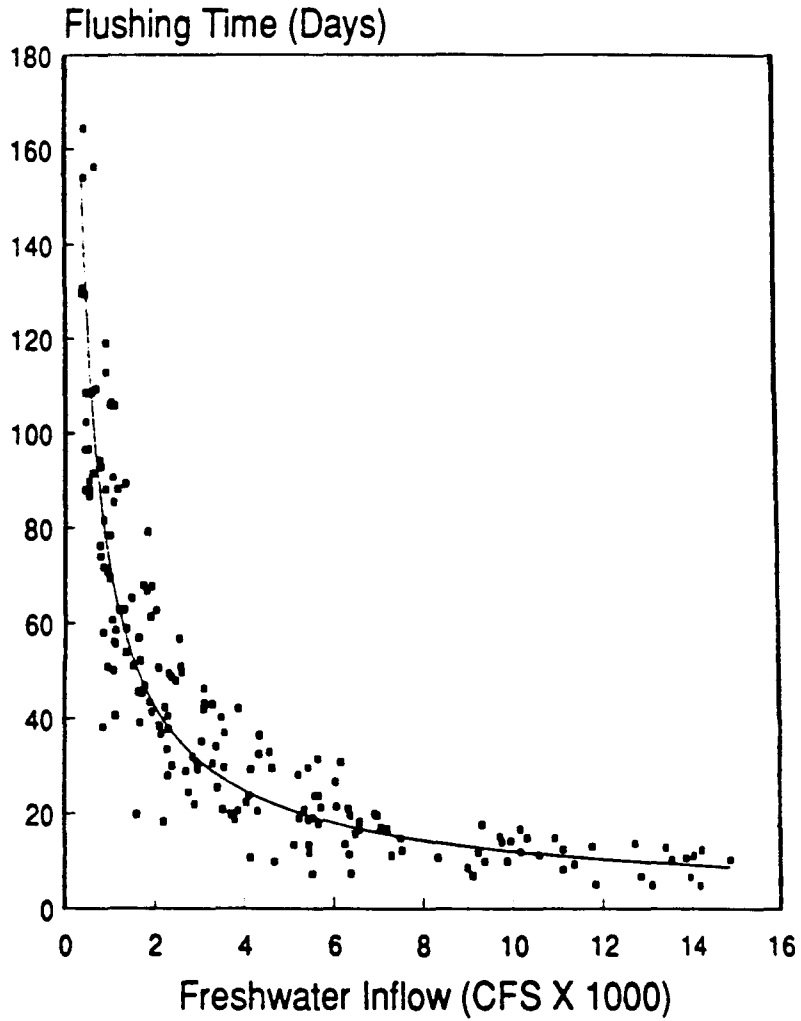
Another study was made to synthesize twenty years of water quality data for the Pamlico River Estuary (Stanley 1988b). Data for the analyses came from several sources. Most of the nutrient and hydrographic data were from two long-term monitoring projects, covering the periods 1967-1973 and 1975-1986, with additional data from two short-term research projects in the mid-1970s. Phytoplankton studies during two periods (1966-1968 and 1982-1985) gave species composition, cell density and biomass data that were used in the analyses. Details of the methodology and the results of this study are presented in Section C.1.c.

An extensive survey of the nutrients and their fates was conducted in Albemarle Sound during the 1970s (Bowden and Hobbie 1977). Albemarle Sound is suggested to have adequate supplies of both phosphorus and nitrogen for abundant phytoplankton growth, sometimes exceeding the levels thought to be the threshold for undesirable eutrophication. Studies have been completed on the Chowan system for nutrient uptake, recycling and phytoplankton response (Craig and Kuenzler 1983; Kuenzler et al. 1982; Stanley and Hobbie 1977).

High concentrations of nitrogen and phosphorous were found to be consistent problems in Virginia's Back Bay. Releases from hog operations' storage lagoons have had significant impacts on water quality, resulting in "excessively high" ammonia nitrogen, phosphorous, and fecal coliform concentrations as well as fish kills in the receiving waterways (Mann Associates 1984). Data from Virginia's Back Bay also indicate a nearly direct relation between suspended solids and total phosphorous, clearly demonstrating the influence of erosion on nutrient concentration of nutrients and water quality.

A. 2. d. The Status and Extent of Understanding. Water residence characteristics are also factors to be considered in susceptibility to accelerated eutrophication. Winter and early spring (November-March) traditionally represent the rainy period in North Carolina, with between 50-75% of annual precipitation falling during this interval (NC State University Climatological Report 1988). Relatively high flushing, high discharge, and short water retention characterizes the tributaries and sounds at this time. Typically, water residence times vary from a few weeks to 2 months in major tributaries (Chowan, Pamlico, Neuse Estuaries); nitrogen-rich (and to a lesser extent phosphorus-enriched) discharge is common. After May during a "normal" rainfall year, hydrological conditions abruptly change; discharge decreases substantially (on the order of 2-3 fold for most tributaries) while retention times dramatically increase from 1 to 3-4 months (Figure III-5). During the spring, summer, and fall estuarine tributaries frequently exhibit lake-like characteristics (i.e., lengthy retention with ephemeral mixed/non-mixed conditions) (Paerl 1987). If the transitional "slowdown" discharge period is abrupt enough, a situation arises in which nutrient and sediment laden spring runoff waters will, in varying degrees depending on the tributaries in question, still reside in oligo- and mesohaline portions of estuaries (Showers et al. 1990). This overlap between

Pamlico River Estuary Flushing Rate
 $Y = aX^b$



$a = 16830$; $b = -0.786$
FW Inflow = Tarboro Flow X 2.04

Fig. III-5. Flushing Time of the Pamlico River Estuary versus Freshwater Inflow. From D.W. Stanley, ECU, Unpublished Data.

nutrient enrichment, increasing water temperatures, stability, and residence time, and day length (light availability) represents excellent conditions for phytoplankton macrophyte growth. Persistent summer-fall low-flow conditions following high spring runoff events appear to set the stage for optimal phytoplankton biomass development and persistence (Christian et al. 1986). In oligohaline waters this scenario appears to have precluded blooms of some of the most problematic nuisance blue-green algae (both non-nitrogen fixing and nitrogen fixing) (NC Division of Environmental Management unpublished data; Paerl 1982a, 1983, 1987; Christian et al. 1986), while mesohaline microflagellate/dinoflagellate blooms frequently thrive under these conditions (Paerl et al. 1984; Stanley 1988a).

The nutritional status and phytoplankton populations of the Pamlico River estuary have been intensively studied for the past two decades (Hobbie 1970a, 1970b, 1971, 1974; Hobbie et al. 1972; Copeland and Hobbie 1972; Davis et al. 1978; Kuenzler et al. 1979; Harrison and Hobbie 1974; Copeland et al. 1984; Stanley 1988b). Phosphate concentrations are relatively high in the middle reaches of this oligo-mesohaline (2-15 ppt salinity), shallow, turbid estuary, especially in the summer. By comparison, inorganic nitrogen concentrations are low relative to phytoplankton needs, except for periods of abundant nitrate in the upper reaches during winter and early spring. Most of the particulate nitrogen and particulate phosphorus appears to be phytoplankton (Kuenzler et al. 1979). Dinoflagellates dominate the phytoplankton, especially during winter blooms of *Heterocapsa triquetra*. Primary productivity and rates of uptake of nitrate, ammonium, and phosphate were measured by Kuenzler et al. (1979). Phytoplankton showed a marked "preference" for ammonium over nitrate; ammonium provided 82% of the nitrogen taken up annually. There was evidence that algal abundance and primary productivity increased in the Pamlico River estuary during the 1970s, although phytoplankton species composition did not change significantly (Kuenzler et al. 1979). The lower, mesohaline part of the Neuse River estuary has been studied less extensively (Hobbie and Smith 1975; Stanley 1983, 1988a; Christian et al. 1986, 1987), but the data indicate many similarities to the Pamlico River estuary.

Little, however, is known about the dynamics of and susceptibility to algal blooms in the open waters of Albemarle-Pamlico sounds. Moreover, it is not known whether nuisance blooms of cyanobacteria, microflagellates or dinoflagellates occur and/or proliferate in these waters. The potential for such blooms and the factors regulating their development and persistence are the subjects of a current study (Paerl, H.W. et al. 1990). Studies in poorly but occasionally stratified estuaries like Chesapeake and Delaware Bays indicate that microflagellates and dinoflagellates often thrive in shallow (3-5 m) waters. Especially important are findings that both nitrogen and phosphorus enrichment lead to enhanced growth of these apparently opportunistic taxa (Steidinger 1983). Therefore, it is prudent to assume that a similar scenario for periodic microflagellate and dinoflagellate blooms exists in the open sound components of the Albemarle-Pamlico estuarine system.

Two very important points are frequently overlooked in assessments of the vulnerability of North Carolina's estuaries to accelerated eutrophication. First, the light/temperature climate is such that rapid proliferation of plant growth is assured given adequate nutrition. On average, Eastern North Carolina experiences a wealth of sunlit days. Approximately 80-90% of days (disregarding thunderstorm events) during spring, summer, and fall months are sunny. This assures adequate supplies of photosynthetically available radiation and leads to maximum water column heating. Second, waters periodically receive nitrogen-enriched acid rain generated in upwind (north, northwest and west), urban, and industrial regions as far as 1,500 miles away (National Acid Precipitation Assessment Program 1988). The shallow confined nature of the Albemarle-Pamlico Estuarine System makes it particularly susceptible to eutrophication impacts of acid rain, since dilution of this nutrient source is minimal. Added to locally-generated point sources and nonpoint sources, acid rain represents an increasingly significant nitrogen source in a system known to be nitrogen sensitive.

The limnological literature abounds with examples of nutrient impacted, shallow, ephemerally stratified (but on average well-mixed) water bodies of becoming victims of accelerating eutrophication. Although the Albemarle Pamlico estuarine system is not a freshwater system, its morphological,

hydrological and physical characteristics resemble polymictic large lake conditions in many ways. The main basins of the Albemarle-Pamlico Estuarine System and its major tributaries (Chowan-Roanoke, Pamlico-Tar, and Neuse Rivers) are shallow and well-mixed, facilitating dispersal of loaded nutrients and sediments and efficient nutrient-sediment exchange between benthic and planktonic regions. These characteristics ensure optimal nutrient availability to both planktonic and sessile primary producers. Transparency is restricted in the turbid, highly colored waters, in part due to humics and flavics, and in part to biogenic production. Extinction coefficients range from 2 to >6 hours, but frequent and thorough vertical mixing of a few minutes to <1 hour for the entire water column, promotes optimal exposure to available light leading to high photosynthetic production. Recent productivity studies employing a light-field-simulator designed to mimic phytoplankton residence in a highly-variable (mixed) light regime revealed resident phytoplankton to be well-adapted to such illumination regimes. Higher rates of primary production were observed in rapidly-mixed conditions (15-20 min for total water column mixing) than in longer high-light conditions (M. Mallin and H.W. Paerl 1991). While the physiological basis for optimal transient light regime photosynthesis requires further investigation, it can be concluded that resident phytoplankton communities are well adapted to a rapidly-mixed, turbid water column.

Despite the scarcity of open-water nutrient and productivity data from the past decade, a reasonably diverse and comprehensive data bank has been established for the main tributaries and some estuaries. Included are the major freshwater input sources for the Albemarle Sound (Chowan, Pasquotank and Roanoke Rivers) and the drainage basins emptying into Pamlico Sound (Pamlico-Tar and Neuse Rivers). Some generalized findings and characteristics appear to apply to the cycling and seasonal concentrations of nitrogen and phosphorus sources and inputs in these tributaries. The dominant form of inorganic nitrogen in virtually all tributaries is nitrate (NO_3^-) (Hobbie et al. 1972; Harrison and Hobbie 1974; Stanley and Hobbie 1977; Paerl 1983). The major source of NO_3^- (Table III-1) appears to be agricultural runoff (Gilliam et al. 1978) and land development, including deforestation and channelization (Skaggs et al. 1980). Together with natural (wetland forest) drainage, such nonpoint sources of NO_3^- (and NO_2^-) contribute as much as 62% of total annual nitrogen inputs in the Chowan system (Craig and Kuenzler 1983) and at least 50% of the total nitrogen inputs into the Neuse and Pamlico River systems (NC Division of Environmental Management 1989b; Harrison and Hobbie 1974; Stanley 1988a, 1988b). Ammonia inputs from nonpoint sources constitute a relatively small fraction (5-15%) of total nitrogen inputs in these tributaries and estuaries. It is generally believed that NH_3 is relatively more important as "internally cycled" nitrogen. It is periodically released from oxygen-depleted and anoxic sediments (Matson et al. 1983; Kuenzler et al. 1984) and rapidly reassimilated by phytoplankton during spring and summer growth periods (Harrison and Hobbie 1974; Stanley and Hobbie 1977; Kuenzler et al. 1979; Stanley 1983). Consequently, seasonal NH_3 concentrations are consistently low and fairly uniform and are more or less independent of major hydrological events such as runoff or drought (Harrison and Hobbie 1974; Paerl 1983, 1987). In contrast, NO_3^- loading and concentrations reveal dynamic seasonal fluctuations, ranging from generally high and abundant levels during high discharge winter and spring months to significantly lower, and at times undetectable, levels in summer and fall phytoplankton growth periods (Hobbie et al. 1972; Harrison and Hobbie 1974; Kuenzler et al. 1979; Tedder et al. 1980; Paerl 1983, 1987; Stanley 1988b).

Estuarine sediment chemistry is quite complicated. Many elements are directly or indirectly involved in nutrient transformations and fluxes. The species and concentrations of these elements vary in space and time. Concentrations often change over short distances (centimeters) with depth in the sediment, but other patterns of spatial change extend the entire length of the estuary. The most important temporal changes in nutrient concentrations, forms, and fluxes range from a few days (for some anoxic events) to annual periodicities, although shorter and longer cycles may exist. The concentrations of many elements are tightly linked to the redox state of the sediments and the end-members can thus be recognized: oxic sediments contain elements predominantly in their oxidized forms (O_2 , SO_4^{2-} , NO_3^- , Fe^{+++} , etc.); whereas, anoxic sediments are dominated by elements in their reduced forms (CO_2 , HS^- , NH_4^+ , Fe^{++} , etc.). Linked closely to inorganic biogeochemistry are the enormous number of species of

Table III-1. Nonpoint Source Impacts in the Estuarine Portion of the Albemarle-Pamlico Estuaries (NC Division of Environmental Management 1989b).

| Parameter | Acreage | Percentage |
|--------------------------------------|-----------|------------|
| WATER QUALITY RATING | | |
| Support | 1,738,761 | 93.1 |
| Partial and Nonsupport | 128,739 | 6.9 |
| MAJOR SOURCES OF DEGRADATION* | | |
| Point Source | 38,290 | 29.7 |
| Nonpoint Source | 90,369 | 70.2 |
| Agriculture | | |
| Feedlots | 1,462 | 1.1 |
| Runoff | 83,011 | 64.5 |
| Urban | | |
| Runoff | 1,664 | 1.3 |
| Finger Canals | 0 | 0.0 |
| Land Disposal | | |
| Sludge | 0 | 0.0 |
| Septic Tanks | 3,143 | 2.4 |
| Other | | |
| Marinas | 1,089 | 0.8 |
| Natural | 0 | 0.0 |
| MAJOR CAUSES OF DEGRADATION* | | |
| Fecal Coliform | 9,579 | 10.6 |
| Dissolved Oxygen | 400 | 0.4 |
| Chlorophyll <i>a</i> | 44,030 | 48.7 |
| Sediment | 3,300 | 3.7 |
| Multiple | 33,060 | 36.6 |

* Partially-supporting and Non-supporting Areas Only. From EPA Source Codes.

organic chemicals and microbially mediated reactions, almost none of which have been studied in North Carolina estuaries.

Definitive studies of estuarine nutrients and productivity began in North Carolina during the early 1970s. Although much has been done, large gaps still exist in our knowledge of causes and effects. Pilot nutrient studies were conducted for Albemarle Sound (Bowden and Hobbie 1977) and the Neuse River Estuary (Hobbie and Smith 1975). A much longer-term nutrient study has been underway in the Pamlico River Estuary since the late 1960s (Hobbie et al. 1972; Hobbie 1974; Stanley 1988b).

While the North Carolina Division of Environmental Management has been conducting periodic (monthly or quarterly) ambient water quality monitoring in North Carolina's estuarine water for several years, a comprehensive monitoring and data management program in the sounds is needed. In response to the need for monitoring information, the North Carolina Division of Environmental Management and the US Geological Survey, in cooperation with the Albemarle-Pamlico Citizens Monitoring Program, have initiated a network of physical, chemical and biological information of maximum utility for researchers and managers (Holman 1989). The monitoring plan includes: 1) emergency response capabilities; 2) continuous monitors of water quality parameters at risk locations; 3) expansion of the existing ambient water quality monitoring; 4) fish tissue toxicants and sediment; 5) one-time synoptic water quality survey; 6) sediment oxygen demand; and 7) citizens' monitoring program.

A. 2. e. Impact of Nutrient Loading on Phytoplankton Biomass and Productivity. Phytoplankton production in the Chowan, Pamlico, and Neuse Rivers, generally relies heavily on the availability of inorganic nitrogen during peak summer growth periods. The fact that nitrogen-fixing blue-green algal species can periodically exert dominance and bloom during mid- to late-summer months in the lower Chowan River (Witherspoon et al. 1979; Paerl 1982a, 1982b) serves as testimony that periods of nitrogen limitation occur in this system. On the Pamlico, late summer flagellate-dominated blooms are effective in locally depleting inorganic nitrogen in broad, oligohaline segments (Hobbie et al. 1972; Harrison and Hobbie 1974; Hobbie 1974; Stanley 1988b). It is believed that nitrogen constitutes a limiting nutrient at certain times of the year (Hobbie 1974). During spring and summer months, the Neuse River receives relatively high NO_3^- loading and exhibits hypereutrophic conditions with respect to NO_3^- and NH_3 concentration compared to the phytoplankton demands (Paerl 1983, 1987; Paerl and Bowles 1986). In the summer, low flow blue-green algal bloom conditions can lead to significant inorganic nitrogen "drawdown", resulting in periodic nitrogen limitation. This has been substantiated with in situ bioassays (Paerl 1983; Paerl and Bowles 1986)

Point source inputs, such as sewage treatment plants and industrial discharges, play a relatively important role in maintaining nitrogen availability during the summer months, largely because agricultural, rural, and urban runoff-related inputs are minimized during these relatively dry, low nonpoint discharge months. At such times it is estimated that point source N inputs can account for as much as 60-70% of total nitrogen entering these river systems (NC Division of Environmental Management, 1985). Hence, on a seasonal basis, point source nitrogen inputs constitute a critical source of nitrogen during times when nitrogen limitation appears most severe. A rather extreme case for the relative importance of a point source discharge in maintaining summer phytoplankton growth and bloom activity was documented for C.F. Industries (Farmers Chemical Co.), a major discharger of nitrogenous waste located at Tunis on the Chowan River. It was widely believed that spring and summer nitrogen discharge from this plant in the early 1970s was responsible for aggravating and intensifying already problematic summer algal blooms, dominated by blue-green nuisance species (NC Division of Environmental Management in-house report; Kuenzler et al. 1982).

Further downstream in typical oligo- to mesohaline estuaries, strong inverse relationships commonly exist between NO_3^- concentration and phytoplankton standing crops (Hobbie 1974; Paerl 1982a). Significant flagellate and dinoflagellate blooms, during which chlorophyll *a* content exceeds 40 ug/l, have occurred during late winter, early spring, and late summer in these regions, where NO_3^- concentrations

and loading are effectively "stripped" out of the water column within a relatively short segment of the estuary. It is generally agreed that such blooms are promoted by relatively long water residence times as the estuaries broaden downstream (Hobbie 1974; Paerl 1983, 1987). Increased clarity due to the settling of previously suspended riverine sediments alleviates light limitation on photosynthesis (Hobbie et al. 1972; Hobbie 1974; Paerl 1982a). These oligo- and mesohaline blooms have been observed on a regular spring-fall basis in both the Pamlico (Hobbie et al. 1972; Hobbie 1974; Stanley and Daniel 1985) and Neuse (Paerl 1982a) estuaries. Blooms act as "biological filters" by stripping ambient waters of NO_3^- content. In the Pamlico and Neuse River Estuaries nitrate-laden upstream waters containing from 200-500 $\mu\text{g N-NO}_3^-/\text{l}$ enter the oligohaline bloom regions. Waters leaving this region commonly contain nearly undetectable concentrations ($<10 \mu\text{g/l}$ of N and NO_3^-) of N and NO_3^- (Hobbie et al. 1972; Harrison and Hobbie 1974; Paerl 1982a; Showers et al. 1990; Rudek et al. 1991). Recently, water column NO_3^- concentrations have been significantly and strongly correlated with phytoplankton productivity in the mesohaline Neuse River Estuary (Mallin et al. 1991). Such findings strongly imply that availability of NO_3^- is limiting the development and proliferation of algal blooms during most of the year.

In a recently completed study by Paerl and co-workers, phytoplankton primary production and its environmental regulation were examined at three stations representative of the lower Neuse River Estuary near the Pamlico Sound interface (Paerl et al. 1990, Rudek et al. 1991). In situ nutrient addition bioassays indicated that the estuary experienced a general state of nitrogen limitation with especially profound limitation during summer periods. Bioassays during spring months showed increased algal biomass and production stimulation with the addition of nitrogen and phosphorus over that found with nitrogen addition alone. While seasonal patterns predominated, the algal community responded during any season to increased flow and concomitant nutrient loadings by increasing biomass and production levels, often very rapidly. This was most dramatically demonstrated by a large Heterocapsa triquetra bloom during late winter of 1989-1990. Dissolved inorganic nitrogen levels were generally low, except during periods of high flow when heavy nutrient loading occurred. Dissolved inorganic phosphorous levels followed a seasonal pattern of high summer and fall values and low winter and spring values. The highest inorganic phosphorous concentrations were, however, measured during the winter 1989-1990 loading event (Figure III-6).

Upstream, NH_3 concentrations entering the bloom region are generally low ($<20\text{-}30 \mu\text{g N-NH}_3/\text{l}$) relative to NO_3^- , therefore, NH_3 supplied via stream inputs are not thought to be strong determinants in regulating magnitudes of phytoplankton production in these estuarine regions. On the other hand, NH_3 does play an important role in the maintenance of phytoplankton and bloom populations by being a chief component of "regenerated" nitrogen (i.e., nitrogen which is recycled between sediments and the water column). Regenerated nitrogen may be particularly important in maintaining net phytoplankton production during low discharge periods when NO_3^- inputs from watersheds are greatly reduced and resultant nitrogen limitation is evident. Evidence for the ecological importance of nitrogen regeneration, chiefly as released and reassimilated NH_3 , has been obtained from the Chowan (Stanley and Hobbie 1977), Pamlico (Harrison and Hobbie 1974) and Neuse (Stanley 1983) River Estuaries. Interestingly, salinity was determined to be the limiting factor to algal growth in Virginia's Back Bay (Mann Associates 1984).

In summary, loading and cycling of nitrogen, chiefly as NO_3^- , are strong determinants in the regulation and ultimate limitation of primary production and bloom development in all the freshwater tributaries and diverse estuaries examined to date. Accordingly, understanding nitrogen loading and flux rates, as well as the magnitude, timing, and location of inputs, is of vital importance in assessing productive and eutrophication processes in the estuarine portions of the Albemarle-Pamlico estuarine system.

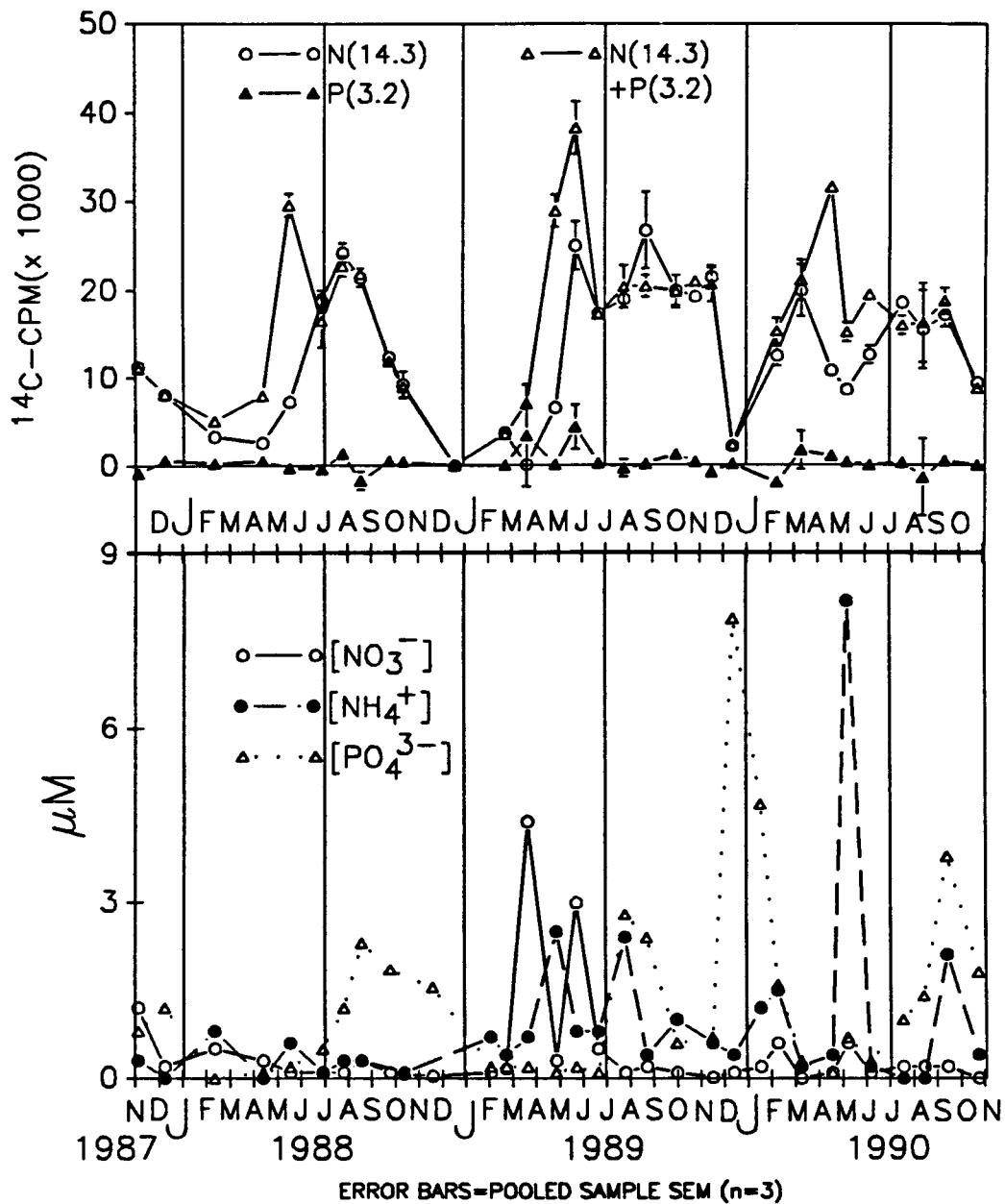


Fig. III-6. **Top panel:** ^{14}C assimilation (CPM = counts per minute as measured on scintillation counter) of selected nutrient addition treatments minus controls, averaged over the four days of each bioassay. N(14.3) = addition of 14.3 $\mu\text{gN/l}$ as NO_3^- . P(3.2) = addition of 3.2 $\mu\text{gP/l}$ as PO_4^{3-} . Error bars not visible are smaller than symbol. **Bottom panel:** Nitrate (NO_3^-), Ammonium (NH_4^+), and Phosphate (PO_4^{3-}) concentrations of surface waters at station site in the lower Neuse River Estuary. No error bars plotted. From Rudek et al. (1991).

Phosphorus loading, cycling, and utilization by phytoplankton are quite different from those of nitrogen. There is virtual agreement, based on previous studies and monitoring efforts, that the combination of both natural and anthropogenically derived sources of phosphorous loading lead to high (by both freshwater and marine standards) standing concentrations of phosphate in North Carolina coastal waters (Copeland and Hobbie 1972; Hobbie et al. 1972; Hobbie 1974; Kuenzler et al. 1979; Kuenzler et al. 1982). Whereas, inorganic nitrogen is often rapidly depleted during summer phytoplankton growth periods, phosphate concentrations act in a much more conservative fashion, indicating both excess supplies and a general lack of phosphorus limitation. Furthermore, phosphorus is effectively recycled between the sediments and the water column (Kuenzler et al. 1982), assuring the maintenance of sufficient supplies of phosphate during periods of maximum phytoplankton demand. Bioassay studies (Figure III-5) conducted by a variety of investigators on diverse riverine and estuarine habitats have come to the conclusion that, phosphate limitation is rare (Copeland and Hobbie 1972; Hobbie 1974; Paerl 1983; Paerl and Bowles 1986). The single exception may be the Chowan River during bloom periods. Phytoplankton biomass development during blooms can, at times, lead to concurrent depletion of inorganic nitrogen (as evidenced by development and dominance of nitrogen fixing blue-green algae) and phosphorus (Sauer and Kuenzler 1981; Paerl 1982a, 1982b; MacKintosh 1979). However, such phosphorus limited periods are extremely ephemeral, lasting only a few weeks during maximal bloom development.

Phosphorus discharge sources include: 1) natural erosion and dissolution of rocks, sediments, and soils in tributary basins, 2) industrial discharges, 3) sewage treatment plants, and 4) phosphate mining operations (in the Pamlico River Estuary). North Carolina's Piedmont and Coastal Plains soils are generally rich in phosphate (Hobbie 1970b) and are responsible for appreciable natural leaching of phosphate. It comes as no surprise that actively-tilled agricultural soils can contribute a majority of the phosphorus loading to the estuaries (NC Division of Environmental Management 1989b). Unlike nitrate-nitrogen loading, which is often maximized during early spring high runoff periods, phosphate loading generally proceeds more steadily, with appreciable spring loading (erosion related) as well as substantial summer loading (from the continuous discharge of sewage treatment plants). In this manner, adequate phosphorus loading is usually assured throughout the year, and so ensures that summer phytoplankton phosphorus demands will be met.

Clearly, arresting current water quality deterioration associated with eutrophication and periodic nuisance blooms in tributaries as well as more incipient symptoms of accelerated eutrophication (such as increased incidence of violations of chlorophyll *a* standards, periodic microflagellate and dinoflagellate blooms, ephemeral anoxia, and associated fish kills) will involve more closely monitoring, controlling nutrient inputs, and elucidating mechanisms and dynamics of nutrient-growth/bloom interactions. Those interactions in particular, must be dealt with and addressed with long-term (5-10 years) research efforts aimed at lower estuarine-open sound waters, about which so little is known.

A. 2. f. Sediments and Their Role in Nutrient Cycling. Bottom sediments play an important role in nutrient cycling in most estuaries. The hydrology of North Carolina's estuaries causes them to be traps for suspended sediments and nutrients, resulting in bottom deposits of sand and mud. High productivity of phytoplankton, and sometimes bordering salt marshes and macrophyte beds, generates abundant particulate organic matter which is eventually deposited on the bottom. Microbial degradation of this organic matter, especially in summer when re-aeration is slow, creates low redox potential in the sediments, a condition which affects many aspects of the cycling of nitrogen, phosphorus, sulfur, iron, and other elements. Mass balance models of phytoplankton nutrition in both the Chowan and the Pamlico Rivers indicated that nutrients delivered to these estuaries by upland runoff alone were insufficient to support the observed rates of phytoplankton primary productivity (Stanley and Hobbie 1977; Kuenzler et al. 1979). This initiated investigations of the importance of the sediments as internal sources of nutrients for estuarine phytoplankton production (Matson et al 1983, Kuenzler, et al. 1984, and Albert 1985).

A number of the biogeochemically important elements in estuaries are delivered to the bottom in particulate form and returned to the water in soluble form. In Back Bay, Virginia, the concentration of suspended solids has been correlated nearly directly with total phosphorous, indicating the direct relation between erosion and water quality (Mann Associates 1984). The basic aspects of nitrogen and phosphorus cycling are known well enough to make the following generalizations regarding sediment cycling and regeneration of carbon, nitrogen and phosphorus (Figure III-7):

1. Large amounts of particulate organic carbon, nitrogen, and phosphorus derived from phytoplankton and allochthonous organic matter sink through the water column and are deposited on the bottom. The quantity of organic matter is, however, relatively small compared to the amount of inorganic sediments deposited annually.
2. Microbial metabolism of the organic matter consumes oxygen--if re-aeration and/or vertical mixing are poor, the sediments may become anoxic. Under anoxic conditions, metabolic byproducts such as carbon dioxide, ammonium, and phosphate diffuse upward and into the water (Figures III-8 and III-9). The concentration gradients in the sediments drive the diffusive flux (Figure III-10). The bottom then constitutes a source of these chemical forms to the overlying water. Reduced sediments are a sink for oxygen and, during periods of thermal or salinity stratification of the water, hypoxic or anoxic bottom waters become rich in phosphate and ammonium (Figure III-11).
3. When stratification is weak, the bottom water maintains sufficient oxygen for an oxidized zone to exist at the sediment surface. Microbes at the sediment surface oxidize ammonium to nitrate (Table III-2), which then diffuses upward into the water or downward where it is denitrified to N_2 gas which is then transported to the atmosphere. Under oxic conditions, phosphate tends to be precipitated or sorbed with ferric iron and is thus immobilized in the sediments until anoxic conditions return.
4. In a study of the Pamlico River, it was discovered that although the rates of nutrient regeneration in bottom sediments were high, the total quantities of inorganic nitrogen and phosphorus returned to the overlying water were less than 25% of the annual needs for Pamlico River estuary phytoplankton production (Table III-3). Thus, it was concluded that water column regeneration, sediment regeneration and external sources (e.g., watershed runoff, precipitation, wastewaters and seawater advection) (Table III-4) are all important sources of phytoplankton nutrients in the Pamlico River estuary (Kuenzler et al. 1984).

A. 2. g. Availability of Information. There have been at least five investigations of bottom sediment characteristics, elemental cycling, and exchanges of materials between sediments and overlying waters in three North Carolina estuaries in this decade (Table III-5). A considerable body of knowledge of sediment characteristics and elemental cycling has been acquired. Research questions, experimental design, and methods of sampling and analysis differed among the studies. For example, Matson et al. (1983) calculated nutrient exchanges from concentration profiles in the sediment; whereas Kuenzler et al. (1984) measured changes in concentrations in benthic chambers. Albert (1985) measured primarily concentration profiles and chemical transformations within sediment cores.

Soil erosion, on its own, can also cause significant water quality degradation by increasing the turbidity of the receiving waters, clogging the gills of fish and larvae, and decreasing the potential for photosynthesis. In Back Bay, Virginia, soil erosion has been cited as a major source of nonpoint source pollution. Twelve thousand tons are estimated to enter the estuarine system every year.

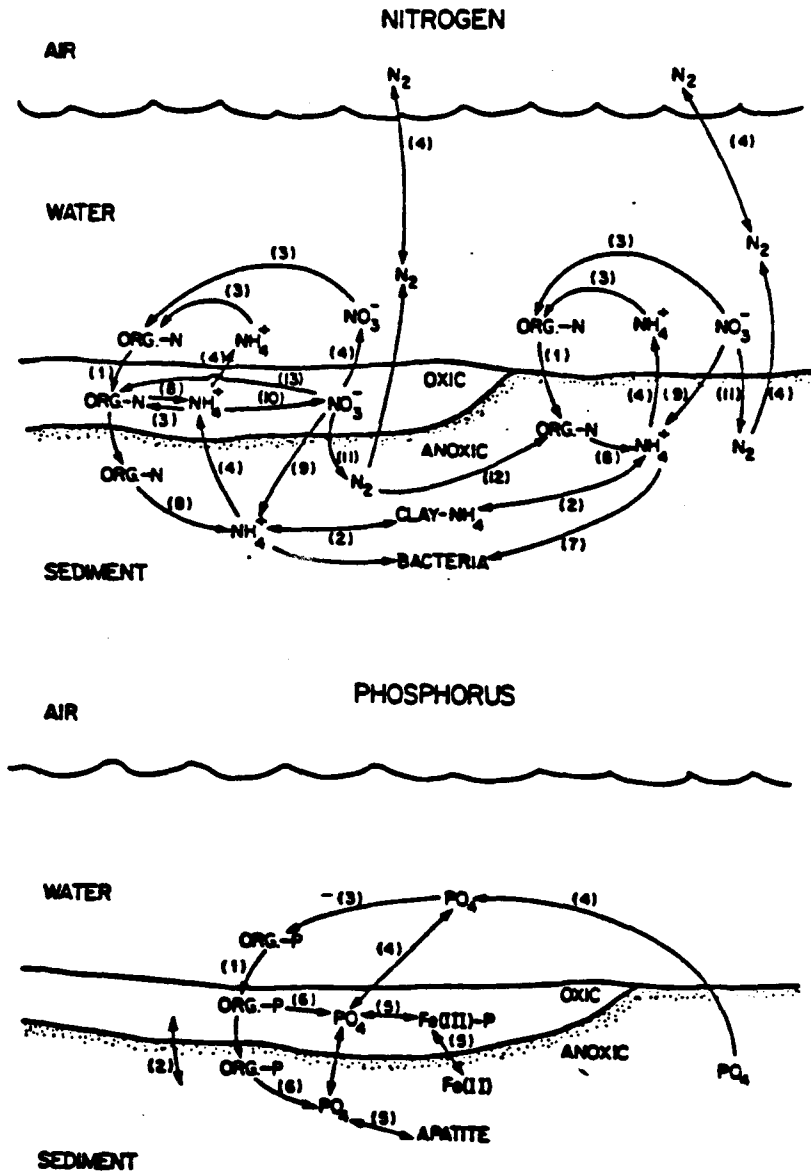


Fig. III-7. Major Pathways of Phosphorus and Nitrogen Cycling in Estuaries. 1) Sedimentation, 2) Sorption, 3) Assimilation, 4) Diffusion, 5) Precipitation-Dissolution, 6) Heterotrophic Regeneration, 7) Immobilization, 8) Ammonification, 9) Dissimilatory Nitrate Reduction, 10) Nitrification, 11) Denitrification, 12) Nitrogen Fixation, and 13) Assimilatory Nitrate Reduction. From Kuenzler et al. (1984).

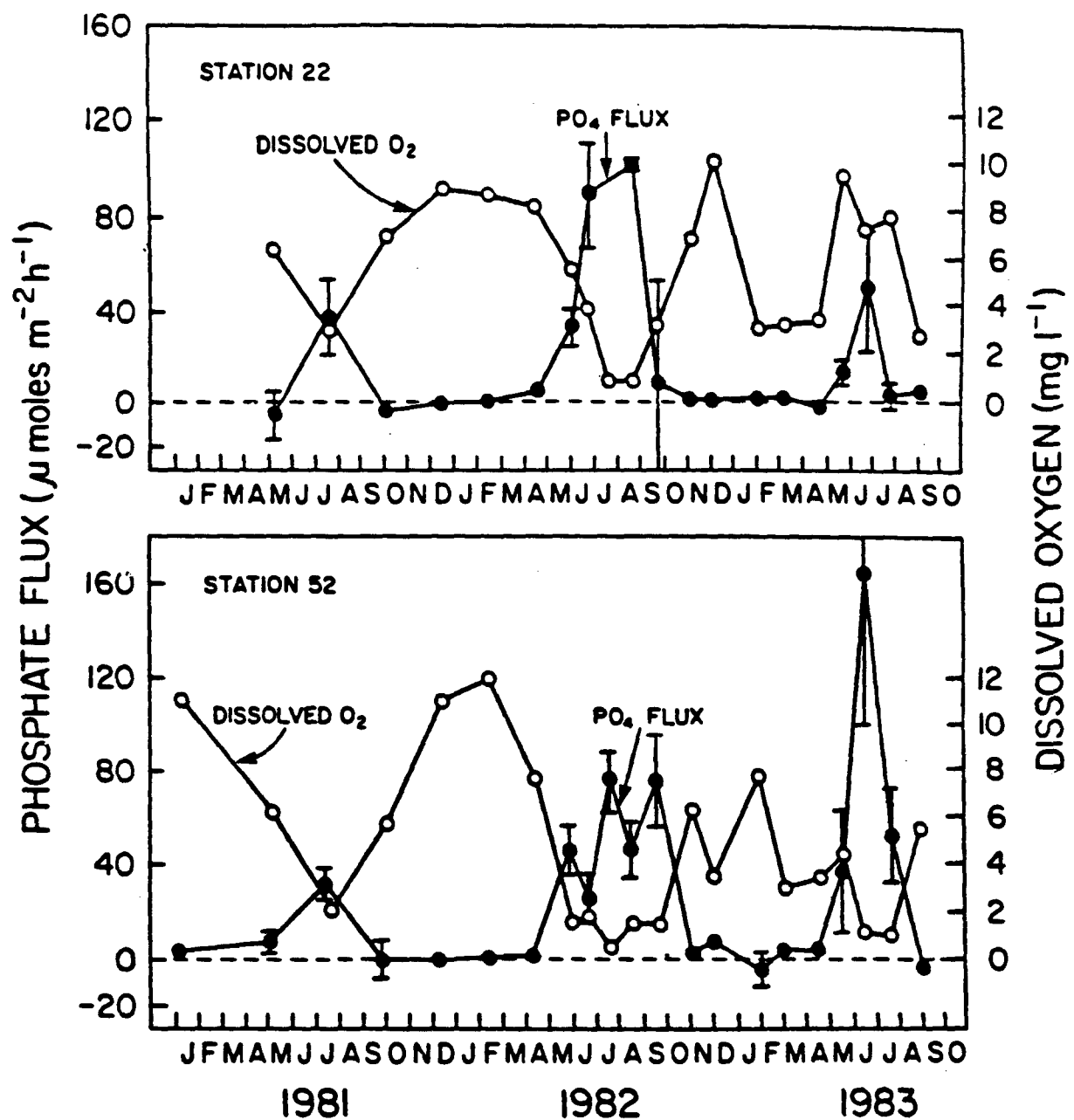


Fig. III-8. Seasonal Pattern of Bottom Water Dissolved Oxygen and Sediment Phosphate Flux in the Pamlico River Estuary. From Kuenzler et al. (1984).

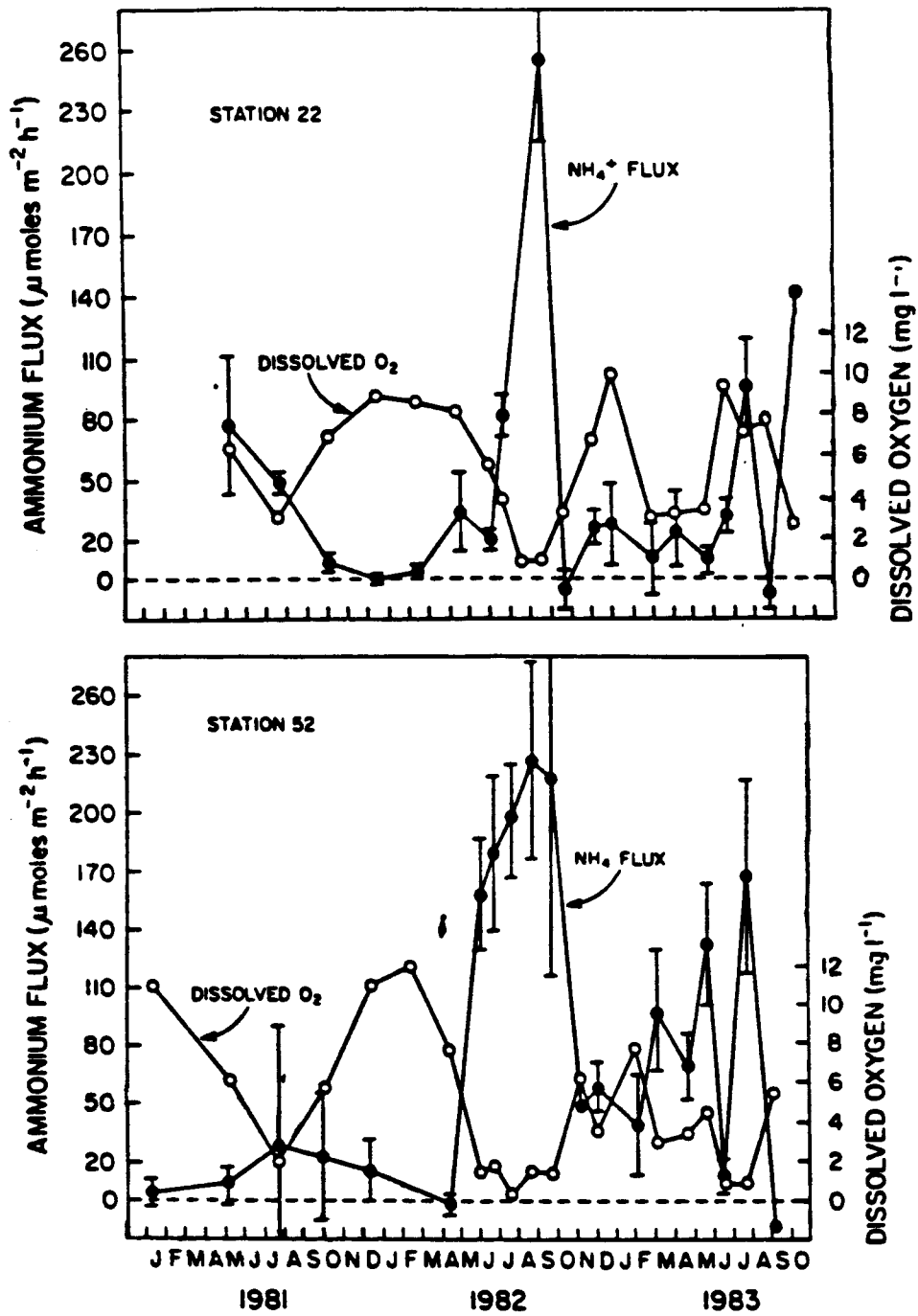


Fig. III-9. Seasonal Pattern of Dissolved Oxygen Concentration and Sediment Ammonium Flux in the Pamlico River. From Kuenzler et al. (1984).

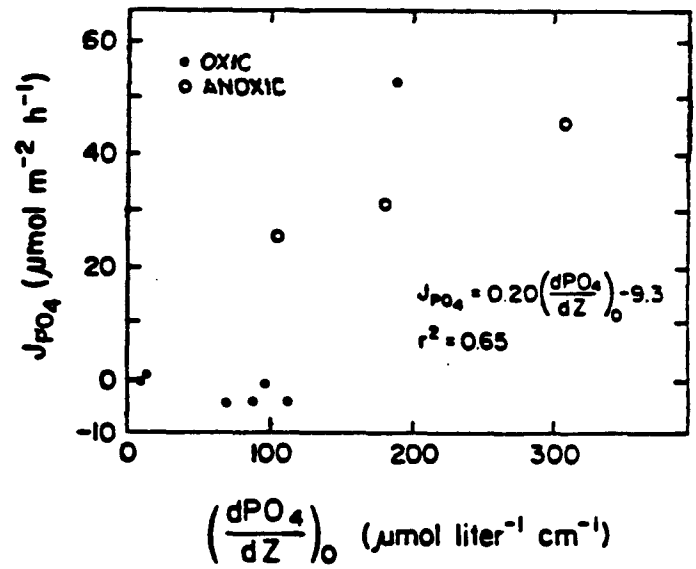
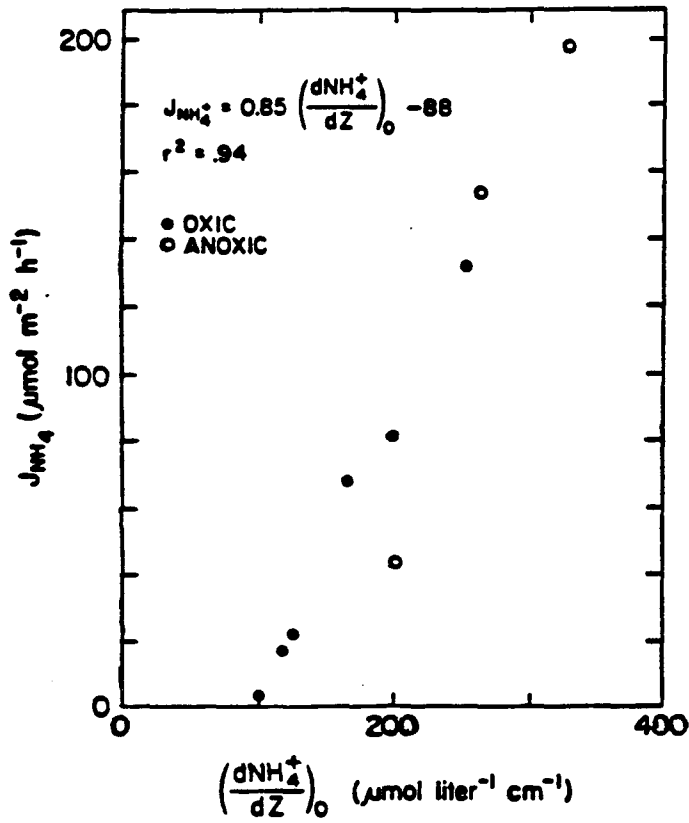


Fig. III-10. Ammonium and Phosphate Flux in Relation to the Pore-Water Concentration Gradient at the Sediment Interface in the Pamlico River. From Kuenzler et al. (1984).

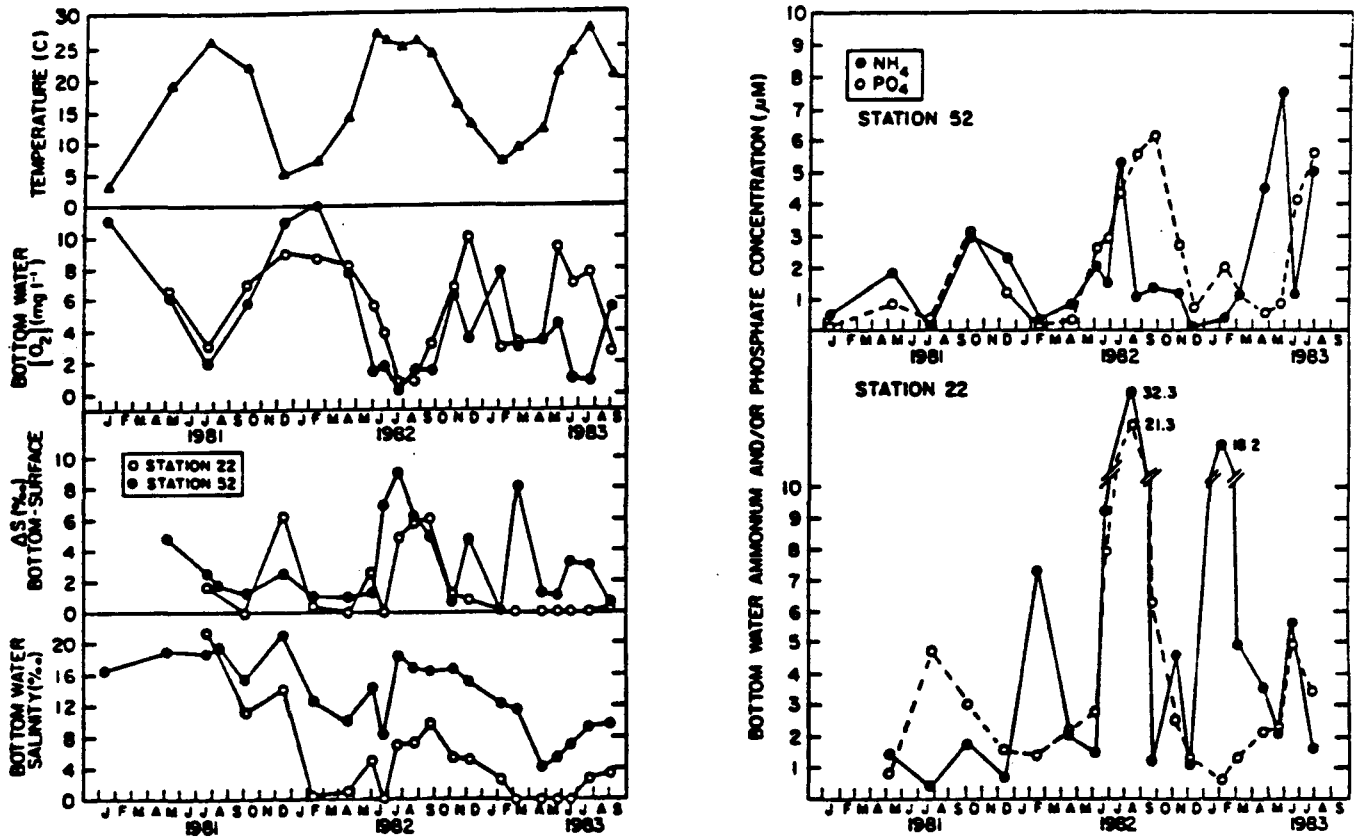


Fig. III-11. Annual Patterns of Bottom Water Temperature, Dissolved Oxygen, Salinity, Salinity Difference between Surface and Bottom, Ammonium, and Phosphate in the Pamlico River. From Kuenzler et al. (1984).

Table III-2. Nitrification potential rate ($\bar{x} + sd$) at four depths in the sediment during 1982-83 in the Pamlico River estuary (rates in nmoles NH_4^+ oxidized $\text{cm}^{-3}\text{d}^{-1}$; integrated rates in $\text{nmoles cm}^{-2}\text{d}^{-1}$). From Kuenzler et al. (1984).

| Depth | Aug | Sept | Nov | Dec | Feb |
|-----------------|-----------|-----------|-----------|------------|-----------|
| 0-1 cm | 20 | 7 + 3 | 15 + 4 | 41 + 42 | 12 + 9 |
| 1-2 cm | 36 | 11 + 4 | 14 + 3 | 50 + .5 | 21 + 3 |
| 2-4 cm | 0 | 12 + 13 | 12 + 9 | 20 + 2 | 6 + 2 |
| 4-6 cm | 0 | 0 | 2 + 1 | 7 + 2 | 3 + 1 |
| Integrated Rate | <u>56</u> | <u>42</u> | <u>57</u> | <u>145</u> | <u>51</u> |

| Depth | Mar | Apr | May | June | July |
|-----------------|-----------|----------|-----------|-----------|-----------|
| 0-1 cm | 4 + 2 | 1 + 2 | 4 + .04 | 28 + 11 | 33 + 17 |
| 1-2 cm | 10 + 6 | 2 + 2 | 0 | 1 + 1 | 0 |
| 2-4 cm | 6 + 9 | 3 + 4 | 3 + 5 | 2 + 2 | 14 + 14 |
| 4-6 cm | 6 + 5 | 0 | 3 + 4 | 1 + 2 | 5 + 1 |
| Integrated Rate | <u>38</u> | <u>9</u> | <u>16</u> | <u>35</u> | <u>71</u> |

Table III-3. Phosphate, dissolved inorganic nitrogen (DIN), and oxygen fluxes ($\mu\text{mole m}^{-2}\text{h}^{-1}$) from sediments in the Pamlico River estuary compared to phosphate, DIN and carbon uptake by phytoplankton. From Kuenzler et al. (1984).

| Element | Algal Uptake | Flux | Flux as % of uptake | C Based** |
|-----------------------------|--------------|---------|---------------------|-----------|
| <u>Annual Average Rates</u> | | | | |
| Phosphate | 225 | 19.1 | 8.5 | 43 |
| DIN | 807 | 51.4 | 6.4 | 7.2 |
| Oxygen | - | 275 | 5.8* | - |
| Carbon | 4760 | - | - | - |
| <u>Summer Average Rates</u> | | | | |
| Phosphate | 142-175 | 30-42 | 21-24 | 31 |
| DIN | 795-1240 | 66-90 | 8.3-8.6 | 6.0-7.4 |
| Oxygen | - | 150-422 | 1.8-5.8* | - |
| Carbon | 7240-8110 | | | - |

* Percent of carbon fixed that could be respired to CO_2 by the observed oxygen uptake of the sediments.

** Based on Redfield stoichiometry to predict net nitrogen and phosphorus uptake relative to carbon uptake.

Table III-4. Nitrogen and phosphorus loading (MT/yr) of the Pamlico River estuary (1976-77) compared to phytoplankton needs. From Kuenzler et al. (1979).

| Chemical Form | <u>Sources</u> | | | | Algal Ann.Needs |
|-------------------------------------|----------------|------------|------------|--------------|--------------------|
| | Watershed | Precip | TGI | Pamlico So. | |
| <u>Nitrogen</u> | | | | | |
| Ammonium | 206 | 67 | | 505 | 22,900 |
| NO ⁻³ + NO ⁻² | 316 | 76 | | 325 | 4,230 |
| Dis. Org. N | 1,860 | 85 | | 5,580 | |
| Part. N | 1,430 | | | 1,860 | |
| Total N | 3,812 | 228 | | 8,270 | 27,100 |
| <u>Phosphorus</u> | | | | | |
| Filt. Reac. P | 84 | 13 | 843 | 184 | |
| Filt. NonR. P | 57 | 4 | | 103 | |
| Part. P | 190 | | | 190 | |
| Total P | 331 | 17 | 843 | 477 | 10,640 |

Table III-5. Recent Studies of Bottom Sediment Characteristics, Benthic Nutrient Cycling and Relationships to Overlying Water in North Carolina Estuaries

| Estuary | Sediment Characteristics | | | | References |
|---------|--------------------------|----------|---------|----------------------|----------------------|
| | Measurements* | Stations | Samples | Elements | |
| Chowan | A to G | 115 | 143 | N,P,O ₂ | Kuenzler et al. 1982 |
| Pamlico | B to F, H to I | 6 | 62 | N,P,C,S,Cl,Si | Matson et al. 1983 |
| Neuse | B to F, H to I | 6 | 63 | N,P,C,S,Cl,Si | Matson et al. 1983 |
| Pamlico | G, J to M | 2 | 22 | N,P,C,O ₂ | Kuenzler et al. 1984 |
| Pamlico | A to C, N to Q | 2 | >20 | S,Fe | Albert 1985 |

* A = Organic C; B = TKN; C = TP; D = Sand; E = Silt; F = Clay; G = Bulk Density; H = Exchangeable NH₄; I = Extractable P; J = Percent Water; K = LOI; L = NO₃; M = NH₄; N = Extractable Fe; O = Total Fe; P = Acid-vol. S; Q = Pyrite S.

A. 3. Metals and Toxicants in the Water Column and in the Sediments

A. 3. a. Introduction. Heavy metals and other elements are normal constituents of most estuarine ecosystems. Natural concentrations, however, are being supplemented and the normal ratios among them are being altered by the activities of man. The dual role of many trace elements in biological systems (i.e., some act as required nutrients and all, at some level, are potentially toxic) is well documented (Crouse et al. 1983a, 1983b).

Many factors affect the availability, transport, and concentration of metals and toxins into and through the coastal system. Accessibility of an element in the abiotic environment for incorporation into the biosphere is referred to as "bioavailability". The bioavailability of any given element depends on a host of factors, sometimes too numerous and complex to test and/or model. Principal among these factors are (1) the feeding habits, stage of life cycle, and age and condition of organisms involved; (2) the chemical form and manner in which a particular element is incorporated into the sediments; and (3) the physical and chemical conditions of the environment.

The transient nature of estuarine water column characteristics and the dilution of point source discharges often maintain trace metal concentrations in water below toxic or even detectable limits. The sedimentary regime, on the other hand, is much less transient and metals can become incorporated into sediments by several different mechanisms and partitioned among a variety of sedimentary phases. Consequently, concentrations in sediments are often several orders of magnitude greater than those in the overlying waters (Wolfe and Rice 1972). It has been well established that fine-grained sediments are the primary reservoir for heavy metals in estuarine systems (Renfro 1973). As a result, sediments are often envisioned as the ultimate sink for much of the soluble and most of the particulate matter entering the estuary.

The Albemarle-Pamlico estuarine system acts as a large settling basin for sediments, organic matter, heavy metals and organic toxins derived from agriculture, urbanization and industrialization within the drainage basin (Copeland et al. 1983, 1984). In addition to the normal runoff and stream drainage mechanisms for transporting materials to the estuary, there are several historic waste disposal sites around the estuary. These virtually unknown and often poorly sited facilities contribute unknown amounts of toxic and hazardous materials into the groundwater and into nearby marshes and lowlands. Since many of these facilities predate the time of environmental awareness, their potential effects on the estuarine system could be significant (Riggs et al. 1989).

A. 3. b. Availability of Information. The first detailed study of the metals and toxins in the Albemarle-Pamlico estuary is currently underway. The US Fish and Wildlife Service has sampled a large number of estuarine animals for the presence of toxins and is currently evaluating results. The first phases of the study, an analysis of heavy metal pollutants in organic-rich muds of the Pamlico and Neuse River estuarine systems, have been completed (Riggs et al. 1989, in press). Analysis and mapping have been completed for eight of the EPA "priority pollutant metals" (Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, and Zinc) plus fluoride and phosphorus in the sediments. Permitted point discharges and nonpoint sources were identified as contributors of significant concentrations of metals to the estuary. A similar evaluation of the Albemarle Sound is currently underway.

Dioxin has been found in the tissue of fish taken from the Roanoke. Health advisories have been posted to warn against eating fish taken from the area. Moreover, accumulations of heavy metals have been found in the sediments of Albemarle Sound (Bales 1991).

S. Riggs et al. (1989, in press) conducted studies to determine the concentrations of heavy metals in the organic rich sediments of the Pamlico and Neuse Rivers. Anthropogenic sources are believed to be largely responsible for heavy metal enrichment within the Neuse River estuarine system. In the Neuse River study 203 stations were cored and the cores analyzed to determine the vertical and lateral

distribution of 15 critical trace elements (CTEs). Riggs et al. compared the trimmed mean of all surface samples with the individual samples from locations affected by or in close proximity to known point source dischargers. Sediments in the vicinity of known point source discharges were significantly enriched in specific metals compared to sediments in other portions of the Neuse River. Surface sediments have been enriched up to and occasionally in excess of 100 times the elemental concentrations occurring in sediments deeper in the cores, inferred to represent pre-man conditions. Riggs et al. identified 17 areas of "enrichment", areas in which one or more CTEs exceeded the control levels by a factor of two or more. In six of these areas, three or more of the CTEs were found to be enriched; in eleven of these areas, only one or two CTEs were found to be enriched.

The results of the similar Pamlico River study (Riggs et al., 1989) determined that heavy metal enrichment was generally less severe; the trimmed means of 10 CTEs were lower in the Pamlico River than in the trimmed mean of the same CTEs in the Neuse River estuarine system. Only arsenic, cobalt, and titanium exceeded the levels found in the Neuse. Individual waste water treatment plants, marinas, industrial plating facilities, and military facilities were identified as probable sources of CTE enrichment (Riggs, in Press).

Low concentrations of toxic heavy metals in discharge waters or in estuarine water columns are not indications that the estuaries are free from metal contamination. Due to rapid changes in estuarine water chemistry, high absorption characteristics of omnipresent inorganic clay mineral on the chemical process associated with metal complexing and organic matter, many trace metals are often enriched in the sediments at levels that are orders of magnitude above acceptable water level concentrations. Enrichment of trace metals continues as storms, biological processes, and man routinely resuspend the mud sediments into the water column. Consequently, the cumulative effect of large discharge volumes with low concentrations can result in significant enrichment of the sediments (Riggs, in press).

A. 4. Point Sources and Nonpoint Sources

A. 4. a. Introduction. Sources of pollution are generally grouped into two categories: point sources and nonpoint sources. Point sources of pollution enter a stream at a discrete location, usually a discharge pipe, and include municipal and private wastewater treatment facilities. These facilities must obtain a permit from the North Carolina Division of Environmental Management (or the Virginia Water Control Board) which limits the amount of pollution that may be discharged to a given stream. In contrast to point source pollution, nonpoint source pollution is that which enters waters mainly as a result of precipitation and subsequent runoff from land—primarily from what has been disturbed by man's activities. Examples include runoff from urban areas, septic tanks, agricultural lands, and construction sites. Nonpoint source pollution is addressed through a combination of regulatory, cost incentive, and voluntary programs.

North Carolina adopted its first comprehensive, modern water pollution control law in 1951. The essentials of the 1951 law (originally entitled State Stream Sanitation Act and renamed in 1967 the Water and Air Resources Act) remain in effect as an important part of the legal basis for North Carolina's water pollution control program. The Water and Air Resources Act provided for a program of pollution abatement and control based principally on classifications and water quality standards applied to the surface waters of the State.

Two principles are involved in defining the quality to be maintained in a water body: (1) the desired use of a body of water, called its "classification" and (2) the levels of contaminants that can be tolerated without impairing the desired use, called its "standards". Twenty-five years ago, the Albemarle-Pamlico study area had some streams that were classified "E", which designated the best use as agricultural and industrial processing and for transporting wastewaters. The corresponding standards were only stringent enough to protect against human health hazards. Still other streams were classified "D", which had

standards sufficient to allow fish to survive but not to allow fish to propagate. Today, all waters are classified "C" or better, indicating water quality that permits the propagation of fish.

The major river basins of the Albemarle-Pamlico area were systematically classified in response to the 1951 law. Each basin was surveyed by the State Stream Sanitation Committee, with the results and classification recommendations summarized in what were termed Pollution Survey Reports. These reports included information on the point sources in each basin, and were published in the following order:

| | |
|-------------------------|------|
| Chowan River Basin | 1955 |
| Roanoke River Basin | 1956 |
| Neuse River Basin | 1959 |
| Pasquotank River Basin | 1960 |
| Tar-Pamlico River Basin | 1961 |

The original classifications resulting from these surveys have been modified in response to stricter federal requirements, improved wastewater treatment and new state initiatives. The standards have also been significantly expanded in response to increased research on the effects of pollutants on aquatic life and human health.

A. 4. b. Point Sources. The current program for control of wastewater discharges to streams is based primarily on the Federal Water Pollution Control Act of 1972. Allowable discharge must meet the more stringent of two separate requirements:

1. Maintenance of the receiving water's quality as specified in State water quality standards, ideally a quality suitable for "the protection and propagation of fish, shellfish and wildlife" and for "recreation in and on the water".
2. Minimum treatment requirements which are imposed uniformly nationwide and are based on the type, age, and size of the discharging facility.

These requirements are enforced through a permit program called the National Pollutant Discharge Elimination System (NPDES). The US Environmental Protection Agency (EPA) manages the NPDES program, although it may delegate program administration to qualified State agencies. In 1975 North Carolina received a delegation from EPA which allows the Division of Environmental Management to administer the NPDES program.

The major pollutants discharged from point sources include those wastes that deplete the dissolved oxygen in the water as they decompose, cause disease in man, stimulate undesirable growths of plants or algae in the water, and are toxic to fish, wildlife or humans. The efforts of the 1950s and 1960s focused primarily on the first two types of pollutants; organic matter which depleted the dissolved oxygen in the water and pathogenic bacteria.

The decomposition of organic substances in wastewater by aquatic organisms consumes dissolved oxygen. Significant reductions in the amount of dissolved oxygen can hinder fish propagation and, in more severe cases, can result in fish kills and odor problems. Wastewater facilities are generally classified according to the percentage of carbonaceous organic matter that is removed during treatment, which can be roughly summarized as follows:

| <u>Type</u> | <u>Percent Removed</u> |
|--------------|------------------------|
| No treatment | 0 |
| Primary | 40 |
| Secondary | 85 |
| Tertiary | 90 |
| Advanced | 95 |

In 1960, there were about 200 point sources in the North Carolina portion of the Albemarle-Pamlico area with a combined flow of 115 million gallons per day (mgd). Roughly one half of these facilities provided no treatment, a little over one third provided only primary treatment, and roughly 10% provided secondary treatment. The combined organic waste reduction was only about 13%. Today there are about 400 facilities with a combined flow of about 250 mgd. All facilities must provide at least secondary treatment and many are required to provide tertiary or advanced levels of treatment.

A variety of pathogenic bacteria exist in raw domestic wastewater. Waterborne diseases (such as typhoid fever, hepatitis, dysentery and cholera) are caused by bacteria in drinking water supplies that are contaminated by inadequately treated wastewater. Some bacterial maladies result from body contact in contaminated recreational waters. Waterborne diseases can also be spread when shellfish ingest pathogens that are then passed on to humans. Because so much untreated wastewater was being discharged in 1960, the Pollution Survey Reports recommended that numerous areas be closed to the taking of shellfish and cited unsafe conditions in several recreational areas such as Pantego Creek, Silver Lake, Pamlico River near Washington, Shallowbag Bay, sections of the Perquimans and Pasquotank Rivers, the Neuse River near New Bern, and the Colerain and Tuscorora Beaches. Disinfection is now required of all wastewater discharges with domestic components. While some areas in the vicinity of dischargers are closed to shellfishing as a safety precaution against accidents, no new domestic discharges are allowed in shellfishing waters. The emerging problems with new shellfish closures are generally related to nonpoint source inputs such as septic tanks, urban runoff, or agricultural operations.

Eutrophication has become a serious problem in several of the estuaries of the Albemarle-Pamlico area. The Chowan River was the first to experience massive algal blooms in the early 1970s, although less spectacular algal problems had been documented on the Tar-Pamlico system even earlier. The lower Neuse River began experiencing problems in the late 1970s. Point sources contribute about 15% of the North Carolina nutrient input to the Chowan, about 50% to the Neuse, and about 18% nitrogen and 75% phosphorus to the Tar-Pamlico. Strategies to reduce nutrients to the Tar-Pamlico, Chowan, and Neuse rivers have been adopted. Industrial point sources are also very important. For example, Texasgulf Inc. (TGI) is a major discharger of phosphate in the middle reaches of the Pamlico River estuary (Table III-4). Union Camp pulp mill in Virginia releases very large volumes of water to the Chowan River during winter, increasing the conductivity, color, turbidity, ammonium concentration, and phosphate concentration of the waters below their outfall (Kuenzler et al. 1982). Nine of the ten municipalities in the Chowan basin have gone to land disposal, eliminating their nutrient inputs. All dischargers over 0.5 mgd in the Neuse must reduce their phosphorus input by 1992.

"Toxic substances" include a variety of materials such as heavy metals (e.g., mercury, zinc, cadmium, lead, chromium, nickel and copper), pesticides (e.g., DDT, parathion, toxaphene, endrin, malathion and others), and many organic chemicals (e.g., polychlorinated biphenyls (PCB) and phthalate esters). Unlike oxygen-demanding wastes which degrade over time, toxic substances are often environmentally persistent and are classified as conservative pollutants. Toxicants are addressed in a comprehensive manner through the use of whole effluent toxicity testing. These tests employ sensitive aquatic species to determine if a wastewater discharge would be toxic to the receiving stream. There are currently 80 dischargers in the Albemarle-Pamlico estuarine area which are required to monitor their wastewater for toxicity. Of these facilities, 36 have permit limits for toxicity. The remaining 44 have permits, but no associated limits.

A. 4. c. Nonpoint Sources. Nonpoint source pollution (NPS) means pollution which enters waters mainly as a result of precipitation and subsequent runoff from lands that have been disturbed by man's activities. Obviously, there is the potential for wide variations in pollutant loadings with runoff from different types of land use under a variety of management regimes. This diversity and corresponding complexity, which arises in studying NPS pollution, makes it very difficult to accurately determine the magnitude of pollutants originating from diffuse sources. However, using a large watershed or river basin approach, pollution loading and land-use categories can be correlated in relatively quick and simple, first-cut NPS investigations (Novotny and Chesters 1981). After a preliminary land-use analysis is conducted for a watershed, more complicated efforts can be undertaken to further differentiate the diffuse sources of pollution.

A. 4. d. Availability of Information. In 1988, the Division of Environmental Management (North Carolina Department of Natural Resources and Community Development) conducted a water quality assessment of the Albemarle-Pamlico study area as part of the statewide Nonpoint Source (NPS) Assessment Report in order to determine impacts from nonpoint sources of pollution (NC Division of Environmental Management 1989a, 1989b). The assessment concentrated on waterbodies which fail to or only partially support their designated uses because of NPS pollution. Following is a description of methods employed to identify NPS pollution problems in the Albemarle-Pamlico estuarine study area.

Two types of information were utilized in the NPS Assessment Report in order to obtain an overall water quality rating which could be assigned to streams and stream segments. The first level is "monitored" waters and is based on current site-specific ambient data. The second level is "evaluated" waters and is based on information other than site-specific data, such as citizen complaints or best professional judgements. By using "evaluated" segments, a much broader, but less precise, picture of nonpoint source pollution can be developed.

The most recent source of "monitored" data used in the NPS Assessment Report was the 1986-87 305b Report (NC Division of Environmental Management 1989a, 1989b). In preparing the 305b Report, all available chemical and biological data from North Carolina's ambient biological and chemical monitoring network in the area were reviewed. Biological data collected during special benthic macroinvertebrate surveys were also utilized.

Another source of information which was used as a reference for the NPS Assessment Report was the Water Quality Assessment Document, which summarizes biological and chemical data (NC Division of Environmental Management 1985). Analyses for this document were based on benthic macroinvertebrate data from many point and nonpoint source studies, one-time surveys on benthic macroinvertebrates, recent research reports, fish collection records, wildlife resources survey and classification reports, and questionnaire results from fisheries biologists in various state agencies. Some references in the 1985 assessment report date back to the 1960s.

To determine overall water quality ratings, older chemical information from 1978 to 1985 was also used when appropriate. Additional chemical water quality data available from the U.S. Geological Survey (USGS) and other sources were gathered and added in order to obtain as much information about use-support as possible. In addition, workshops were held for federal, state, municipal, and county representatives and the general public. One goal of the workshops was to gather either data or educated judgments (evaluations) for streams, lakes and estuaries not rated at that time. Information was also obtained regarding point and nonpoint sources and causes of the partially supporting and non-supporting ratings (e.g., sediment or dissolved oxygen). All data, evaluations, and source information were added to the water quality monitoring data and overall water quality ratings were assigned to streams and stream segments.

Information was used to determine ratings in the order described below.

1. Biological Ratings generally were preferred over any other source of information since this is a direct measurement of long-term effects of water quality on aquatic life. Chemical data, however, were used to determine ratings for water supply segments.
2. Chemical Ratings were given second preference.
3. Workshop "Evaluations" or Best Professional Judgement were given third preference.
4. Assessment Document information was used when no other more recent information was available.

After overall ratings were assigned, sources of pollution (point or nonpoint) for partially supporting and non-supporting streams were sought (Tables III-6, III-8), as were the actual pollutants or causes of degradation (e.g., sediment, toxicants; Table III-7). The NC Division of Environmental Management Regional offices or workshops provided much of the information used for the monitored segments. Information on point sources, such as permit compliance records, was reviewed in order to find major dischargers potentially impacting streams. The Biological Assessment Group and the Aquatic Toxicology Unit of the Environmental Sciences Branch were consulted to identify facilities known to have toxic effects based on chronic and acute bioassays. Groundwater and precipitation were also considered as sources of nutrients and other substances.

The Shellfish Sanitation Branch within the North Carolina Department of Health and Human Resources is responsible for determining the status of shellfishing waters and keeps a historical record of the opening and closing of waters to the collection of shellfish. This is extremely valuable use-support information. With respect to this information, partially supporting waters are those that are permanently closed to shellfishing while support-threatened waters are those that are temporarily opened. Waters closed to shellfishing are considered partially supporting because they still support recreational and other aquatic life uses. Non-supporting areas are those with excessive algal blooms as noted by NC Division of Environmental Management regional offices and documented through special studies.

The NC Division of Environmental Management maintains chemical ambient monitoring stations in estuarine waters. Data from these stations were treated and rated in the same manner as the 1986-1987 chemical data for rivers and streams. It should be noted, however, that for saltwater, violations of metal standards were not used to determine use-support ratings since chemical analyses for metals are extremely sensitive to salinity levels.

Only rarely did shellfishing and chemical data conflict for a saltwater segment in determining overall ratings for estuarine areas. These ratings were reviewed by the NC Division of Environmental Management Water Quality regional staff, the NC Division of Shellfish Sanitation (Morehead City, NC), and during the workshops. Ratings were then modified accordingly. Evaluated areas (areas lacking data) were assigned the same use-support rating as the closest monitored areas within about 15 miles. Only the middle and northern Currituck Sound and the central portion of the New River were "evaluated"; the remaining estuarine areas were "monitored". Distribution of nonpoint source impacts on the estuary are given in Table III-1.

Workshops provided information on sources and causes of pollution for degraded areas. Other data or information used to determine sources and causes for degradation were the NC Division of Shellfish Sanitation Surveys, regional office special studies and data, and special water quality reports and studies. Sources of pollution that were suggested in the NC Division of Shellfish Sanitation Surveys or in other sources were evenly weighted to determine acres degraded. The actual pollutants or causes of degradation were either listed as the most important cause (often using best professional judgement)

Table III-6. Water Quality Ratings in the Streams of the Albemarle-Pamlico Estuarine Area. From the NC Division of Environmental Management (1989b).

| Water Quality Rating | Cumulative Length of Streams | Percentage of Total Stream Length |
|------------------------|------------------------------|-----------------------------------|
| Support | 4,427.1 | 48.7 |
| Partial and Nonsupport | 3,613.1 | 39.7 |
| Not Evaluated | 1,054.5 | 11.6 |
| Total | 9,094.7 | 100.0 |

Table III-7. Major Causes of Degradation in the Streams of the Albemarle-Pamlico Estuarine Area. From the NC Division of Environmental Management (1989b).

| Causes of Degradation | Extent of Degradation (mi) | Percentage of Degraded Miles |
|-----------------------|----------------------------|------------------------------|
| Sediment | 1,762.6 | 48.7 |
| Fecal Coliform | 36.1 | 1.0 |
| Dissolved Oxygen | 41.8 | 1.2 |
| Metals | 124.0 | 3.4 |
| pH 0.0 | 0.0 | |
| Ammonia | 0.0 | 0.0 |
| Chlorophyll <u>a</u> | 0.0 | 0.0 |
| Phosphorus | 0.0 | 0.0 |
| Multiple | 501.9 | 13.9 |
| Unknown | 1,155.7 | 31.9 |

Table III-8. Sources of Nonpoint Pollution Impacts in the Streams of the Albemarle-Pamlico Estuarine Area. From the NC Division of Environmental Management (1989b).

| Sources of Degradation* | Mileage+ | Percent of Total Degraded Stream Mi.** |
|---------------------------|----------|--|
| Nonpoint Sources (total) | 3,489.1 | 96.6 |
| Point Sources (total) | 441.6 | 12.2 |
| Agriculture (total) | 2,415.6 | 66.9 |
| Runoff | 510.7 | 14.1 |
| Animal Waste | 480.6 | 13.3 |
| Miscellaneous | 240.0 | 6.6 |
| Forestry (total) | 93.2 | 2.6 |
| Harvest | 94.5 | 2.6 |
| Forest Management | 5.3 | 0.1 |
| Construction (total) | 284.0 | 7.9 |
| Highways and Bridges | 0.0 | 0.0 |
| Land Development | 71.6 | 2.0 |
| Urban (total) | 376.8 | 10.4 |
| Sewers | 61.4 | 1.7 |
| Runoff | 104.4 | 2.9 |
| Miscellaneous | 17.4 | 0.5 |
| Mining (total) | 0.0 | 0.0 |
| Land Disposal (total) | 144.6 | 4.0 |
| Landfills | 63.6 | 1.8 |
| Septic Tanks | 89.5 | 2.5 |
| Miscellaneous | 39.8 | 1.1 |
| Hydromodification (total) | 227.9 | 6.3 |
| Channelization | 4.0 | 0.1 |
| Miscellaneous | 27.0 | 0.7 |
| Unknown | 591.8 | 16.4 |

* Partially and Non-supporting Streams Only. From EPA Source Codes.

+ Point source and nonpoint source impacted stream mileages were compiled from independent workshops and field research projects, so sub-totals may not correlate perfectly.

** Some double-counting of sources of degradation occurred, so percentages may not correlate perfectly.

or listed as one of multiple causes. In addition to the nonpoint source pollutants considered in freshwater streams, freshwater inflows to estuarine waters were considered as a nonpoint source pollutant. It should be noted that use classifications were based on "actual" use criteria, rather than "desired" use criteria, and that "supporting use" merely means that a body of water or stream has not been degraded enough to violate the actual use criteria.

B. STATUS OF MANAGEMENT ACTIVITIES

B. 1. Introduction

Several attempts have been made to limit nutrient inputs into the estuaries as a means of controlling eutrophication. This technique, however, is replete with problems. For phosphorus to be growth-limiting for phytoplankton of the Neuse River, for example, it has been estimated that input reductions of up to 60-80% of current levels would have to be achieved (Paerl and Bowles 1986; Paerl 1987). This is a formidable, if not impossible, task since perhaps 30-40% of the Neuse's phosphorus inputs can be considered as having natural, non-anthropogenic origins. The Neuse River system represents a somewhat extreme case in that ambient PO_4^{3-} concentrations are generally the highest of any major tributary emptying into the Albemarle-Pamlico estuarine system; levels of 100 to 450 $\mu\text{g/l}$ P- PO_4^{3-} are commonly found throughout the year (Paerl 1987). The Tar and Pamlico Rivers also contain quite high PO_4^{3-} concentrations (Stanley 1988b), but concentrations are somewhat diluted (50-300 $\mu\text{g/l}$ P- PO_4^{3-}) by the time the rivers discharge into the Pamlico River Estuary. In either case, PO_4^{3-} appears in excess of phytoplankton demands in the estuaries throughout much of the year.

The fact that PO_4^{3-} does not occur in concentrations that would limit growth, as do NO_3^- and NH_3 , does not necessarily mean that generally high levels of PO_4^{3-} discharge are not problematic. If, for example, NO_3^- input reductions are initiated as a means of controlling eutrophication in the form of nuisance blooms of the non-nitrogen-fixing blue-green alga Microcystis aeruginosa, it is conceivable that nitrogen fixing blue-green algae such as Anabaena and Aphanizomenon will replace M. aeruginosa. To control the growth and proliferation of nitrogen fixing blue-green algae, only one feasible management option remains--concurrent phosphorus input constraints. Hence, dual nutrient (nitrogen and phosphorus) input controls should be practiced in this as well as other systems susceptible to blue-green algal blooms.

Another argument for dual nutrient input control is based on recent findings (Paerl et al. 1990 and Rudek et al. 1991) concerning high runoff during spring months which combine the influences of excessive nitrogen loading (chiefly as NO_3^-) and dilution of phosphorus by rainfall. This combination can result in periods of phosphorus and nitrogen co-limited growth conditions in the lower Neuse River Estuary-Pamlico Sound region (see Figure III-6). It would appear that the combined impacts of heavy and, since the 1940s, increasing nitrogen fertilization, increased atmospheric nitrogen loading in rainfall (due to the enhanced generation of the oxides of nitrogen), and more recently, improved sewage treatment and a phosphate detergent ban decreased phosphorus loading to the region. All contribute to a phosphorus limited period in the estuaries. Whether or not such a phosphorus limited period characterized the Albemarle-Pamlico estuarine system in previous decades is unknown.

Besides studying land-use trends and their potential relationships to water quality, it is interesting to note the evolution of efforts to control NPS pollution. In addition to the National Estuary Program (Section 320 of the Water Quality Act of 1987), there are eight major initiatives that have been taken to understand and control NPS pollution within the Albemarle-Pamlico estuarine system area. These initiatives represent a trend toward increasing responsibility at the federal, state, and local levels to implement the proper mix of regulatory and voluntary controls.

B. 2. Section 208

Traditionally, pollution control efforts were directed toward point sources. In 1972, however, Section 208 of the Federal Water Pollution Control Act Amendments (Area-wide Waste Treatment Management) emphasized both point and nonpoint source pollution control. States were directed to develop plans that would specify actions needed to upgrade water quality on a statewide basis and recommend management agencies that would be responsible for plan implementation. These management plans were to be used by the implementing agencies to direct their efforts in water pollution control. The State of North Carolina developed water quality management plans for agriculture, construction, forestry, mining, on-site wastewater treatment, solid waste, and urban stormwater management.

B. 3. Sedimentation Control

The North Carolina General Assembly enacted the Sedimentation Pollution Control Act in 1973. The Act authorized the establishment of a sediment control program to prevent accelerated erosion and off-site sedimentation caused by land-disturbing activities other than agriculture, forestry, and mining. The Land Quality Section of the NC Division of Land Resources is responsible for administration and enforcement of the requirements of the Act under the authority of the NC Sedimentation Control Commission. The sediment control program requires, prior to construction, the submission and approval of erosion control plans on all projects disturbing one or more contiguous acres. On-site inspections are conducted to determine compliance with the plan and to evaluate the effectiveness of the best management practices (BMPs) that will be used. The intent is to offer permanent downstream protection for stream banks and channels from damages caused by increased runoff velocities. If voluntary compliance with the approved plan is not achieved and violations occur, the Land Quality Section will pursue enforcement through civil penalties and injunctive relief.

B. 4. Coastal Area Management Act

In order to foster protection of sensitive coastal areas, the North Carolina General Assembly enacted the Coastal Area Management Act (CAMA) in 1974. One major goal of the Act was to provide protection of areas of environmental concern (AEC) by requiring permits for development in these areas. The NC Division of Coastal Management (NC DEHNR) is responsible for administration of the program. Ideally the program is a cooperative effort between state and local governments. State and local governments are both responsible for enforcement of the Act while local governments hold the initiative for planning.

There are three major areas of responsibility for the NC Division of Coastal Management in implementing CAMA. First, land use plans are to be developed by each coastal jurisdiction under supervision of the state for the protection and appropriate development of AECs. Second, a permit is required for all development or land disturbing activity in an AEC. A "major" permit is required if the development is in excess of 20 acres, requires drilling or excavation on land or underwater, or the structure is greater than 60,000 sq. ft. in size. Anything other than "major" development requires a "minor" permit, which is administered by the local government. Finally, a consistency review is made of federal projects to ensure that the policy and provisions of CAMA are satisfied.

B. 5. Nutrient Sensitive Waters

To address the need for limiting nutrients in certain waters, the NC Environmental Management Commission (EMC) adopted a nutrient sensitive waters (NSW) classification in May of 1979. This classification gave the EMC the authority to limit the input of nutrients into waters experiencing or subject to excessive growths of microscopic or macroscopic vegetation. If necessary, the NSW classification could include all waters in a river basin. Because of a history of algal blooms, the Chowan River was designated NSW in September 1979 and the lower Neuse River (below Falls Lake) in May 1988.

B. 6. Agriculture and Forestry Cost Share Programs

Two nonpoint source cost share programs evolved from the NSW classification with the purpose of reducing nonpoint source pollution for water improvement. The North Carolina General Assembly appropriated funds in 1984 to assist landowners from 16 counties within the NSW watersheds of the Chowan River, Falls Lake, and Jordan Lake to implement BMPs. The NC Environmental Management Commission designated these watersheds "NSW" due to severe eutrophication problems caused by point and nonpoint sources. Each watershed was seriously affected by soil erosion from agricultural lands and by corresponding nutrient and sediment problems. A general statute (NCGS Article 21, Chapter 143) expanding the program to include 17 counties in the Albemarle-Pamlico region was added in 1986. The program was expanded in 1989 to include all counties in North Carolina. It should be noted that the program currently covers the entire Albemarle-Pamlico estuarine area.

In targeted areas, the cost share program will pay up to 75% of the cost of implementing a system of approved BMPs. Technical assistance is available to the landowners or users that would provide the greatest benefit for water quality protection.

The NC General Assembly also appropriated funds in 1984 to establish a Forestry Cost Share Program to compliment existing programs to control point source discharges, agricultural runoff, and urban runoff. The purpose of the program is to protect the quality of soil and water resources in watersheds through the use of accepted forestry BMPs. The Division of Forest Resources is responsible for administering the program, which will pay landowners up to 75% of the cost of implementing BMPs.

B. 7. Food Security Act of 1985 and 1990 Farm Bill

Several provisions authorized by the Food Security Act of 1985 (FSA) and 1990 Farm Bill offer excellent opportunities for the abatement of agricultural nonpoint source pollution in the Albemarle-Pamlico Estuary area. The FSA makes the goals of the US Department of Agriculture farm and conservation programs more consistent by encouraging the reduction of soil erosion, the reduction of production of surplus commodities, and the protection of wetlands. The provisions can also serve as tools to remove from production those areas which critically degrade water quality by contributing to sedimentation. The provisions are known as the Conservation Reserve, Conservation Compliance, Sodbuster, Swampbuster, and Conservation Easement.

The Conservation Reserve Program (CRP) is administered by the U.S. Department of Agriculture Agricultural Stabilization and Conservation Service (ASCS) and the US Soil Conservation Service. Other cooperating agencies include the NC State University Agriculture Extension Service, NC Division of Forest Resources, and Local Soil and Water Conservation Districts. The CRP was established to encourage the removal of highly erodible land from crop production and to promote planting long-term

permanent grasses and tree cover. The ASCS will share up to half of the cost of establishing protective cover. The intention of the Program is to protect the long term ability of the United States to produce food and fiber by reducing soil erosion, improving water quality, and improving habitat for fish and wildlife. Additional objectives are to curb the production of surplus commodities and to provide farmers with income supports through rental payments over a 10-year contract period for land entered under the CRP. The 1990 Farm Bill extended this contract period to 30 years. Vegetative filter strip establishment has been incorporated into the CRP and has great potential for environmental benefits. Some of the benefits include improved water quality and wildlife habitat. Active steps have been initiated to obtain farmer participation in the Program.

The Conservation Compliance provision of the FSA discourages the production of crops on highly erodible cropland where the land is not carefully protected from erosion. Highly erodible land is defined as land where the potential erosion (erodibility index) is eight times or greater than the rate at which the soil can maintain continued productivity. This rate is determined by the US Soil Conservation Service. A conservation plan must be developed by January 1, 1990 and fully operational by January 1, 1995. If a soil survey is not available, the farmer has two years after soil mapping is completed to develop and begin applying a conservation plan. If a conservation plan is not developed and implemented, the farmer loses eligibility in price and income supports, crop insurance, Farmers Home Administration loans, Commodity Credit Corporation storage payments, farm storage facility loans, Conservation Reserve Program annual payments, and other programs under which US Department of Agriculture makes commodity-related payments.

The Sodbuster provision of the FSA is directed toward discouraging the conversion of highly erodible land for agricultural production. It applies to highly erodible land that was not planted in annually tilled crops during the period 1981-85. As with other provisions of the FSA, the US Soil Conservation Service determines if a field is highly erodible. If a highly erodible field is planted in an agricultural commodity without an approved conservation system, the landowner (or farmer) becomes ineligible for certain US Department of Agriculture program benefits.

The purpose of Swampbuster is to discourage the conversion of wetlands to cropland use. Wetlands are defined as areas that have a predominance of hydric soils which are inundated or saturated by surface water or groundwater at a frequency or duration sufficient to support a prevalence of hydrophytic (water-loving) vegetation. It is the responsibility of the US Soil Conservation Service to determine if an area is a wetland. Like the other provisions of the FSA, a farmer will lose eligibility for certain US Department of Agriculture program benefits on all the land farmed if a wetland area is converted to cropland.

The Conservation Easement provision encourages producers whose Farmers Home Administration (FHA) loans are in or near default to place their wetland, highly erodible land and/or fragile land in conservation, recreation or wildlife uses for periods of at least 50 years. The producer benefits by having the FHA loan partially cancelled. Environmental benefits include reducing the level of soil disturbing activities and the threat of agricultural pollutants.

The Wetlands Reserve Program of the 1990 Farm Bill was established to restore 1 million acres of former wetlands over a five year period. The federal government will compensate owners of the previously converted cropland, rangeland, and pastureland who voluntarily transfer their property rights as permanent conservation easements to the reserve. The conditions of the conservation easements should prohibit the landowner from further development or alteration of the land. Also, much of the cost of improvements to these lands to enhance their wetlands functions will be paid by the federal government.

B. 8. Coastal Stormwater Management Regulations

Coastal stormwater control has become an increasingly important issue as development continues. The initial debate focused primarily on stormwater and the closure of shellfish waters. In November 1986, the EMC adopted rules which required new development in a limited zone (575 feet) around Class SA (shellfish) waters to control stormwater either by limiting density or completely controlling a 4.5 inch, 24-hour storm with the use of a stormwater treatment system. The regulations applied to development activities which required either a CAMA major permit (through the NC Division of Coastal Management) or a Sediment/Erosion Control Plan (through the NC Division of Land Resources). The design storm, low-density limits, and areal coverage were all quite controversial and the adopted rules represented a compromise by all parties. A sunset provision was added to the rules to force the NC Division of Environmental Management (and Commission) to reconsider the rules after a year. The original rules expired December 31, 1987.

New stormwater regulations with an effective date of January 1, 1988 were subsequently adopted with similar requirements except the design storm was changed to the 1.5 inch, 24-hour storm. The new regulations apply the stormwater controls to development activities within all 20 CAMA coastal counties, and so includes those counties surrounding the Albemarle-Pamlico estuary system. While the near-water impact of stormwater is very important, as addressed in the original rules, the cumulative impact of stormwater runoff throughout the coastal zone also needed to be addressed. Therefore, the expanded area of coverage helps provide protection of both shellfish waters and general coastal water quality.

Other major items specified in the new rules address the sizing of stormwater treatment systems, innovative infiltration systems, and low-density options. For developments adjacent to SA waters, infiltration systems must be able to retain runoff from 1.5 inches of rainfall in 24 hours; whereas, development in other areas must control only 1 inch of rainfall. Wet detention ponds are not allowed for stormwater control near SA waters and must be sized for 85-90% total suspended solids removal in other areas. Porous pavement is considered an innovative infiltration system (only five are to be allowed until they are proven to work), but evidence regarding its effectiveness in coastal areas has not yet been provided. A low-density option of the new regulations applies a "built-upon" limit of 25% for SA areas and 30% for other coastal areas. Development exceeding these levels is required to have an engineered stormwater system.

B. 9. Section 319

The federal Water Quality Act (WQA) of 1987, which was essentially the reauthorization of a similar act passed in 1972, emphasized nonpoint source pollution control as well as conventional point source control. According to Section 319 of the WQA, each state must develop strategies for managing nonpoint source pollution. In North Carolina, the Water Quality Section of the NC Division of Environmental Management was designated as the coordinating agency for nonpoint source pollution management.

Two reports were prepared in fulfillment of Section 319 (NC Division of Environmental Management 1989a, 1989b). The first report focuses on identifying the causes and sources of nonpoint source (NPS) pollution for impaired waterbodies in the Albemarle-Pamlico Estuarine area. The second report emphasizes management strategies and programs to address the nonpoint source problems identified in the assessment report. The NPS Management Program balances two priorities. One priority is to implement the overall NPS Program which includes regulations, technical and financial assistance, and educational efforts. The second priority involves targeting specific watersheds to improve degraded water quality or minimize nonpoint source impacts on high quality waters. Ideally, the watersheds selected are ones which can demonstrate water quality benefits from NPS projects within the four-year time span

mandated in Section 319 of the Water Quality Act of 1987. It is recognized, however, that the time needed to demonstrate water quality improvements may often exceed four years.

The approach of controlling NPS pollution in the Albemarle-Pamlico estuarine area (and throughout North Carolina) is through a combination of land-use controls and technology-based BMPs. In urban areas, the preferred method of treatment is land use control through low-density development because of the long-term maintenance requirements associated with structural BMPs. In situations where low-density development is not feasible, stormwater controls devices (BMPs) are allowed. Nonpoint source strategies for other categories of pollution (e.g., agriculture, construction, or mining) depend more on the implementation of BMPs such as setbacks or filter strips, and waste reduction/management systems. The installation of these BMPs and management systems may be voluntary or required by regulations.

C. EVALUATION OF TRENDS

C. 1. Historical Perspective and Current Trends

C. 1. a. General Statement. Accelerated nutrient loading, particularly over the past 2 to 3 decades, has ushered in some ominous and increasingly common symptoms of eutrophication which, to the best of our knowledge, were extremely rare prior to World War II. Prior to the late 1960s virtually no field surveys yielding quantitative data on nitrogen and/or phosphorus concentration or loading characteristics can be documented for North Carolina's coastal waters, including major river systems and estuaries.

Several early reports describe hydrologic, hydrographic, and very limited chemical characteristics of specific waters (Dubach 1977). The first extensive field surveys specifically oriented towards identifying concentrations, sources and sinks as well as some bio-geochemical cycling characteristics of nitrogen and phosphorus occurred in the 1960s and 1970s (Copeland and Hobbie 1972; Hobbie et al. 1972; Harrison and Hobbie 1974; Kuenzler et al. 1982) for the Pamlico River Estuary. Bowden and Hobbie (1977) initially described nutrient characteristics of the Albemarle Sound, Hobbie and Smith (1975) examined nutrients in the Neuse River, while Stanley and Hobbie (1977) reported on nitrogen cycling in the lower Chowan River.

During the mid 1970s the NC Division of Environmental Management and the US Geological Survey developed and deployed monitoring networks in coastal regions that included nutrient analyses. Relevant river and estuarine systems included were the Chowan-Albemarle, Roanoke, Tar-Pamlico and Neuse. Throughout the 1970s and early 1980s more specific and goal-oriented nutrient/eutrophication studies on these systems and their watersheds were initiated. Included were examinations of nutrient uptake kinetics of phytoplankton in the Pamlico (Kuenzler et al. 1982), Chowan (Stanley and Hobbie 1977; Kuenzler et al. 1982), and Neuse (Stanley 1983) Rivers, and determinations of algal growth requirements including nutrient limitations through the use of bioassays in the Chowan (Witherspoon et al. 1979; Sauer and Kuenzler 1981; Paerl 1982a, 1982b) and Neuse (Paerl 1983) Rivers.

Origins, processing, and runoff characteristics of agricultural field sites were likewise investigated by Gilliam et al. (1978), while Kirby-Smith and Barber (1979) evaluated the potential estuarine water quality impacts of converting forest to intensive agriculture, with particular reference to nutrient discharge alterations. Skaggs et al. (1980) have more recently monitored effects of land development on the chemical characteristics of drainage water in Eastern North Carolina. Matson et al. (1983) and Kuenzler et al. (1984) examined biogeochemical processing and cycling of nitrogen and phosphorus compounds in sediments of the Neuse Estuary, while Kuenzler et al. (1982) addressed similar questions in the Chowan River. Meanwhile, water quality models (based in large part on nutrient dynamics) were being developed for the Chowan (Amein and Galler 1979) and Pamlico (Lauria and O'Melia 1980)

Rivers. More recent modeling efforts have incorporated both physical (flow, discharge, salinity stratification, light) as well as nutrient factors into predicting trophic states and nuisance bloom characteristics of coastal rivers (Christian et al. 1986; Lung and Paerl 1988). Information is extensive for the Pamlico system but limited for the Albemarle.

Recognition of quantitatively important nutrient input sources, refinement of research techniques, and discovery of additional nutrient discharge and cycling factors have led to recent studies in the areas of nitrogen losses from agricultural drainage areas (Jacobs and Gilliam 1983), strategies for reducing agricultural nonpoint input sources (Humenik et al. 1983), and identification and partitioning of point and nonpoint nutrient inputs within watersheds (Craig and Kuenzler 1983). Bioassay techniques have been developed to facilitate potentially limiting nutrients under highly enriched hypereutrophic conditions (Paerl and Bowles 1986; Paerl 1987) and to help prioritize and set specific target levels for future nutrient reduction levels effective in curbing "runaway eutrophication" and associated nuisance blooms.

C. 1. b. Neuse River Estuary Water Quality Trends: Basin Land Use and Nutrient Loading. An important analysis of the land uses and nutrient loading in the Neuse River basin was completed by Stanley (1988a). The summary below was taken from that study. According to estimates made in the study, basin-wide changes in acreages of major land use categories have been small in the Neuse region during the past century (Figure III-12). Total agricultural cropland acreages have varied somewhat since 1930, ranging from highs of 25-27% of the total basin area in 1945 and 1980 to a low of 16% in 1970. Forestland declined gradually from around 75% of total basin area in the late 1800s to around 64% of the total by the 1930s and has changed little since then. A detailed county-by-county analysis showed that cropland acreage has increased substantially in recent years in some of the coastal areas, while declining in the Piedmont areas.

The percentage of total land area in the watershed devoted to cropland has remained nearly constant at around 20-25%, but some crops are much more economically important now than in the past, while others have become less important over the years. In terms of acres harvested, corn has been dominant in the Neuse basin throughout the past century, accounting for between 290,000 and 450,000 acres (115,000-175,000 ha), or roughly 40-50% of the total cropland. Soybeans, the second most widely planted crop today, were first planted in significant acreages in the 1930s and 1940s, but until about 1960 never made up more than 5-10% of the total. By 1985, however, there were 290,000 acres (117,450 ha) of soybeans, roughly one-third of the total harvested cropland (Stanley 1988a).

On the other hand, acreages of tobacco and especially cotton have declined in the Neuse basin. Annual tobacco plantings peaked in the 1930s and 1940s at around 230,000 acres (93,000 ha), but now are down to around 60,000 acres (24,300 ha), or approximately 7% of total cropland. Cotton production in the basin was very important up until the 1930s, but then it declined rapidly and had practically ceased by about 1970. At its peak in the 1920s, cotton was the second most widely planted crop, taking up as much as 35% of the total cropland in some years. Wheat and other small grains have never been dominant crops in this area. In 1985 only about 15% of the Neuse basin cropland (120,000 acres or 48,600 ha) was devoted to wheat. Hay crops are a minor part of the total cropland use today (<5% of total). This crop was slightly more important in the past, but was never dominant (Stanley 1988a).

In every census since 1880, swine have been the most numerous large farm animal in the Neuse basin (Figure III-13). Between 1880 and 1940, the swine inventory fluctuated between 150,000 and 200,000 head, but since 1945 it has risen steadily so that currently there are about 500,000 of these animals. Cattle numbers, on the other hand, have ranged between 25,000 and 75,000, but with no particular pattern; the numbers in recent years are no higher than those 100 years ago. Inventories of mules peaked in the 1940s at around 50,000, but they, along with horses and sheep, have become an insignificant part of the total in the past two decades. Thus, the overall pattern of change in large farm

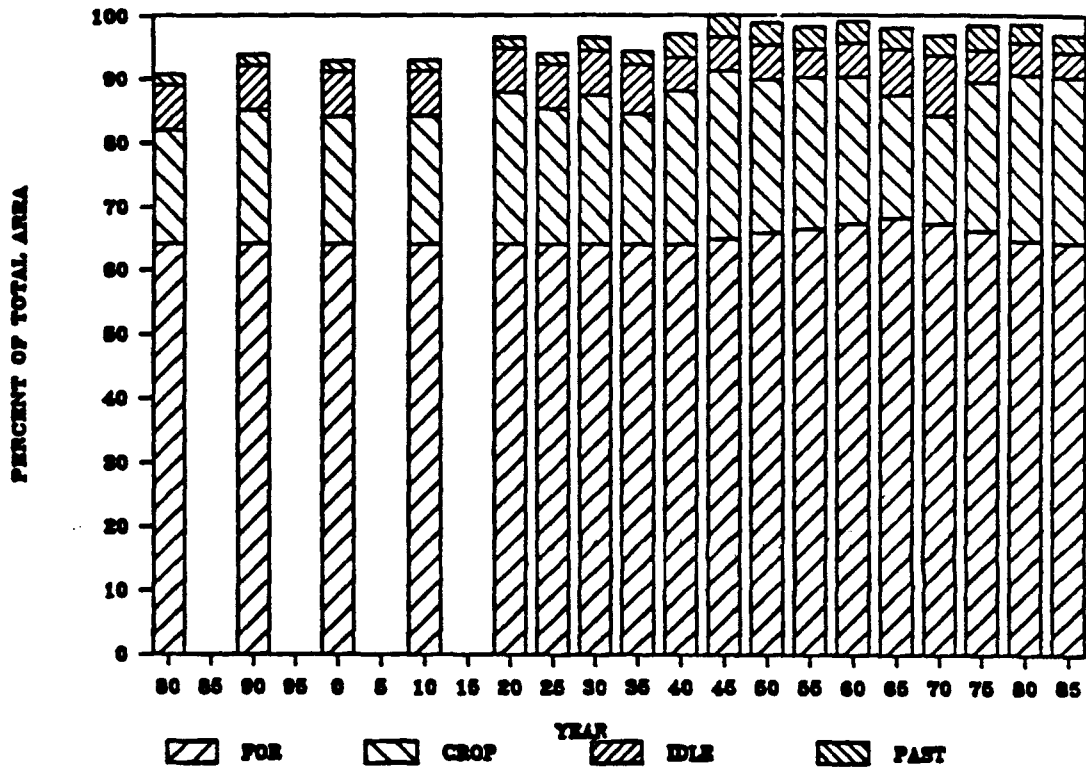


Fig. III-12. Land Use in the Neuse River Basin, 1880-1985. From Stanley (1988a).

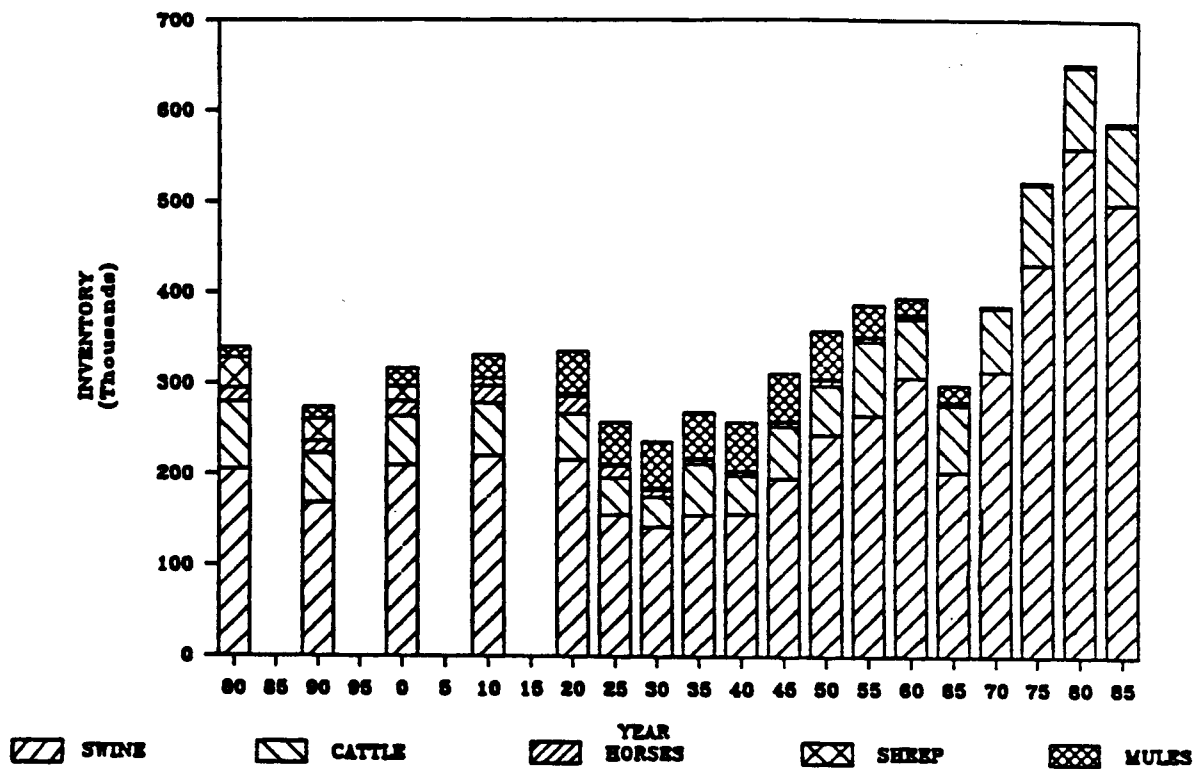


Fig. III-13. Inventory of Large Farm Animals, 1880-1985, in the Neuse River Basin, Poultry not Included. From Stanley (1988a).

animals inventory in the Neuse basin during the past century is dominated by the doubling in swine numbers (Stanley 1988a).

Poultry numbers in the Neuse basin have increased dramatically in the past two decades. The total poultry inventory (broilers, chickens, and turkeys) grew slowly from around 0.4 million in 1880 to approximately 1.6 million in 1960. Since then, however, poultry inventories have increased at an amazing rate, so that by 1985 there were over 8 million.

The estimated sewered population in the Neuse basin has increased steadily over the past century to 440,000 in 1985 (Stanley 1988a). Most of these people live in the upper half of the watershed, particularly in the Durham-Raleigh area. Conventional secondary treatment removes little phosphorus and only about 25-45% of the nitrogen (Gakstatter et al. 1978). When these treatment efficiencies are combined with historical data on the types of treatment practiced by municipal plants in the Neuse basin, it becomes clear that before 1950 there was no significant nitrogen or phosphorus removal from wastewater discharged into the river. As secondary treatment came into widespread use in the 1950s and 1960s in the Neuse basin, the overall nutrient removal efficiencies increased, but there has been little additional improvement in the last 10 years because further increases in treatment efficiencies have not occurred. Consequently, even now only about 27% of the Neuse basin total point source nitrogen and less than 2% of the total point source phosphorus are removed by treatment.

Total annual phosphorus loading from all Neuse basin sources (point and nonpoint) is estimated to have increased about 60% over the past century, from 1.04 million kg/year in 1880 to 1.7 million kg/year in 1985 (Figure III-14). Most of that increase has occurred during the past 40 years and appears to be due primarily to increases in point source phosphorus (i.e., increases in sewered population). In 1880, point sources accounted for only about 2% of the total load, compared to 42% from forests, 24% from cropland, 12% from farm animals, 18% from idle cropland, and 2% from pastures. In 1985 the point source phosphorus was 30% of the total. The farm animal contribution also has increased, from 0.13 million kg/year in 1880 to 0.25 million kg/year in 1985. Phosphorus from the other sources (cropland, forests, idle cropland and pastures) has not increased significantly; this is not surprising since the acreages of these land use types have not increased.

Total annual nitrogen loading is estimated to have increased 70% during the past 100 years, from 4.6 million kg/year in 1880 to 7.8 million kg/year in 1985 (Figure III-15). Like phosphorus, the rate of increase in nitrogen loading has not been constant. The loading increased until the mid-1950s, then declined slightly before increasing rapidly in the 1970s and 1980s. This pattern can be explained, in part, by improvements in nitrogen removal at waste treatment plants in the 1950s and 1960s, which tended to slow increases in point source loading that were occurring as the sewered population grew. But with no further improvement in the nitrogen removal efficiency since the mid-1970s, the nitrogen loading began to increase sharply as population continued to increase. Another factor leading to reductions in nitrogen loading in the late 1960s was the temporary reduction in cropland acreages which reduced cropland nitrogen runoff.

Point source increases have contributed significantly to the increased nitrogen loading. In 1880, only 2.5% of the total nitrogen was from point sources, compared to 55% from croplands, 19% from forests, 14% from farm animals, and the remainder from pasturelands and idle croplands. By 1985 the point source nitrogen contribution had increased to 24% of the total. Farm animal nitrogen also had nearly doubled and made up 14% of the estimated total.

The 1985 estimated total nitrogen and phosphorus loadings presented here (Stanley 1988a) are consistent with estimates prepared recently by the NC Division of Environmental Management (1989b). The NC Division of Environmental Management (DEM) calculated, by methods similar to those used by Stanley, that current total annual nitrogen and phosphorus loadings are 6.24 million kg/year and 1.0 million kg/year, respectively. DEM estimates are only 80% and 68%, respectively, of Stanley's nitrogen

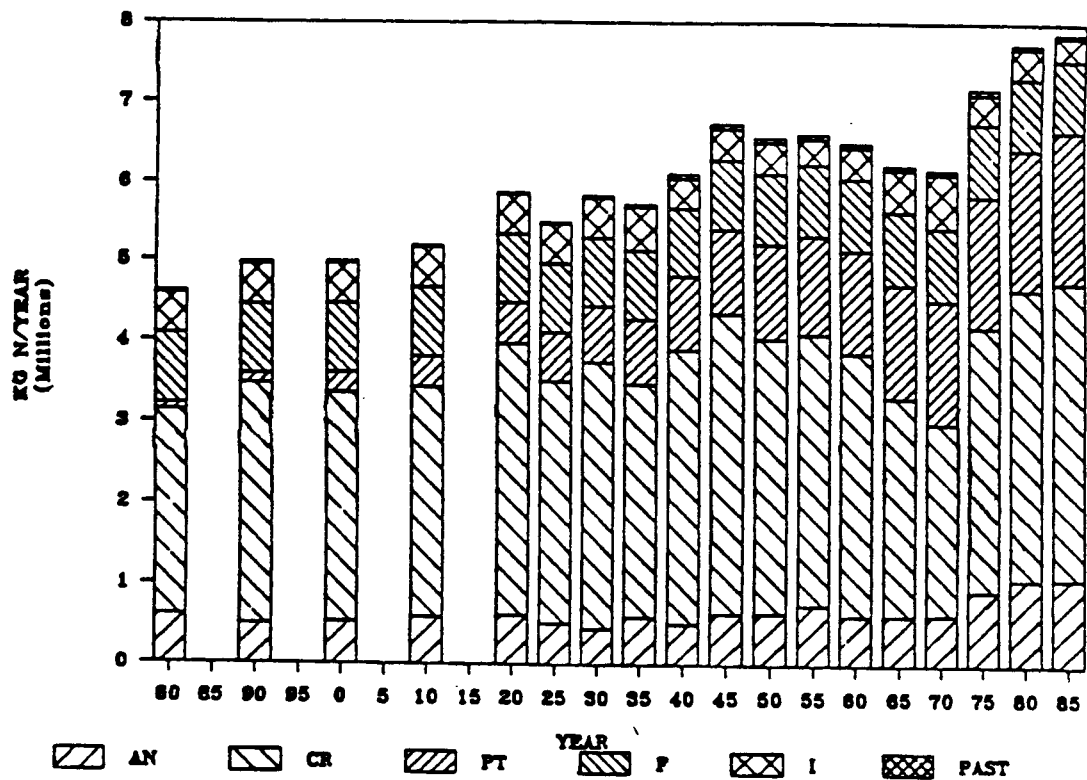


Fig. III-14. Estimated Nitrogen Loading to the Neuse River Estuary, 1880-1985. AN = Farm Animals, CR = Cropland, PT = Point Sources, F = Forestland, I = Idle Cropland, and PAST = Pastureland. From Stanley (1988a).

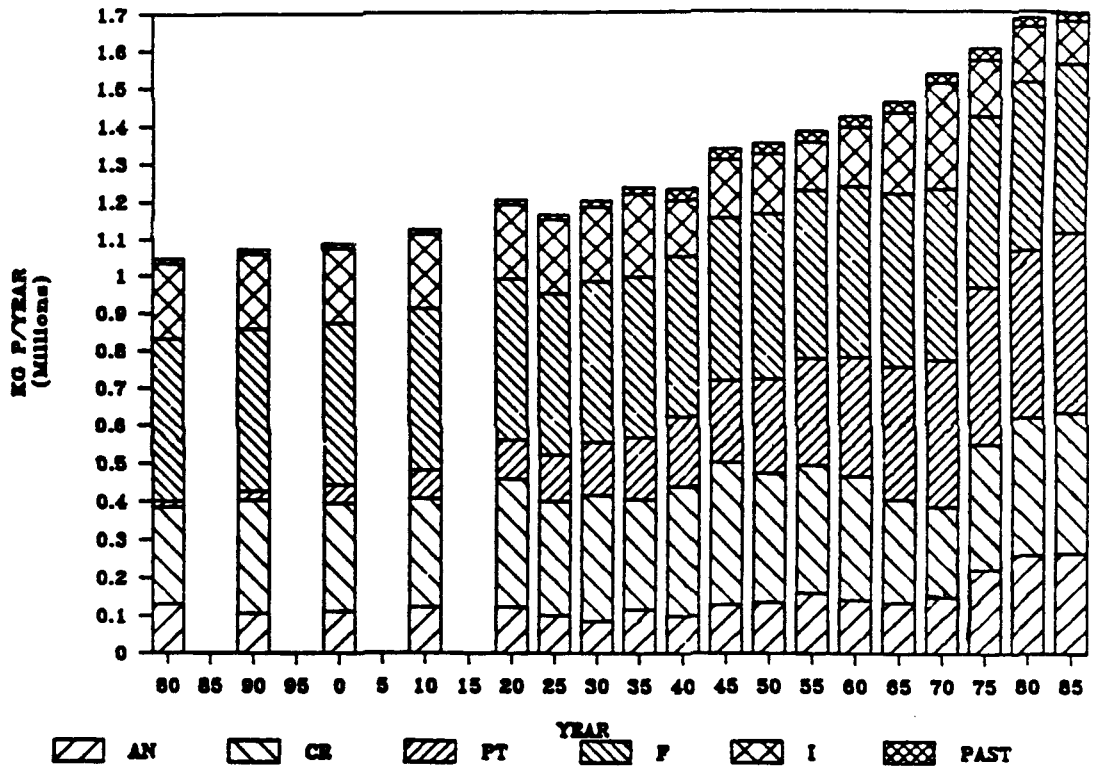


Fig. III-15. Estimated Phosphorous Loading to the Neuse River Estuary, 1880-1985. Symbols same as in Fig. III-14. From Stanley (1988a).

and phosphorus loading estimates. DEM, however, did not include that part of the basin downstream from New Bern (about 24% of the total) nor did they present historical estimates for additional comparisons.

Although there are no good historical instream data that could be used as a check on the estimates presented by Stanley (1988a), there are some recent instream data for comparison. Christian et al. (1987), working in the lower Neuse River above New Bern, multiplied nitrogen and phosphorus concentrations from grab samples by mean daily river flows to give total annual instream loading estimates. Their results, 3.5 million kg/year of nitrogen and 0.8 million kg/year of phosphorus, are about twice the estimates of expected loading developed by Stanley (1988a). This difference is similar to what Craig and Kuenzler (1983) found in a similar comparison for the Chowan River. Their explanation was that lowland swamp forests along these coastal rivers represent a major sink for nutrients; removing, for example, 83% of the total nitrogen and 51% of the total phosphorus from water draining into the lower Chowan. Such losses are within the range of values derived from detailed input-output studies of swamp forests within the Southeast (Craig and Kuenzler 1983).

Stanley (1988a) noted that his estimates of nitrogen and phosphorus loading in the past may have been too low because he did not take into account the large increase in fertilizer use that has occurred in the Neuse basin over the past 50 years. Phosphorus fertilizer use increased in the 1930s and 1940s, but has remained nearly constant since. Meanwhile, however, there has been a very rapid rise in the amount of nitrogen fertilizer sold. In fact, annual sales have increased about 10-fold during the last half-century, from 6 million kg/year in 1933 to about 60 million kg/year in 1984. The increases in fertilizer usage probably have increased the annual losses of the nutrients from croplands. The loading coefficients that Stanley used are based mostly on recent studies under high fertilization rate conditions. Actual loading coefficients were probably lower in the past when less fertilizer was being applied to the croplands. For example, assuming that only 5% of the additional fertilizer applied to crops is lost to the streams draining the farmland, the 50 million kg/yr difference in nitrogen used in 1932 and in 1984 would result in a 2.5 million kg/year difference in loss of nitrogen from croplands. In other words, the actual loss of nitrogen from croplands in 1932 might have been 2.5 million kg/year less than Stanley estimated (i.e., actually 0.2 million kg/year rather than the 2.7 million kg/year estimated). Of course, crop yields have increased dramatically over the past 50 years, and a substantial fraction of the added fertilizer went into the increased harvest. There is no way to be sure what percentage of added nutrient is actually lost in runoff.

One way to deal with the effects of changing fertilizer use and harvest is to construct mass balance models for each crop, rather than to simply use a constant loading coefficient as Stanley did in his calculations. Craig and Kuenzler (1983), and others, have used the mass balance approach to identify all the significant inputs, storage, and outputs of a particular nutrient within a defined system (e.g., cropland, pasture or forest). The advantages of this approach are obvious, but there are disadvantages associated with having to make estimates of numerous process rate coefficients such as those for denitrification, erosion, and nitrogen fixation.

It is clear from the historical trend information presented above that the rapidly increasing farm animal numbers, particularly swine and poultry, in the Neuse basin, could lead to greatly increased nitrogen and phosphorus loading. Stanley assumed that only 5% of the nutrients produced by farm animals is lost to the Neuse River drainage, however, if the loss were increased to 10 or 15%, there would be a substantial impact on the total nutrient loads. Such an increase may not be unrealistic, given that many of these animal operations involve the use of feed lots or buildings in which hundreds (swine) to tens-of-thousands (poultry) of animals are confined in very small areas. In such cases, these could become point discharges and, indeed, the wastes are now often treated by aeration lagoons or other techniques similar to those employed by conventional municipal treatment plants. Unfortunately, the animal waste treatment facilities are not as strongly regulated as municipal point sources, but North

Carolina State officials are becoming increasingly aware of the potential problems (NC Division of Environmental Management (1989a).

Phytoplankton community composition, productivity, and biomass characteristics of the mesohaline lower Neuse River Estuary were assessed monthly from May 1988 through February 1990 (Mallin et al. 1991). An incubation method which considered water column mixing and variable light exposure was used to determine phytoplankton primary productivity. The summer productivity peaks in the shallow estuary were stimulated by increases in irradiance and temperature (Figure III-16), however, dissolved inorganic nitrogen loading was the major factor controlling ultimate yearly production. Dynamic, unpredictable rainfall events determined magnitudes of seasonal production pulses through nitrogen loading and helped determine phytoplankton species composition. Dinoflagellates occasionally bloomed and were present in moderate numbers, but rainfall events produced large pulses of cryptomonads, and dry seasons and subsequent higher salinities led to dominance by small centric diatoms. Daily production was strongly correlated ($r = 0.82$) with nitrate concentration and inversely correlated ($r = -0.73$) with salinity, while nitrate and salinity were inversely correlated ($r = -0.71$), emphasizing the importance of freshwater input as a nutrient loading source to the lower Neuse River Estuary. During 1989, mean daily areal phytoplankton production was 938 mgC/m^2 , mean chlorophyll *a* was 11.8 mg/m^3 , and mean phytoplankton density was 1.56×10^3 cells/ml. Estimated 1989 annual areal phytoplankton production for the lower estuary was 343 gC/m^2 .

C. 1. c. Pamlico River Estuary Water Quality Trends. A detailed analysis of historical trends in nutrient data for the Pamlico River Estuary has been developed by Stanley (1988b). A non-parametric trend test (Kendall Seasonal Trend Test) gave information on the statistical significance and magnitude of trends over the last twenty years for each of the various water quality measures. Since no single station in the Pamlico has been monitored continuously since 1967, the estuary was divided into segments and monthly averages for each segment were used in the trend analysis. Data from upriver, mid-river, and downriver areas of the estuary were analyzed for trend. A review of the Pamlico sampling and analytical methods used since 1967 showed that ammonia nitrogen data from 1975-1979 could not be used in the trend tests, and that changes in total dissolved nitrogen and total nitrogen methods were substantial and might interfere with comparisons between the two major studies. Also, there was evidence that data from the two phytoplankton studies were not comparable. For the other hydrographic and nutrient parameters, the methodological changes were not deemed serious enough to interfere with the trend analyses.

Three climatic variables and Tar River discharge were tested for trends because such trends, if they existed, might be linked to trends in the water quality variables. However, air temperature, wind velocity, precipitation, and river flow either showed no trend or, in the case of air temperature, a very slight ($0.13 \text{ }^\circ\text{F}$) upward trend. There were, however, several 1- to 3-year periods of unusually high or low river flows.

The Seasonal Kendall test indicated no significant trends in surface or bottom water temperature. Trends in salinity were detected for some river segments, but the changes were very small (about 1 ppt during 20 years). The 20-year trend was much smaller than the shorter-term interannual variations associated with years of high and low Tar River discharge. These fluctuations were as high as 8 ppt between two successive years.

Nitrate nitrogen appears to have decreased in the upper estuary by about 25% since 1970, with most of the decrease probably occurring before 1975. Part of the change is likely to be related to changes in salinity, but exactly how much is unknown. Ammonia nitrogen abundance appears to have trended downward at a rapid rate in all areas of the estuary. Upriver, the decline has been about 60% over the past 17 years.

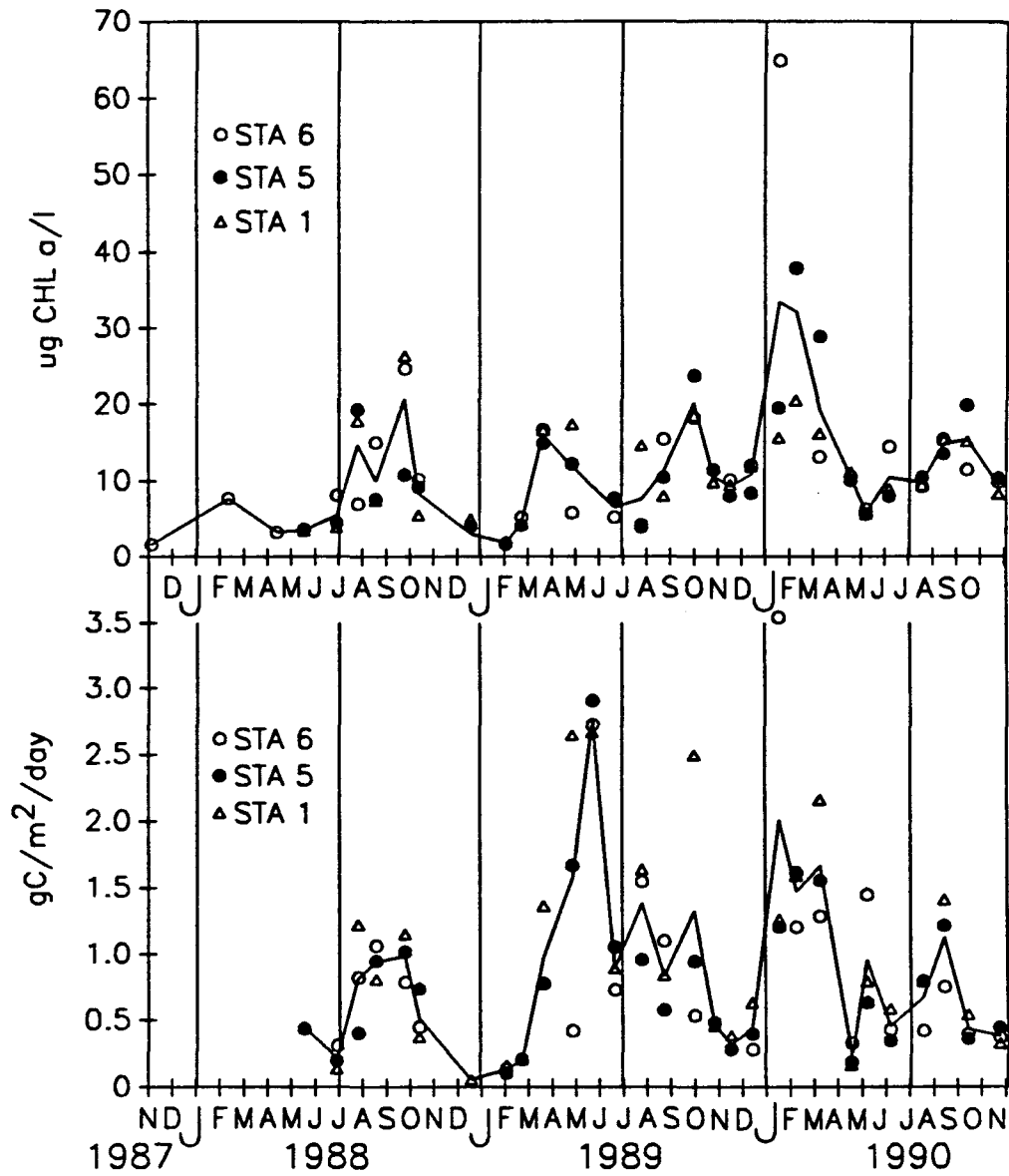


Fig. III-16. Top Panel: Surface measurements of chlorophyll a.
Bottom Panel: Aerial productivity values from stations 1, 5, and 6 in the lower Neuse River Estuary.
 (Note: Line represents mean among stations measured.)

Total phosphorus levels in the middle of the Pamlico Estuary have doubled since 1967. There have been smaller increases in the upriver and downriver segments, but in the 1975-1986 period there was a significant increase in total phosphorus only in the downriver segment. Total dissolved and orthophosphate phosphorus have also increased significantly, particularly in the lower estuary. The fact that phosphorus abundance has not changed in the mid-river segment since 1975 probably reflects declining phosphorus loading from Texasgulf Chemicals counter-balanced, to some extent, by increased loading from the Tar River basin. Monthly loading of phosphorus from the plant site has apparently decreased by about two-thirds since the mid-1970s. This ought to have produced a significant downward trend in phosphate in the river, given that the Texasgulf discharge accounts for approximately 40% of the total phosphorus input to the Pamlico. But, the decreased Texasgulf load probably has been offset, to some large extent, by increased loading from the Tar River, so that the overall pattern is one of little change since 1975. Unfortunately, there are no historical Tar River loading data which could be used to test this hypothesis.

Chlorophyll *a*, an indicator of algal abundance, has increased in the middle and upper river segments, but not downriver. At the head of the estuary, the increase was about 50% during the 16-year period of record. Chlorophyll *a* values exceed the State standard of 40 ug/liter <1% of the time in some years up to about 10% in others (during the period April through November when the standard is in effect). But there has been no trend toward increasing frequency of the high values. In most years high chlorophyll concentrations were more frequent in the upper and middle river areas than in the lower estuary. Also, high values (>40 ug/liter) are usually more common in the winter than in the summer (Figure III-17). Actual phytoplankton species composition in the Pamlico appears not to have changed significantly over the past two decades. Nuisance blue-green algae are not an important component of the Pamlico flora, and clearly do not reach bloom proportions in the tidal freshwater areas of the Pamlico Estuary. This is in strong contrast to the lower Neuse River and the lower Chowan River, where significant blue-green algae blooms have occurred in several years over the past decade. Water

Water column nutrient ratios (dissolved inorganic nitrogen/orthophosphate) calculated for the Pamlico indicate that nitrogen is more likely than phosphorus to limit phytoplankton growth during the summer (Figure III-18). The ratios indicate that phosphorus could become limiting upriver during the winter, but other factors such as low temperatures and low light penetration into the water are probably more important in controlling algal growth then.

The Pamlico River Estuary has been compared (Nixon 1983; Stanley 1988b) to other well-studied estuaries in the United States in terms of: a) nutrient concentrations, b) bottom water dissolved oxygen, and c) phytoplankton. Except for higher orthophosphate phosphorus in the Pamlico there was little difference in salinity and nutrients between the Pamlico and the adjacent Neuse River Estuary. Inorganic nitrogen and phosphorus in the Pamlico shows temporal and spatial patterns similar to those in most temperate estuaries, although there are wide ranges in the concentrations, both within each of the systems, and among different systems. Phosphorus concentration in the Pamlico is higher than in most estuaries (but not the highest of those included in the survey), while nitrogen seems to be about average. Nitrogen, not phosphorus, is thought to be the nutrient most limiting algal growth in other estuaries that have been studied. Short-term hypoxia appears to be common in estuaries, but there is a great deal of uncertainty over the impact of cultural eutrophication. In other estuaries most of the oxygen depletion seems to be caused by the same factors operating in the Pamlico (i.e., water column stratification, wind and river flow). In only a few instances are there long-term data, and the interpretation of that data is not easy. Phytoplankton algal species composition and biomass in the Pamlico are not very different from that in most other estuaries in the region for which data are available. Annual primary production in the estuary is probably higher than average, but the data are inadequate to allow individual rankings. No such evaluation has been done for the Albemarle Sound region.

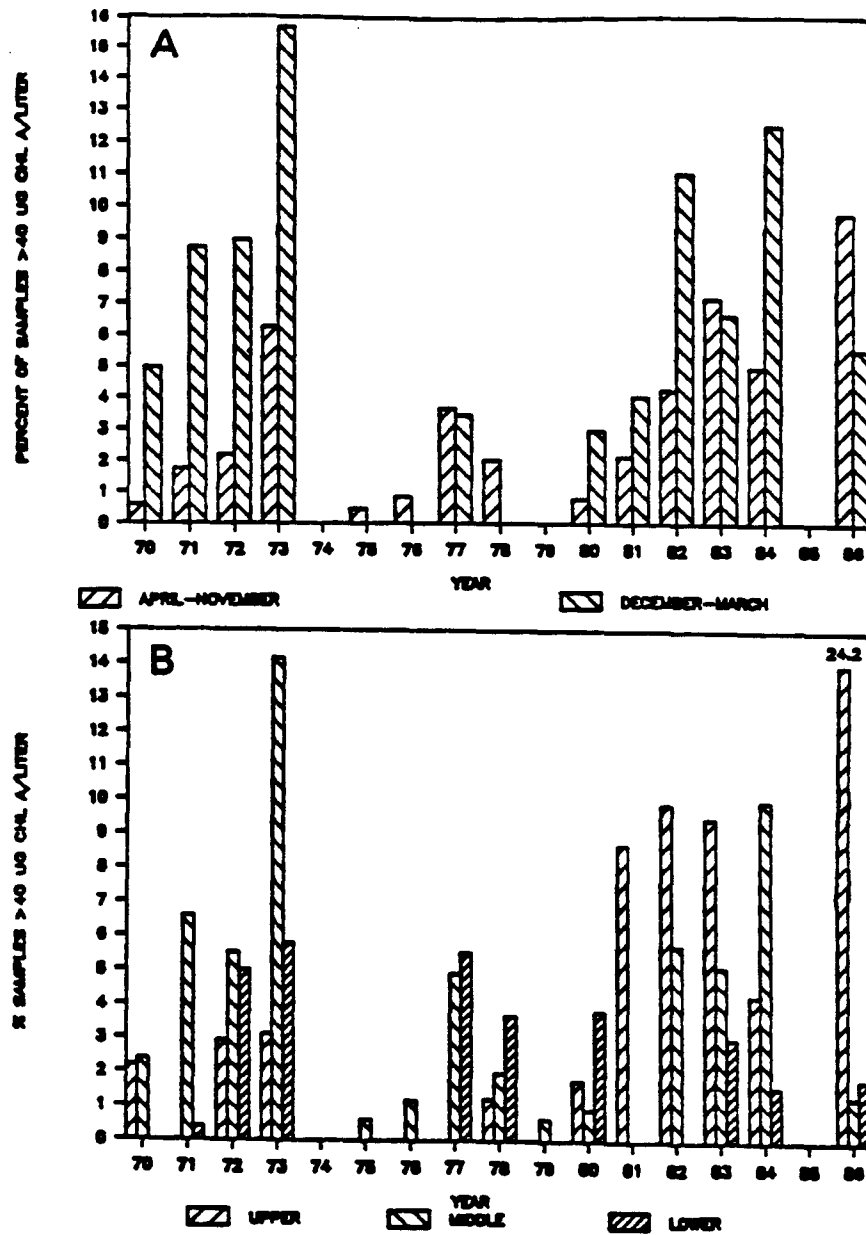


Fig. III-17. Pamlico River Estuary Chlorophyll *a* in Percentage of Sample Values Greater than 40 ug/l Each Year (1970-1986). A = Data grouped by April-November and December-March periods; B = Data grouped by Upper, Middle, and Lower river segments. From Stanley (1988b).

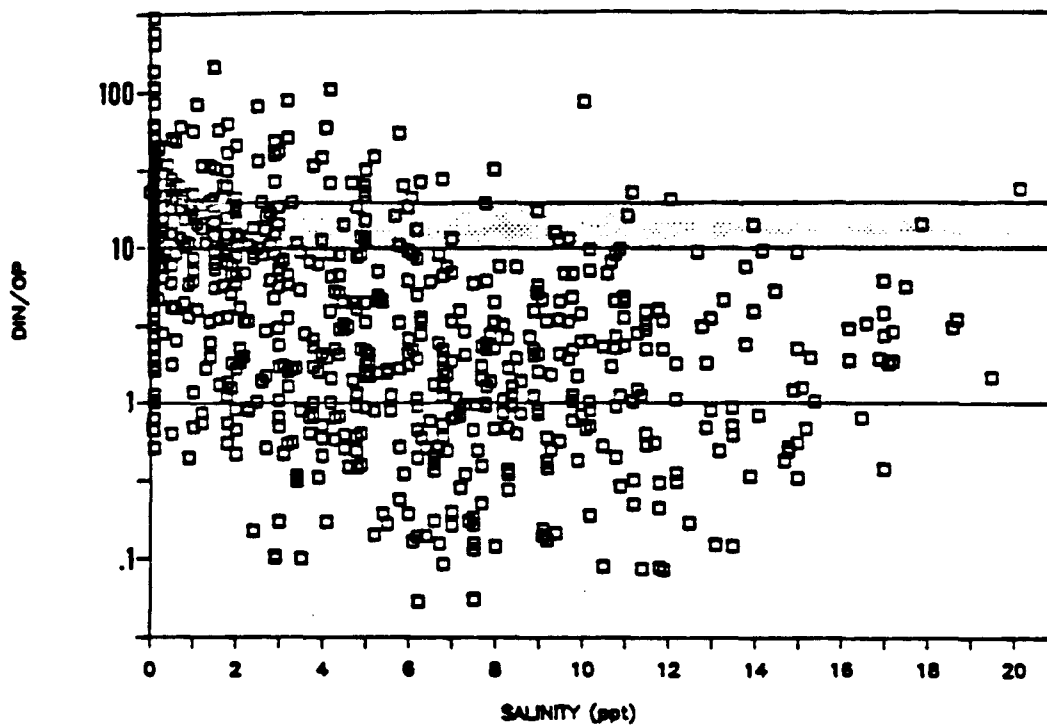


Fig. III-18. Dissolved Inorganic Nitrogen (DIN): Ortho-Phosphate (OP) Ratio Versus Salinity in the Pamlico River Estuary, 1979-1986. Shaded Area Indicates Usual Range of N:P Ratio in Algal Cells. From Stanley (1988b).

C. 1. d. Albemarle-Pamlico Water Quality Trends and Basin Characteristics. Harned and Davenport (1990) conducted an exhaustive analysis of water quality trends and basin characteristics in the Albemarle-Pamlico Sounds. The following is drawn directly from Harned and Davenport (1990). Wastewater discharges in the Neuse River basin have increased 650 percent since the 1950s. The Neuse River basin has the greatest total wastewater discharges of any of the basins in the study area, averaging about 200 million gallons per day in 1988. Wastewater discharges into the Neuse and Tar Rivers were nearly equal to the 7-day, 10-year low flows for these rivers. Data from seven stations of the US Geological Survey National Stream Quality Accounting Network were used to evaluate water quality for the major streams flowing into the Albemarle-Pamlico estuarine system. Water-quality data for 296 stations in the estuarine system were examined for the period 1945-88.

The statistical test used for trend analysis was the Seasonal Kendall test, the same as that used by Stanley (1986). This nonparametric procedure is useful for analyses of water-quality properties that show non-normally distributed frequency distributions. The Seasonal Kendall trend analyses of water-quality data indicate that change has occurred in the water quality of the Albemarle-Pamlico estuarine system from 1945 to 1988. Dissolved-oxygen concentrations increased at a mean rate of 0.1 milligram per liter per year throughout the estuarine system, except in the Chowan River where decreases of approximately 0.06 milligram per liter per year occurred. In general, pH increased in streams throughout the area at a mean rate of 0.04 pH units per year, except in the Pamlico River where pH decreased by 0.03 pH units per year. A general increase in pH and dissolved-oxygen concentrations (if daytime measurements) might be indicative of more productive estuary conditions for algal growth. Suspended-solids concentrations decreased throughout the area at a mean rate of 1.1 milligrams per liter per year, probably as a result of a general decrease in suspended inorganic material. Increasing trends of salinity concentrations, as much as 0.1 part per thousand per year, were detected in Albemarle Sound.

Total ammonia plus organic nitrogen concentrations decreased (-0.03 milligram per liter per year) in streams throughout most of the area but increased (0.02 milligram per liter per year) in the Pamlico River. However, ammonia nitrogen concentrations decreased (-0.0035 milligram per liter per year) in the Pamlico River; therefore, increases in organic nitrogen probably caused the observed increase in combined ammonia plus organic nitrogen concentrations. This probably results from increased eutrophication in the system and its associated increased production of plant biomass. Nitrogen concentrations generally increased downstream and were usually sufficient for development of algal blooms.

Total phosphorus concentrations increased (0.003 milligrams per liter per year) in the Pamlico River and decreased (-0.004 milligram per liter per year) elsewhere. There was a general pattern of decreasing phosphorus concentrations downstream for the Neuse and Pamlico Rivers; however, phosphorus concentrations in the Pamlico River peaked near Durham Creek.

Soluble nutrient concentrations, including ammonia nitrogen, nitrite plus nitrate, and dissolved phosphorus, are a net result of the effects of biological uptake, solution and dissolution of nutrients available in sediment, and new nutrient inputs. If plant biomass increases over time, this could be reflected in decreases in soluble nutrients such as observed ammonia nitrogen and phosphorus concentrations on the estuary system.

On the basis of annual median concentrations, nitrogen was the limiting nutrient for algal growth in the Neuse and Pamlico Rivers. Phosphorus was the limiting nutrient in most of the rest of the Albemarle-Pamlico system. Direct tests for specific nutrient limitations need to be made to confirm limitations at specific sites in the estuarine system.

Trends in chlorophyll-a concentrations increased in the Neuse River, upper Pamlico River, in the upstream end of Albemarle Sound, and near Bull Bay in Albemarle Sound (maximum rate, 1.0 microgram per liter per year). Chlorophyll-a concentrations decreased in the part of the Chowan River

near Mount Gould. A pattern of increases in chlorophyll-a concentrations downstream in the Neuse, Chowan, and Alligator Rivers is apparent. Chlorophyll-a concentrations in the Pamlico River increased downstream, peaked in Durham Creek, and declined farther downstream. Chlorophyll-a concentrations were largest in the Pamlico (interquartile range 3-27 micrograms per liter) and Neuse Rivers (interquartile range 3-17 micrograms per liter) and in Currituck Sound (interquartile range 7-22 micrograms per liter).

C. 2. Potential Effects of Current Trends

C. 2. a. Anoxia (Hypoxia) -- An Example. Bottom water dissolved oxygen concentration is controlled primarily by climatic and hydrologic factors in the Pamlico River Estuary. There has been no trend toward lower oxygen concentrations over the past 17 years (Stanley 1988b). Low bottom water oxygen (hypoxia) does not occur in the estuary when water temperatures are lower than around 20°C. Above 20°C, dissolved oxygen values of less than 1 mg/liter were found in about 20% of the samples from the upper estuary, but in only 4% of the samples from the lower estuary. In addition to high water temperature, another requirement for hypoxia development in the Pamlico is stratification. Salinity stratification prevents mixing of the bottom water with surface waters, which prevents aeration of the bottom water and leads to hypoxia. Two key factors controlling stratification in the Pamlico River Estuary are river flow and wind velocity. High summer flows favor development of stratification (and hence hypoxia) in the lower estuary, while preventing it in the upper estuary. Conversely, drought periods favor hypoxia development upriver but not downriver. Wind velocity is inversely correlated with hypoxia. That is, calm weather favors development of stratification and hypoxia. On the other hand, strong winds can de-stratify the water column in only a few hours and lead to mixing and re-aeration of hypoxic bottom waters, especially downriver where the fetch is greatest.

Although systematic information concerning the exact cause and effects of hypoxia are not available, one intensive study was made during the summer of 1976 (Davis et al. 1978) that sheds some light on short-term changes in oxygen in the river. This study showed that only a few days are required for hypoxia to develop, and that it can be broken up and reversed very quickly. In 1976 Davis and his coworkers measured surface and bottom water salinity, temperature, and dissolved oxygen at stations along the axis of the estuary at intervals ranging from a few days to two weeks. Two sequences illustrate the point, June 24 through July 20, 1976 and August 24 through August 31, 1976. The estuary was well mixed on June 24, but a period of calm on this and succeeding days led quickly to severe deoxygenation by June 29. Stratification and low concentrations of dissolved oxygen in the bottom water were also evident on July 14, following a week of calm or light winds, but the stratification was completely broken up by July 20 following a frontal passage and strong northeasterly winds on the previous day. A complete cycle of development and break-up of bottom water hypoxia in less than a week was detected in the August samples. Deoxygenation was just beginning to occur in the upper reaches of the estuary on August 24. Deoxygenation intensified during the next three days as calm weather persisted (a North Carolina air stagnation advisory was in effect on August 26 and 27), so that by August 27 deoxygenation was recorded throughout the estuary. But, during the night of August 30 and throughout the day on August 31, there were strong winds from the east and northeast, which were probably responsible for the downriver mixing apparent in the hydrograph of August 31 (Davis et al. 1978).

Stanley (1988b) conducted an analysis of over 10 years of data to determine the relative influences of factors affecting deoxygenation. One possible explanation for the lack of low dissolved oxygen in the winter is the lack of salinity stratification. Vertical salinity gradients greater than 1 ppt (an indication of stratification) are, however, just as common in colder water periods as in the summer, at both ends of the estuary. Thus, factors other than lack of vertical stratification must be responsible for the lack of hypoxia in the winter. Lower respiration rates in colder water seem to be the most likely explanation. Spearman Rank Correlation analyses were used to provide information about the factors which have the most influence on dissolved oxygen in the Pamlico during the summer. Several variables were tested for

correlation with dissolved oxygen concentrations at four stations sampled between 1975 and 1986. The results indicated that three factors, vertical salinity gradient, water temperature, and wind velocity/direction, were statistically significantly correlated with bottom dissolved oxygen concentration (Figure III-19). The vertical salinity gradient (DSAL), the difference between bottom and surface salinities, gave the highest correlation coefficient. The oxygen-DSAL relationship was inverse and was strongest at the three stations farthest up the estuary. Bottom water temperature was also negatively correlated with oxygen. The only variable showing a significant positive correlation to bottom water dissolved oxygen was wind velocity, as either average velocity on the previous day or the mean velocity over the previous two days. Differences in the correlation coefficients among the four stations suggest that this factor is somewhat less potent in the upper half of the estuary than at the mouth. The correlations between bottom water dissolved oxygen and year, nitrogen, phosphorus and chlorophyll *a* were not statistically significant.

Additional Spearman analyses were used to test for correlations between vertical salinity gradient (VSG) and two factors that could influence the strength of the VSG (Figure III-20); i.e., river flow and wind velocity (Stanley 1988b). The river flow data are from Tarboro, the nearest gauging station on the Tar River, about 75 km above the estuary. Thus, there are varying time-lags, depending on flow, between the gaging station and even the most upriver estuary sampling station. There are no velocity estimates for the lower Tar to provide insight into this problem, so several lagged and averaged flow parameters were used. The computed correlation coefficients between flow and VSG were all about the same, regardless of the flow parameter used. A more interesting result was that the VSG-flow correlations were positive for the downriver stations and negative for the two upriver stations. In other words, high summer flows enhance development of anoxia downriver, while preventing it upriver. Conversely, drought periods favor anoxia development upriver but not downriver. This is an interesting example of spatial variability in the estuary that is not obvious without close examination of these interrelationships. Wind velocity on the date of sampling was significantly correlated with stratification, but only at the station farthest downriver. Lagged or 2-3 day averaged wind data gave no significant correlations with the VSG. Two conclusions might be drawn from these results. First, bottom water dissolved oxygen seems to respond very rapidly to changes in wind velocity. In other words, only brief periods of calm or windy weather are needed to induce or break up bottom water hypoxia. Second, the influence of wind on the VSG and bottom water dissolved oxygen apparently increases downriver. This seems logical, since the river width increases toward the mouth. Given this increase in fetch, mixing induced by wind waves ought to range more widely downriver than in the more protected areas upriver.

Nixon (1989) also analyzed the historical Pamlico River estuary oxygen data and came to the following conclusions:

1. In spite of the popular belief that there is a direct link between the size of the winter-spring phytoplankton bloom and the severity of low oxygen conditions or "dead water" in the Pamlico during the following summer, no evidence of such a relationship could be found. The data show that the dominant factor determining the extent and duration of hypoxic and anoxic bottom water in the Pamlico is the degree of vertical salinity stratification.
2. The development of strong vertical salinity stratification (greater than 2%) is common in the Pamlico River because the Outer Banks severely restrict the tidal mixing energy that can enter the estuary. As a result, vertical mixing is dependent on the vagaries of the wind. During summer, the prevailing winds blow northeast or southwest across the channel. Unfortunately, the frequency of cross-channel winds with enough strength to produce vertical mixing is low enough that the estuary is often left unmixed for periods greater than the approximately five days required to consume most or all of the oxygen in the bottom waters. It is the frequency or recurrence interval of the strong winds that determines the magnitude of the summer "dead water" problem.

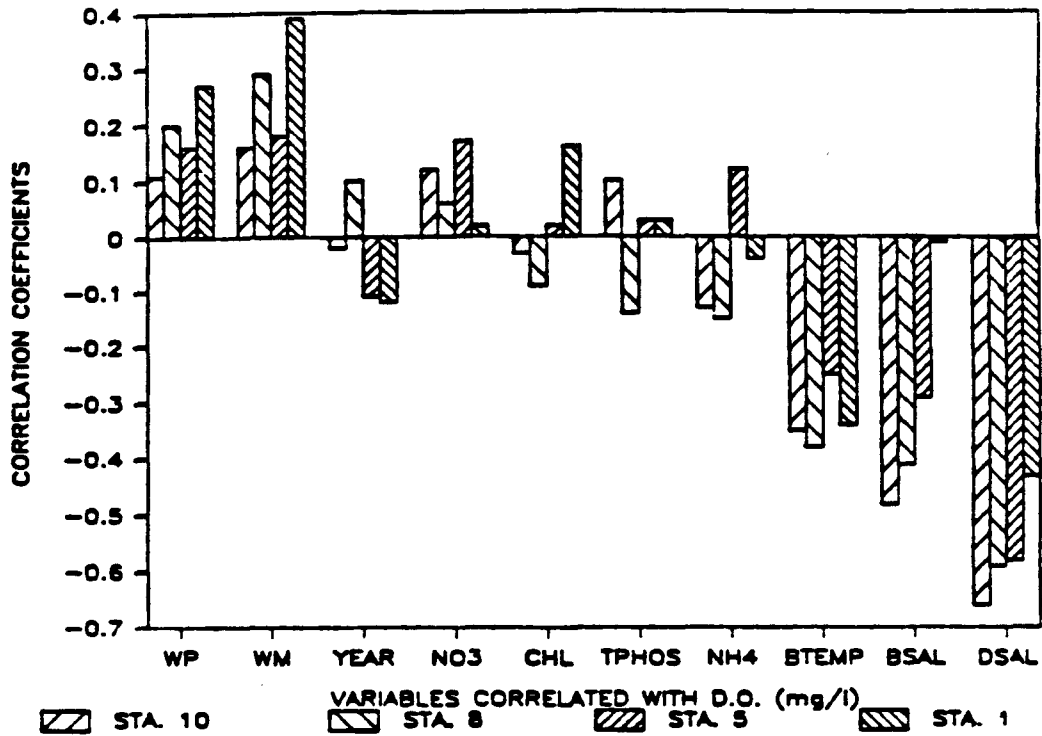


Fig. III-19. Spearman Rank Correlation between Bottom Water Dissolved Oxygen (mg/l) and Total Wind Miles on the Previous Day (WP), Average Total Wind Miles on the Sampling Date and the Previous Day (WM), Year, Nitrate Nitrogen (NO_3), Chlorophyll a (CHL), Total Phosphorus (TPHOS), Ammonia Nitrogen (NH_4), Bottom Water Temperature (BTEMP), Bottom Water Salinity (BSAL), and Vertical Salinity Gradient (DSAL) in the Pamlico River. From Stanley (1988b).

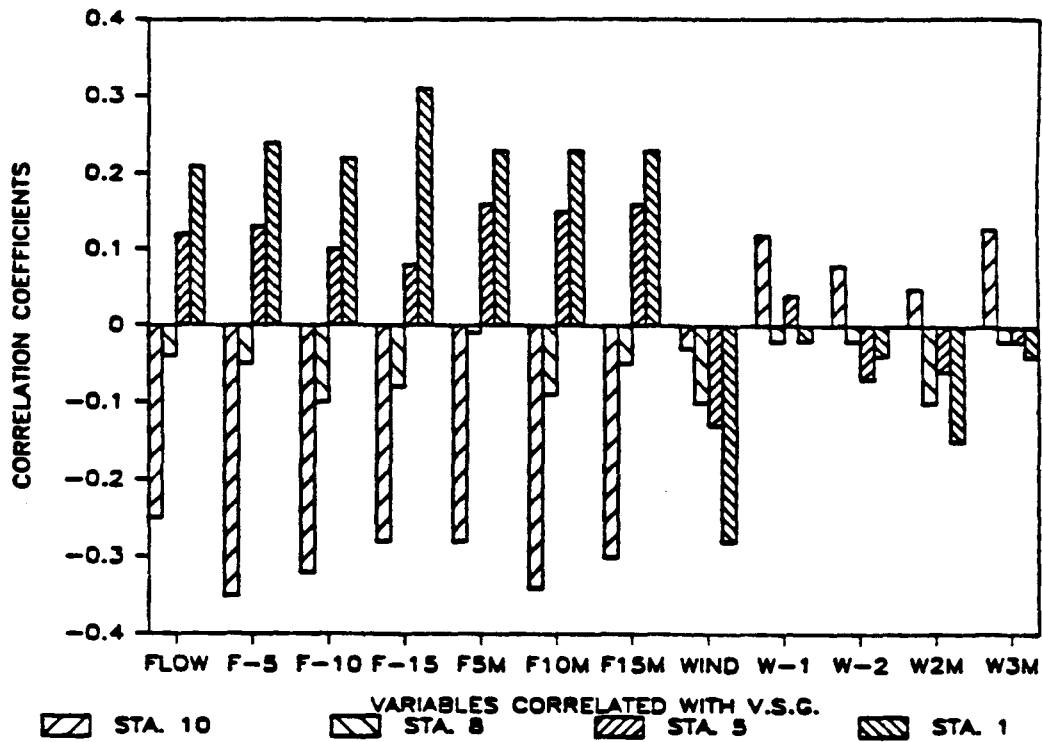


Fig. III-20. Spearman Rank Correlation between Vertical Salinity Gradient and River Flow on Sampling Date (FLOW), Flows 5 Days (F-5), 10 Days (F-10), and 15 Days (F-15) before Sampling, Average Flows for 5-Day (F5M), 10-Day (F10M), and 15-Day (F15M) Intervals before Sampling, Total Wind Miles on Sampling Date (WIND), Total Wind Miles 1 Day (W-1) and 2 Days (W-2) before Sampling Date, and Average Total Wind for 2-Day (W2M) and 3-Day (W3M) Intervals before Sampling in the Pamlico River. From Stanley (1988b).

3. The mechanism by which the stronger cross-channel winds produce vertical mixing appears to be by inducing upwelling along the lee shore of the estuary. During this process, surface water is carried across the estuary from the lee to the windward shore, and bottom water rises to replace it along the lee shore. As a consequence, surface waters may be cooler along the lee shore and benthic or bottom dwelling organisms along the lee side of the estuary may be exposed more frequently and for longer periods to bottom water that is lower in dissolved oxygen. During summer, the prevailing cross-channel winds blow toward the northeast more frequently than toward the southwest. This could explain why there have been more frequent reports of blue crab mortalities along the south shore of the Pamlico than along the north shore.

The general effect of hypoxia on the fauna of the Pamlico is difficult to assess. Anoxia or hypoxia in estuarine bottom waters obviously has the potential to seriously impact the biota either acutely via kills or chronically via physiological stress. The short-term effects were documented in the Pamlico during the late 1960s by Tenore (1970, 1972). He found that the macrobenthos in deeper waters of the estuary had low species diversity and density in the summer, and that variations in the density were correlated positively with anoxia/hypoxia. Large kills of the benthos occurred quickly in the affected areas following the onset of hypoxia, however, these areas were recolonized by the following winter (Tenore 1972). While these results seem dramatic, and are often cited to illustrate the Pamlico's oxygen "problem", they are probably typical for most estuaries (Stanley 1985).

There are no systematic data regarding fish and benthos kills in North Carolina estuaries, although most kills have been attributed to low dissolved oxygen. Most measurements have been made after a kill is reported so that precise determination of circumstances at the time of a kill is difficult. The implementation of the Pamlico Environmental Response Team (PERT) has the potential of enabling the NC Division of Environmental Management to gather more pertinent information. Stanley (1985) recently attempted an assessment of dissolved oxygen conditions in 23 estuaries in North Carolina, South Carolina and Georgia. One conclusion from this review was that none of these estuaries suffers from extended, widely-ranging hypoxia. Rather, the events appear to be of short duration and do not appear to have a serious impact on the estuaries, although benthic fauna are affected temporarily. Lack of long-term monitoring data for all these systems except the Pamlico River makes it impossible to determine exactly how much impact cultural eutrophication has had on the dissolved oxygen conditions. A study by Turner et al. (1987) showed that oxygen depletion in the bottom waters of Mobile Bay is caused by the same factors operating in the Pamlico River. They found that hypoxia was directly related to the intensity of water column stratification, which in turn was coincidental with low wind velocities. More than 80% of the dissolved oxygen variation in their samples was explained by variations in the vertical salinity gradient. An analysis showing a trend toward worsening dissolved oxygen conditions in the bottom waters of Chesapeake Bay (Officer et al. 1984) has been widely publicized, but the study results have come under recent attack by two bay-area scientists (Seliger and Boggs 1988) who have re-examined the data. Until a comprehensive analysis of the interacting factors leading to anoxia in the Albemarle-Pamlico estuarine system has been completed, the direct cause of low dissolved oxygen conditions will remain elusive. Currently, the predictive trend is that the conditions will remain sporadic and spatially limited.

C. 2. b. Nutrient Enrichment. In situ nutrient addition bioassays for nitrogen, phosphorus, and trace metals conducted on four to six week intervals have thus far proven valuable in identifying those nutrients responsible for regulating and limiting algal growth and algal community growth potentials (Paerl and Bowles 1986; Paerl 1987). Advantages of the in situ bioassay approach over the more traditional "standard" algal assays include: 1) the ability to examine nutrient enrichment responses by naturally occurring algal communities, 2) incubation and assay conditions which closely approximate light, temperature and turbulence regimes in the estuary, and 3) the utility of examining two parallel (and relevant) indicators of algal growth, carbon dioxide assimilation, and chlorophyll content, in highly replicated treatments.

Hans Paerl, University of North Carolina Institute of Marine Science, and co-workers have completed a three year study of nutrient addition and bioassays (November 1987-October 1990) in the lower Neuse River Estuary (Paerl et al. 1990). The bioassay results suggest a seasonal pattern in concert with estuarine phytoplankton biomass concentrations and productivity rates (Figures III-6 and III-16). Severe nitrogen limitation occurs in summer when algal biomass and production are high. There is somewhat less profound nitrogen limitation in fall and winter when biomass and production are at annual minima. Nitrogen and phosphorous co-stimulation (or synergism) occurs in the spring. With the exception of the winter 1989-90, these patterns repeated in years when flow and hence loading were low (1988), near average (1990), and high (1989).

The co-stimulation of phytoplankton biomass and production by nitrogen and phosphorus appears to be associated with periods of relatively high dissolved inorganic N:P (DIN:DIP) ratios in the water column which occurred during spring months. During periods when the DIN:DIP ratios were in excess of 10, phosphorus enrichment often played a synergistic role with nitrogen in stimulating phytoplankton growth potentials. Other estuaries have been found to exhibit seasonal variations in nutrient limitation. In the Patuxent River estuary, a tributary of the Chesapeake Bay, algal growth was found to be nitrogen limited during the summer, low-flow season and phosphorus limited during the late winter, high-flow season (D'Elia et al. 1986). As in the Neuse River Estuary, DIN:DIP ratios were elevated during phosphorus limitation. Graneli et al. (1990) also found phosphorus limitation in winter and nitrogen limitation in spring and summer in the coastal area of the southern Baltic Sea.

The bioassay results from the fall of 1989 through the spring of 1990 illustrate how the Neuse River Estuary is dependent on acute loading events to supply nutrients eventually needed for chronic nutrient recycling. The bioassays showed a progression from severe nitrogen limitation in the fall of 1989 (high NO_3^- stimulation), to no stimulation in December during a nutrient loading event, to nitrogen limitation during a *Heterocapsa triquetra* bloom in January and February, to a nitrogen and phosphorus co-limited algal community in April and May after the bloom declines. The phytoplankton community in April and May may have been dependent upon nutrients regenerated from the organic matter previously transported to the bottom as a result of the bloom decline in March (Figure III-5).

However, despite the inter-annual variations in hydrologic and nutrient loading events during our study, it is striking how similar phytoplankton production and biomass levels were after the high flow season, when compared year to year (Figure III-16). The summer production and chlorophyll *a* levels from 1988-1990 were similar to estuarine averages ranging from 1.0 to 1.4 $\text{gC/m}^2/\text{day}$ and from 15.4 to 20.6 $\mu\text{g chl}a/\text{l}$. The fate of the algal biomass produced in the winter-spring floods of 1989 and 1990 is not known, although some was likely converted to increased zooplankton biomass (Mallin, unpublished).

Trace metals added alone or in combination with nitrogen and phosphorus failed to exhibit any impacts upon growth potentials (data not shown) and so we concluded that natural availability of these metals exceeds phytoplankton growth requirements in the Neuse River Estuary. Diatoms may be limited by the availability of silica (Oviatt et al. 1989). Silica (1.5 $\mu\text{g/l}$) was added as a bioassay from April 1989 through October 1989, but silica did not seem to be limiting phytoplankton biomass or production in the Neuse River Estuary during the spring, summer, and fall of 1989.

The sounds of the Albemarle-Pamlico estuarine system have extremely limited tidal exchange with the off-shore waters. Given this, it would not bode well for the future of Albemarle and Pamlico Sounds if their tributary estuaries were being flushed or were transporting their nutrient loads as particulate matter downstream.

C. 2. c. Sediment Conditions. There is some evidence that the Albemarle-Pamlico estuarine sediments have been degraded from recent anthropogenic loadings and other human disturbances, but there is little or no evidence that any degradation has been due to changes in bottom sediment nutrient

processing routes or rates. We do not have a long-term data base which would support arguments regarding changes and trends in sediment characteristics and water quality impacts.

On the other hand, very poor water quality conditions in other Atlantic estuaries, such as the Potomac River, provide a warning signal. There is a need for more extensive knowledge of sediment-water interactions and for long-term monitoring of changes in sediment types and functioning. This is just now beginning under the Albemarle-Pamlico Estuarine Study (Riggs et al. 1989; Wells 1989). Standardized methods must be adopted for the primary monitoring program in order to compare results from different areas, different years, and different investigators. On the other hand, investigators should be supported and indeed be encouraged, to ask new questions and to develop new approaches to study old problems. It is important to adopt or develop comprehensive models of estuarine water quality which incorporate sediment interactions along with nutrient loadings, hydrology, insolation, temperature, and other controlling factors. Outputs of the model should aim to predict such variables as anoxic bottom waters, nutrient concentrations and phytoplankton productivity.

C. 3. Identification of Needed Information

Considerable investment of manpower and funds have been directed towards accumulating information concerning water quality in the Albemarle-Pamlico estuarine system. Much of the work has been isolated in time and space, thus limiting attempts to build a total picture of functional characteristics of the trends in water quality. Several needs have been identified:

1. **Determine loadings of nitrogen and phosphorus (dissolved, particulate, organic, and inorganic) in the Albemarle-Pamlico estuarine system, and elucidate the cycling characteristics and ultimate fates of these loadings.** The ultimate utility of such information will be dictated by the consideration given to existing and future freshwater nutrient input data, sediment input and sedimentation/resuspension information, and water input/circulation/retention data for the Albemarle-Pamlico estuarine system. This effort should utilize a "grid approach" so as to obtain data with spatial and temporal integrity.
2. **Investigate the relative importance of nitrogen and phosphorus as potential limiting factors governing primary production.** This would link nutrient input, cycling, and fate information with in situ primary productivity, nutrient addition/dilution bioassays and nutrient uptake/cycling kinetics determinations. This effort should focus on locations bordering major estuarine input sources such as the Neuse, Pamlico, Chowan Rivers, as well as on several locations in the mid-Sound region.
3. **Conduct a comparative study aimed at delineating physical and chemical limitations on primary production in the Albemarle-Pamlico estuarine system.** Turbidity (sediment resuspension and water color) and temperature exert independent limitations on quantitative and qualitative aspects of primary production. It is well known that nutrients (most likely nitrogen) operate simultaneously to limit primary production. This study must address the relative importance of each type of limiting factor on a seasonal and temporal basis in all parts of the estuarine system. In all likelihood, a novel, non-monitoring oriented experimental approach should be employed in addressing this vital set of questions. Information generated from this project should be presented in such a manner as to be useful for both water quality management and flux/mass balance modeling efforts.
4. **Determine the presence of, and potential for, proliferation of phytoplankton considered undesirable from trophic, recreational, and aesthetic perspectives, in response to nutrient and sediment enrichment in the Albemarle-Pamlico estuarine system.** Specifically, blue-green algae and toxic dinoflagellates (red tides) should be investigated with the goal of establishing nutrient

input and concentration "thresholds", above which periodic dominance and blooms might be anticipated. Ancillary environmental factors known to play regulatory roles in nuisance bloom development, such as salinity, turbidity, thermohaline stratification, and humic substances, should receive parallel consideration in spatial and temporal evaluations of bloom development within the estuarine system.

5. **Investigate the incidence and impacts of enhanced hypolimnetic and sediment deoxygenation.** The interaction and impact of stratification, water movement, temperature and wind on the intensity and stability of deoxygenation needs to be characterized. In addition, the roles of enhanced nutrient loading from "internal" recycling processes and loading and the resultant eutrophication need to be identified and their relationship to hypoxia determined.
6. **Examine and evaluate potential trophic (food chain) impacts attributable to eutrophication.** It should be emphasized that such impacts may prove to be positive (i.e., enhanced production of desirable herbivore, fish and shellfish species due to enhanced production of desirable phytoplankton) or negative (i.e., decreases in production of utilizable commercial fish and/or shellfish species resulting from enhanced production of non-utilizable or toxic phytoplankton). This effort should incorporate both laboratory-oriented feeding and phytoplankton assimilation studies, and field evaluations of the utilization of primary producers (emphasizing potential nuisance species) by herbivorous zooplankton, larval and mature invertebrates, and commercially important fish.
7. **Develop a model to consider all factors which affect water quality.** Although sediment-water exchanges are important to nutrient cycling and metal storage in estuaries, these exchanges are only one of the fluxes that dominate cycling in certain places at certain times. A multidisciplinary evaluation of the physical, chemical, and biological interaction of inputs is the only way that the total picture can be determined.
8. **Conduct a long-term seasonal assessment of the phytoplankton productivity, biomass, and taxonomic structure of Pamlico Sound proper, and characterize the zooplankton community.** Currently, these data do not exist for Pamlico Sound proper, but are essential for any future assessment of the food chains there.

D. CONCLUSIONS

1. The US Geological Survey has gathered abundant data on stream discharges in North Carolina over several decades. Groundwater discharge directly into the estuaries and tidal exchange through the inlets are also important hydrologic processes affecting Albemarle-Pamlico water quality. Yet, there is little information on these processes for the system.
2. Among the vast suite of nutrients essential for primary production, nitrogen and phosphorus have been of most concern as "limiting factors" controlling eutrophication. Accelerated eutrophication is of environmental and economic concern. Frequently, serious water quality degradation, in the form of uncontrolled nuisance algal blooms, accompanies accelerated eutrophication. To varying degrees, symptoms and fully developed cases of eutrophication have affected some tributaries of the Albemarle-Pamlico estuarine system. In all cases, enhanced sediment and soluble nutrient loadings have been identified or suspected as causative agents for some forms of water quality degradation.

3. Sources of pollution are generally grouped into two categories--point sources and nonpoint sources. Point sources of pollution enter a stream or estuary at a discrete location (or point), usually a discharge pipe. Point sources include municipal and private wastewater treatment facilities. These facilities must obtain a permit from the NC Division of Environmental Management which limits the amount of pollution that may be discharged to a given water body. In contrast to point source pollution, nonpoint source pollution is that which enters waters mainly as a result of precipitation and subsequent runoff from land -- primarily from what has been disturbed by man's activities. Examples include runoff from urban areas, agricultural lands and construction sites. Nonpoint source pollution is addressed through a combination of regulatory, cost incentive and voluntary programs.
4. The first detailed study of the metals and toxins in the Albemarle-Pamlico estuarine system is underway. The first phase, the evaluation of heavy metal pollutants in organic-rich muds of the Pamlico River Estuary, has been completed. The Neuse River and Albemarle Sound estuaries will be evaluated by late 1991.
5. There have been at least 5 investigations of bottom sediment characteristics, elemental cycling, and exchange of materials between sediments and overlying waters in the Chowan River, Pamlico River, and Neuse River estuarine systems.
6. In 1988, the NC Division of Environmental Management conducted a water quality assessment of the Albemarle-Pamlico study area as part of the statewide Nonpoint Source Assessment Report to determine impacts from nonpoint sources of pollution. Using information from "monitored" and "evaluated" stream segments, overall water quality ratings were assigned to nearly all stream and estuary segments. In the Albemarle-Pamlico study area, 49% of all stream segments were judged to be un-affected by nonpoint sources of pollution, nearly 40% were partially or seriously impacted, and 11% were not evaluated. In the estuarine portion of the study area, about 93% of the segments were un-affected by nonpoint sources.
7. Despite the scarcity of open-water nutrient and productivity data, a reasonably diverse and comprehensive data bank has been established for some of the main tributaries; the Chowan, Pamlico, and Neuse River Estuaries. The main forms of nutrient inputs are nitrates and phosphates; ammonia is more significant as an "internally cycled" nutrient. Nonpoint sources are thought to be the major contributors of both nitrates and phosphates, although point sources are more significant sources of phosphates than nitrates and during the summer nitrates from point sources become relatively more important.
8. Nitrogen loading and cycling (chiefly as nitrate) are strong determinants in the regulation and ultimate limitation of primary production as well as in bloom development in the freshwater tributaries and diverse estuaries examined to date. Accordingly, nitrogen loading and flux rates, and magnitude, timing, and location of inputs, are of vital importance in assessing production and eutrophication processes in the estuarine portions of the study area. Phosphorus loading, cycling and utilization by phytoplankton, on the other hand, present quite a different picture. There are, indeed, quite high standing concentrations of phosphate in North Carolina coastal waters. In the Pamlico River estuary the concentration is higher than in most similar systems in the country. Whereas inorganic nitrogen is often rapidly depleted during summer phytoplankton growth periods, phosphate concentrations act in a much more conservative fashion, indicating both excess supplies and a general lack of phosphorus limitation. Furthermore, phosphorus is effectively recycled between sediments and the water column, assuring the maintenance of sufficient supplies of phosphate during periods of maximum phytoplankton demand. Exceptions may occur, however, in the Chowan River during bloom periods when high algal biomass leads to parallel depletion of nitrogen and phosphorus. Phosphorus appears to have limiting effects during the high runoff spring months when rapid

dilution can occur, i.e., additions provide stimulation of productivity in the presence of nitrogen.

9. Accelerated nutrient loading, particularly over the past 2 to 3 decades, has ushered in some ominous and increasingly common symptoms of eutrophication, which apparently were extremely rare prior to World War II. However, eutrophication data prior to the mid-1960s do not exist. Trend analysis for the Neuse River Estuary indicates that total phosphorus loadings from all sources increased about 60% during the past century, primarily due to point sources, and total annual nitrogen loading was estimated to have increased about 70%, from both point and nonpoint sources. By contrast, total phosphorus levels in the middle of the Pamlico Estuary have doubled since 1967, with smaller increases in both upstream and downstream sections. Nitrogen concentrations are very similar to those of the Neuse River. No trend analyses have been performed on other estuaries in the study area. It is recommended that a long-term trend analysis be completed for the Albemarle Sound area.
10. Bottom water dissolved oxygen concentration is controlled primarily by climatic and hydrologic factors in the Pamlico River Estuary, the only area where studies have been conducted. There has been no trend toward lower dissolved oxygen concentrations over the past 17 years of record. Low oxygen bottom water (hypoxia) does not occur in the estuary when water temperatures are lower than about 20°C. Above 20°C, dissolved oxygen values of less than 1 mg/liter were found in about 20% of the samples from the upper estuary, but in only 4% of the samples from the lower estuary. Salinity stratification prevents mixing of the bottom water with surface water, which prevents aeration of the bottom water leading to hypoxia. Hypoxia can become established in a short period of time during summer and, conversely, can dissipate very quickly if mixing occurs. A monitoring program needs to be established to provide more consistent data upon which to model hypoxia.
11. There is little or no evidence to support the hypothesis that the Albemarle-Pamlico estuarine sediments are qualitatively much different today than they were in past centuries. Long-term data upon which to base arguments regarding changes and trends in sediment characteristics and subsequent water quality impacts are not available.
12. A model needs to be developed to consider all factors which affect water quality. Although sediment-water exchanges are important to nutrient cycling and metal storage in estuaries, these exchanges are only one flux that dominates cycling in certain places at certain times -- there are many others. A multidisciplinary approach to the physical, chemical and biological interaction of inputs and interactions is the only way that the total picture can be determined.

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IV. FISHERIES

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A. INTRODUCTION

The fishery resources of the Albemarle-Pamlico (A/P) estuarine system are extremely important to the state and region. The estuary is not only a major fishing area, but also provides essential habitats for the production of fishery resources caught along the entire Atlantic Coast. Evidence of water quality degradation, alteration of the estuary's habitats, modification of riverine flow, and intense harvest effort raise serious concerns about the future of the area's important fishery stocks and fisheries.

The A/P system's habitats include one of the largest bodies of coastal freshwater in the country (Albemarle Sound), one of the most productive lagoonal estuaries in the country (Pamlico Sound), major anadromous fish spawning and nursery grounds, large seagrass meadows, vast expanses of adjacent wetlands (including peat pocosins), and nursery grounds for most of the economically important fishery species in the mid-Atlantic area. About 90% of North Carolina's commercial seafood catch (by weight) is in some way dependent on the vast, shallow sounds and the many embayments and tributaries around the sounds (Table IV-1). More than 60% of the recreational catch (by number) is also estuarine-dependent (Mumford and West 1989).

The fishery resources of the estuary can be classified according to life history strategies. The first are anadromous fishes, which spend the bulk of their lives in salt water, but return to freshwater streams to spawn. Such fish include the river herrings and shads (*Alosa* sp.), striped bass (*Morone saxatilis*), and sturgeons (*Acipenser* sp.). The second are resident species, which spend their entire lives in the estuary. This group includes finfish, such as white perch (*M. americana*) and catfish (*Ictalurus* sp.), as well as molluscan species such as hard clams (*Mercenaria mercenaria*) and oysters (*Crassostrea virginica*). The third are estuarine migratory species, the most economically important fishery resource, which generally spawn in the open ocean, around inlets, or near shore, but which recruit into the estuaries. Included in this group are spot (*Leiostomus xanthurus*), Atlantic menhaden (*Brevoortia tyrannus*), Atlantic croaker (*Micropogonias undulatus*), weakfish (*Cynoscion regalis*), flounders (*Paralichthys lethostigma* and *P. dentatus*), shrimp (*Penaeus* spp.), and blue crabs (*Callinectes sapidus*) (Figure IV-1). These species not only overwhelmingly dominate the fisheries in the estuary (approximately 80% of the commercial catch), but also emigrate to join important nearshore stocks which migrate seasonally along the Atlantic coast. It is for this group that the Albemarle-Pamlico estuarine system serves as a major nursery area for the entire Atlantic Coast.

The Albemarle-Pamlico estuarine system is not only an important habitat for the production of fishery resources, but is also a major fishing area. Recreational and commercial fishermen in the area use as wide a variety of gears and methods as the variety of species they seek. The area contains numerous fishing ports for the state's "highly migratory" fishing fleet. Commercial and recreational fishing and their associated industries have major economic impacts on the region (Street and McClees 1981).

Historically, fishing has been extremely important. Native Americans and, subsequently, European settlers in coastal North Carolina relied on fishing as a source of food and commerce. Early colonists took advantage of the abundant shad, herring, and striped bass runs in the spring and other finfish and shellfish year-round.

The A/P region's modern commercial and sport fisheries depend on variety. No single species is consistently available for harvest throughout the year, principally because of migratory habits related to sawning, feeding, and growth. Regulatory controls also limit the harvest of some species, such as striped bass and oysters, to certain seasons. Commercial fishermen utilize both movable and fixed gears. Otter trawls, oyster dredges, and long haul seines are the most important moveable gears. Common fixed gears include pound nets, gill nets, and crab pots. Recreational fishermen generally use hook-and-line gear. In North Carolina, however, recreational fishermen also use commercial gear, though in much

Table IV-1. Commercial Landings of Estuarine-dependent Finfish, Crustaceans, and Shellfish in North Carolina, 1986-1990, in Thousands of Pounds. (DMF Data)

| Species | 1986 | 1987 | 1988 | 1989 | 1990 |
|-------------------------------|--------------|--------------|---------------|--------------|--------------|
| <u>Finfish</u> | | | | | |
| River herring | 6,814 | 3,195 | 4,191 | 1,491 | 1,158 |
| Atlantic croaker | 9,425 | 7,289 | 8,434 | 6,824 | 5,731 |
| Flounder | | | | | |
| (summer, southern) | 8,845 | 7,984 | 10,265 | 7,555 | 5,137 |
| Atlantic Menhaden | 66,378 | 55,499 | 73,716 | 66,756 | 71,647 |
| Mullet | 1,932 | 2,590 | 3,061 | 2,062 | 2,909 |
| Weakfish and spotted seatrout | 14,501 | 12,198 | 15,388 | 10,568 | 5,998 |
| Spot | 3,354 | 2,806 | 3,080 | 3,254 | 3,380 |
| Striped bass | 189 | 262 | 116 | 101 | 114 |
| Others | <u>9,888</u> | <u>9,151</u> | <u>11,372</u> | <u>7,957</u> | <u>7,824</u> |
| Subtotal | 121,326 | 100,974 | 129,622 | 106,568 | 103,898 |
| <u>Crustaceans</u> | | | | | |
| Blue crab | 23,755 | 32,424 | 35,604 | 34,725 | 38,002 |
| Shrimp (heads on) | <u>6,162</u> | <u>4,416</u> | <u>8,139</u> | <u>8,923</u> | <u>7,802</u> |
| Subtotal | 29,917 | 36,870 | 43,743 | 43,648 | 45,804 |
| <u>Shellfish (meats)</u> | | | | | |
| Clams | 1,356 | 1,207 | 940 | 1,295 | 1,334 |
| Oysters | 745 | 1,426 | 913 | 530 | 323 |
| Bay scallops | 306 | 155 | 39 | 84 | 62 |
| Others | <u>99</u> | <u>94</u> | <u>106</u> | <u>66</u> | <u>80</u> |
| Subtotal | 2,506 | 2,882 | 1,998 | 1,975 | 1,799 |
| Total (estuarine-dependent) | 153,749 | 140,726 | 175,363 | 152,191 | 151,501 |
| Total (state-wide) | 168,882 | 157,324 | 192,693 | 165,197 | 173,909 |
| % estuarine-dependent | 91.0 | 89.4 | 91.0 | 92.1 | 87.1 |

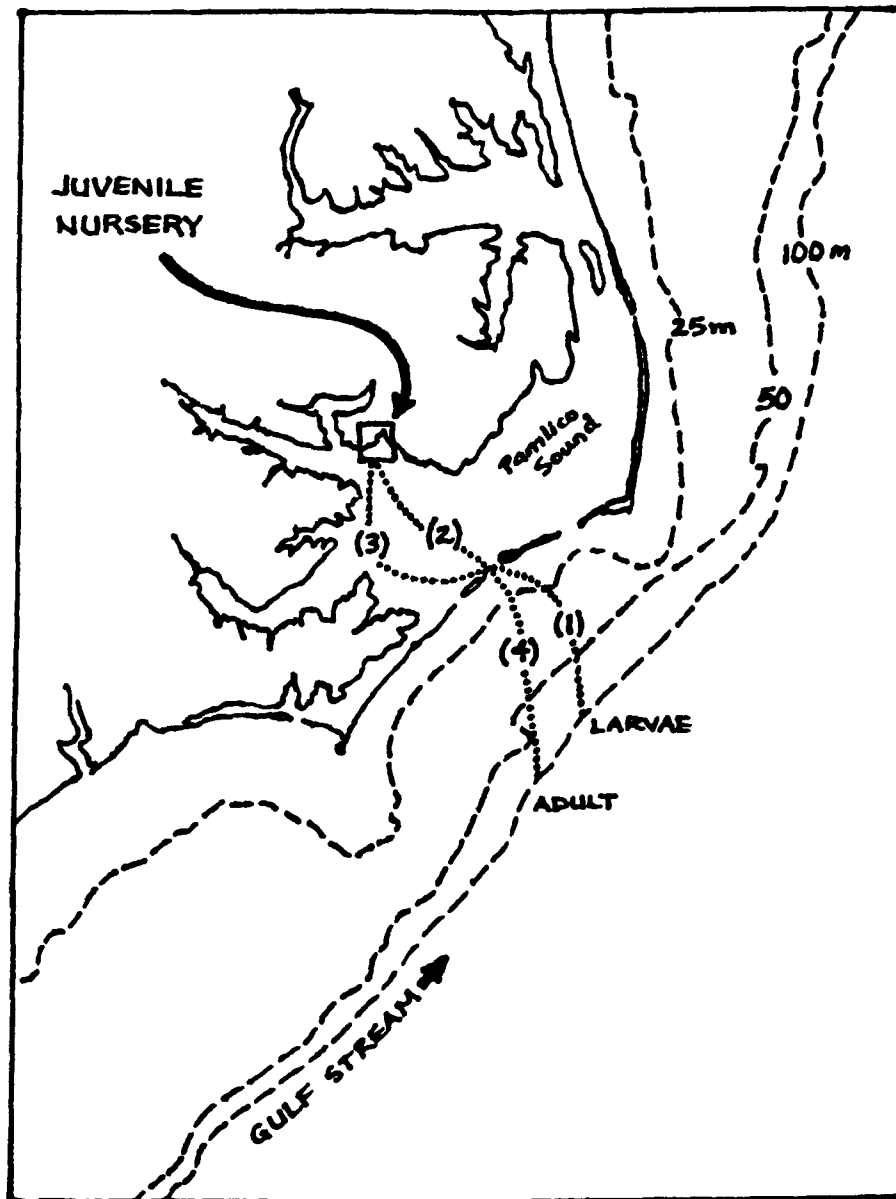


Fig. IV-1. Migration Patterns of Typical Fish Species in the Albemarle-Pamlico Estuarine System. (From Miller et al. 1984.)

1. Passive transport of larvae towards inlet (winter).
2. Wind-driven movement of juveniles towards nurseries (early spring).
3. Movement of juveniles from nurseries towards inlets (late summer).
4. Spawning migration of adults (late fall, early winter).

smaller quantities than commercial fishermen. Over half of the commercial vessel licenses sold annually by the North Carolina Division of Marine Fisheries (DMF) are issued for recreational use of commercial gear. Of the licenses which indicated that they used gill nets in 1988, most were recreational (DMF Unpublished Data). More than half of the licensed vessels using crab pots were recreational (DMF Unpublished Data). Several thousand fishermen pull small shrimp trawls for recreation.

A. 1. Available Data

A variety of data are available for evaluating trends in fisheries and the fishery resources. The DMF samples the catches of the major commercial fisheries (pound net, long haul, oceanic trawl and gill net, crab pot, and anadromous gill net fisheries) for species composition, size composition, age (for selected species), and fishing effort. Division personnel sample juvenile finfish, shrimp, and blue crabs in estuarine nursery areas to determine relative abundance and growth. Similar sampling is conducted for oysters and bay scallops (*Argopecten irradians concentricus*). A survey of the open waters of Pamlico Sound is conducted to gather data on relative abundance, distribution, and growth of species present. Anadromous fishes are sampled in the Albemarle Sound area.

Most DMF sampling programs, whose data are presented in this report, began in the early to mid-1970s. Sampling of planted oysters began in the mid-1970s, while sampling of wild oysters began in 1987 in the Pamlico Sound area. The sounds survey was also initiated in 1987. Sampling of the blue crab fisheries began in 1990.

Because of their long-term importance to commercial and recreational fishermen, the DMF considers certain species to be "target species". Biological sampling and analyses emphasize these species: three species of shrimp, oysters, bay scallops, Atlantic croaker, spot, weakfish, red drum, summer flounder, southern flounder, bluefish (*Pomatomus saltatrix*), blueback herring (*Alosa aestivalis*), alewife (*A. pseudoharenaus*), American shad (*A. sapidissima*), hickory shad (*A. mediocsis*), striped bass, Spanish mackerel (*Scomberomorus maculatus*), king mackerel (*S. caralla*), and spotted sea trout (*C. nebulosis*). All except king mackerel are principally riverine, estuarine, or near-shore ocean species. These relatively long-term programs have generally utilized standard methods and allow comparisons over time and area.

The longest fisheries database is that for commercial landings statistics; for North Carolina, it extends back to 1880. Commercial landings data are frequently used to indicate levels and trends in fisheries, primarily because they are the longest record available. However, landings data are influenced by many factors, such as market demand, price, fishing effort, weather, availability of alternate species, regulations, data collection procedures, as well as stock abundance. As a result, landings data should be viewed primarily as a very general indicator of the fisheries themselves, but not of the fish stocks. As such, the data can characterize the various fisheries and provide insight into the fishing trends relative to all of the various factors which influence the statistics. The present commercial fisheries statistics program in North Carolina is conducted cooperatively by DMF and the National Marine Fisheries Service (NMFS) and provides data on landings, value, fishing gear, and water body of harvest.

Unfortunately, no long term data exist on the recreational fisheries of the area. Recreational fishery statistics were collected by the NMFS from 1979 to 1986 to characterize regional and national sport fisheries, but they have very limited applicability to North Carolina alone due to low sample sizes. In 1987, DMF began a cooperative program with the NMFS to increase the amount and reliability of recreational data collected in order to characterize the North Carolina recreational fisheries. The program, which gathers catch and biological data, uses the same methodology as the national program and provides statistically reliable estimates of catch of major species for the entire state. Modifications to the survey were made to obtain species composition and average catch rates by water bodies, which are comparable to the reported commercial landings, however, the data cannot be extrapolated to total estimates for the A/P region.

In addition to the monitoring programs noted above, numerous short term projects have been conducted, directed at certain species or specific areas and habitats. Short term projects rarely provide information which can be compared with other data to detect trends over time.

The principal weaknesses in the existing data gathering programs are the general brevity of most databases, lack of consistent sampling for some important species (such as hard clams), incomplete sampling for other species (blue crabs, for example), and lack of effort data for many fisheries.

Two kinds of effort data are generally recognized: effective effort and nominal effort. Data on effective effort, a measure of the actual mortality effects of a given unit of fishing effort on a stock of fish, are very rare. To determine effective effort, detailed biological and fisheries data are needed over an extended period of time. Information on vessels, and gear are usually required (vessel length, horsepower, net specifications, and other parameters). Nominal effort is simply a measure of some selected unit, such as number of trips or days, regardless of vessel or gear characteristics. For example, in the Atlantic menhaden fishery, if a purse seine vessel lands at least one catch in a given week, one unit of effort is recorded. Thus, a small vessel landing a small catch is accorded the same unit of effort as a large vessel which lands several large catches during the same week (Atlantic Menhaden Management Board 1981). The DMF collects nominal effort for several important fisheries: the Chowan River pound nets, the winter trawl fishery, the shrimp trawl fishery, the Pamlico Sound summer pound net fishery, and the long haul seine fishery.

A. 2. General Trends

Commercial landings data provide the best available information to reflect possible trends in fisheries. An examination of total commercial landings data for North Carolina indicates, however, that the five-year period with the greatest recorded landings was 1978-1982, with average landings of 357 million pounds, and a peak of 432 million pounds, the all-time record (Street 1988). Landings for the Albemarle-Pamlico-Core Sound area also rose during this period, reaching their highest level in 1980 (DMF Unpublished Data). During the late 1970s and early 1980s, commercial landings of a number of species (or species groups) taken in the A/P area established all-time records or reached levels not seen for many years (Table IV-2). Such species included Atlantic menhaden, blue crabs, flounder, weakfish, Atlantic croaker, white perch, hard clams, and shrimp. Biological data, such as size and age composition, which has been anecdotal since the late 1970s, and anecdotal information from fishermen strongly indicate that the elevated harvests during this period reflected actual increased abundance relative to previous years. Why the apparent abundance of all those species increased at the same time, however, is unknown. Since that period, harvests have declined, although they generally remain above those of the years immediately preceding the peak (Table IV-2).

A. 3. Water Quality Concerns

As in most estuaries, the high productivity of the Albemarle-Pamlico system is a result of dynamic interactions of chemical, physical, and biological characteristics. In recent years much attention has been focused on whether water quality changes in the Albemarle-Pamlico estuarine system are threatening or have already negatively affected fisheries' productivity. Some of the estuary's problems which are water quality-associated and concern fisheries' productivity include: 1) fish and shellfish diseases, 2) algal blooms, 3) fish kills, 4) anoxia and hypoxia, 5) loss of critical habitats, 6) freshwater discharge, 7) fecal contamination resulting in shellfishing closures, and 8) toxic substances.

Fish and shellfish diseases are a significant problem in the Albemarle-Pamlico estuarine system. During the 1970s, large numbers of freshwater finfish species in the western portions of Albemarle

Table IV-2. Commercial Fisheries Landings in Albemarle, Pamlico, and Core Sound Areas, NC, 1972-1990 (in thousands of pounds). (Data do not include menhaden landed by purse seine). (DMF Data)

| Year | Albemarle Sound area | Pamlico Sound area | Core Sound area | Total | Percent state total |
|---------------|----------------------|--------------------|-----------------|--------|---------------------|
| 1972 | 16,205 | 13,746 | 6,881 | 36,832 | 44.3 |
| 1973 | 12,734 | 14,350 | 8,845 | 35,929 | 56.6 |
| 1974 | 12,270 | 17,835 | 12,480 | 42,585 | 56.9 |
| 1975 | 11,326 | 20,611 | 10,700 | 42,637 | 54.7 |
| 1976 | 11,635 | 22,383 | 6,555 | 40,573 | 47.4 |
| 1977 | 13,385 | 25,678 | 6,612 | 45,675 | 49.0 |
| 1978 | 13,107 | 36,383 | 8,559 | 58,049 | 54.1 |
| 1979 | 12,906 | 45,651 | 10,869 | 69,426 | 51.0 |
| 1980 | 13,755 | 62,161 | 13,633 | 89,549 | 56.2 |
| 1981 | 12,506 | 50,227 | 8,579 | 71,312 | 58.2 |
| 1982 | 20,657 | 49,478 | 9,159 | 79,294 | 65.6 |
| 1983 | 16,633 | 41,542 | 9,507 | 67,682 | 61.7 |
| 1984 | 13,916 | 41,796 | 10,166 | 65,878 | 55.1 |
| 1985 | 22,005 | 42,319 | 11,392 | 75,716 | 64.6 |
| 1986 | 19,050 | 29,568 | 8,198 | 56,816 | 55.4 |
| 1987 | 18,439 | 33,645 | 7,336 | 59,420 | 58.4 |
| 1988 | 14,142 | 42,743 | 8,698 | 65,583 | 55.6 |
| 1989 | 15,489 | 37,911 | 7,442 | 60,842 | 61.8 |
| 1990 | 11,495 | 45,659 | 8,022 | 65,176 | 66.0 |
| Mean | 14,824 | 35,457 | 9,139 | 59,418 | 55.2 |
| % state total | 15.3 | 35.5 | 9.3 | | |

Sound were affected by red sore disease (NC Division of Environmental Management et al. 1975, 1976). Approximately 50% of all commercially harvested finfish were observed with red sore disease during peak occurrences. While red sore disease subsided in Albemarle Sound in the 1980s, a multitude of ulcer-diseases has occurred, principally in the Pamlico River, but also in other areas (Noga and Dykstra 1986; Noga et al. 1991; Levine et al. 1990(a)). Most of the commercially important estuarine fish species utilizing the Pamlico River, including Atlantic croaker, spot, weakfish, southern flounder, red drum, spotted seatrout, and Atlantic menhaden have been observed with lesions. The most prevalent disease is ulcerative mycosis, a fungal infection primarily affecting Atlantic menhaden (Noga and Dykstra 1986; Dykstra et al. 1986). As many as 80-100% of the Atlantic menhaden in random cast net samples have had ulcerative mycosis (Levine et al. 1990(b)). Recently, an aggressive shell disease has been noted on blue crabs in the Pamlico River (McKenna et al. 1990; Engel and Noga 1989).

Diseases can affect fisheries productivity by several means. The stocks of affected species can be depleted by acute mortalities caused by disease; however, acute mortalities usually have to be of enormous magnitude to be detected in the fish population (Vaughan et al. 1986). Of greater concern is the effect on fish stocks of the chronic recurrence of disease which induces continual mortalities (Merriner and Vaughan 1987). Diseases also affect commercial fisheries' production indirectly by making infected individuals unmarketable; examples include the various ulcer-associated diseases on estuarine species recently documented in the Pamlico River. Diseases, especially those involving gross lesions, can also indirectly negatively affect recreational production by decreasing the attractiveness of fishery areas where fish disease is prevalent.

Perhaps most important is the implication that the fish and shellfish diseases are indicators of stressed environmental conditions in the Albemarle-Pamlico estuarine system. Sindermann (1983) considered skin ulcers on fish as one of the best pathological indicators of water quality stress. Environmental stress could sub-lethally affect vital life history characteristics of fish in the estuary, such as reproduction and growth. If the multitude of recently discovered fish and shellfish diseases do indicate the deterioration of water quality, the effects on fish stocks and production will be difficult to assess due to the chronic and usually cumulative nature of such effects and the natural variability of fish stocks.

Algal blooms can also affect utilization of the estuary by fish and shellfish in several ways. Extremely dense concentrations of algae can deplete dissolved oxygen from estuarine waters during periods when photosynthesis is reduced, such as at night. Also, some species of algae release toxins can bioaccumulate in, and may kill, fish and shellfish (Paerl 1987). Algal blooms are becoming more of an environmental concern; the number of events which have been documented in North Carolina has increased from 16 in 1984 to 87 in 1989 (NC Division of Environmental Management 1990). The number of documented algal blooms in the Albemarle-Pamlico estuarine system has increased since 1984, especially in the estuarine waters of the Tar-Pamlico River, where 90 blooms were recorded from 1986 to 1989. No blooms were reported in the Tar-Pamlico during 1984, approximately five were noted in 1985, and in 1989 approximately 35 algal blooms were noted in the lower Tar-Pamlico River. Stanley (1988) found that levels of chlorophyll *a*, an indicator of algal abundance, increased in the middle and upper Pamlico River from 1967 to 1986. Nutrient enrichment of North Carolina's waters is thought to be responsible for the increasing number of algae blooms (Rader In Press).

Algal blooms in the Tar-Pamlico River are frequently associated with fish kills (NC Division of Environmental Management 1989). The effects of such kills on the fishery resources are usually acute and very difficult to discern because of the natural variability of fish and shellfish populations. Toxins produced from algal blooms have the potential to kill fish, and so may have contributed to fish kills in the Tar-Pamlico River, but no studies have been able to conclusively isolate algal toxins as the causative agents in fish kills in the A/P region (Jay Sauber, NC DEM, per. comm.). Besides initiating acute events such as fish kills, algal blooms can affect fisheries production in subtle, chronic ways. Modification of the algae community in the Roanoke River is suspected as a reason for the decline of striped bass in

Albemarle Sound (Rulifson et al. 1986). Changes in phytoplankton species compositions may have affected zooplankton compositions and impacted the feeding ecology of larval striped bass. Changes in algae population dynamics are also suspected of negatively affecting the larval feeding ecology of fish in the Neuse River (Paerl 1987).

One of the most dramatic examples of how an algal bloom can impact fishery resources is the red tide bloom observed in the near-shore waters of North Carolina during 1987 (Tester et al. 1988; Rader In Press). Large numbers of bay scallops were killed in Core and Bogue sounds (Summerson and Peterson 1990) and hundreds of square miles of estuarine waters were closed to shellfishing due to the large bloom of a dinoflagellate (Ptychodiscus brevis). The red tide had severe economic and social impacts on the fishing industry in Bogue and Core sounds (Rader In Press).

Another major environmental concern of the fishing industry and fishery managers is the increasing occurrence of fish and crab kills in the Albemarle-Pamlico estuarine system, especially in the Tar-Pamlico River. A total of 87 fish and crab kills were reported in the Tar-Pamlico River between 1966 and 1984 (Rader et al. 1987). From 1985 to 1987 a total of 31 fish and crab kills were documented by the NC Division of Environmental Management (DEM) in the Tar-Pamlico. In 1988, DEM and DMF received 40 reports of fish/crab kills in the Tar-Pamlico, while in 1989, 69 reports of fish kills were received. Most of the documented kills have been attributed to hypoxia caused by algal blooms or salinity stratification and occur during warmer months in localized areas. In 1988 and 1989, however, the DEM and DMF documented extensive continuous Atlantic menhaden kills occurring over 10 to 15 miles of the Tar-Pamlico River during June of each year. These kills were characterized by high proportions (>90%) of Atlantic menhaden with ulcerative mycosis during periods with adequate oxygen in the water.

Fish kills can potentially affect fish stocks by inducing acute mortalities; however, as with diseases, the mortalities have to be of enormous magnitude to detect an effect on fish stocks. More important is the potential chronic effect of recurring fish kills and the apparent increase in the number of kills in the Albemarle-Pamlico estuarine system.

Another water quality problem that is related to fisheries production in the Albemarle-Pamlico estuarine system is hypoxia (low oxygen) and anoxia (no oxygen). Hypoxia and anoxia are caused by a combination of factors including freshwater runoff (with its accompanying organic matter), water column stratification, biological processes which remove oxygen, and physical processes such as wind and temperature (Davis et al. 1978; Rader et al. 1987). Stanley (1985) reviewed data from 42 areas in North Carolina, South Carolina, and Georgia, of which 23 regions had sufficient data to assess levels of oxygen depletion and eutrophication. Six of the 23 areas were found to experience substantial hypoxia and anoxia; 3 of those 6 were in the Albemarle-Pamlico estuarine system (Chowan, Neuse, and Pamlico rivers).

Hypoxia and anoxia are of concern to fishery managers and to commercial and sport fishermen because such conditions are frequently responsible for fish and crab kills in the estuaries. Low oxygen conditions often kill substantial numbers of blue crabs captured in crab pots, thereby affecting commercial fishermen who harvest with such gear. In estuaries where hypoxia is common, fishermen have to modify fishing techniques in response to the low oxygen conditions. One response is to move crab pots to shallower waters where oxygen concentration is usually higher, another is to fish the pots more frequently. Hypoxia may also cause substantial mortalities of commercially valuable benthic communities such as oysters. Hypoxia can contribute to changes in fisheries ecology, such as in the Neuse River, where low oxygen conditions appear to encourage early emigration of juvenile fish (Hester and Copeland 1975). Low oxygen is one of the primary factors affecting the distribution of benthic organisms in the Pamlico River (Tenore 1970). Hypoxia is suspected of contributing to the decline of striped bass in Chesapeake Bay (Price et al. 1985), the decline of American shad in the Hudson River (Talbot 1954), and possibly the variation of shrimp landings in the Gulf of Mexico (Renaud 1985).

Major concerns exist as to whether hypoxic events in the Albemarle-Pamlico estuarine system are becoming more severe as a result of changing temporal and spatial trends, such as were noted in Chesapeake Bay by Officer et al. (1984). A major hypoxic event occurred in August 1985, when low oxygen levels were recorded for a 100-square-mile area from New Bern, down the Neuse River, out into Pamlico Sound, and up the Pamlico River almost to Washington (DMF Unpublished Data).

The loss of critical fish and shellfish habitats as a result of water quality changes has also affected fishery resources in the Albemarle-Pamlico estuarine system. Rader et al. (1987) hypothesized that one of the major contributors to apparent declines in fisheries production in the lower Pamlico River and tributaries of Pamlico Sound is the significant increase in freshwater flow into primary nursery areas. The increased freshwater discharges are a result of large-scale land clearing and draining for agricultural purposes around the Albemarle-Pamlico estuarine system (Skaggs et al. 1980). Unstable salinity patterns in nursery areas resulting from freshwater discharges have negatively affected utilization of these areas by economically important juvenile pinnaeid shrimp and, likely, juvenile finfish (Pate and Jones 1981). Several coastal tributaries in the Albemarle-Pamlico estuarine system have shown a net decrease in salinity over time which may be due to alteration of flow regimes (Sholar 1980; Phillips 1982). Concomitant with the decreased salinities has been a downstream displacement of oyster beds in the Pungo and Pamlico rivers (Sholar 1980). Changes in flow regimes also have affected striped bass spawning success and critical nursery areas in the Roanoke River (Manooch and Rulifson 1989).

Loss of estuarine submerged aquatic vegetation beds in tributaries of the Albemarle-Pamlico estuarine system greatly concerns fishery managers. These beds provide critical nursery habitat for many estuarine species. Historically, submerged vegetation beds were very common in tributaries of the Albemarle-Pamlico estuarine system, especially the Tar-Pamlico River (Davis and Brinson 1976). The loss of valuable grass beds in parts of Albemarle Sound and the western tributaries of Pamlico Sound is thought to be related to changes in water quality (Rader In Press), as has been noted in Chesapeake Bay (Orth and Moore 1984).

Closures of productive shellfishing waters due to probable contamination with fecal organisms, as indicated by the presence of fecal coliform bacteria, also merit the concern of resource managers in the Albemarle-Pamlico estuarine system. The pollution and closures do not affect the organisms, just their use by man. When open for harvest, shellfish waters provide oysters and clams for consumption as very valuable raw products. The total amount of estuarine acreage permanently closed to shellfishing in North Carolina generally remained constant from 1980 to 1989 (approximately 320,000 acres), however, closures increased to approximately 370,000 acres in 1990 and 1991. Decreases in permanent closures between 1982 and 1989 (due primarily to improvements in waste water treatment plants) seem to have been balanced by increases in temporary stormwater-related closures. Most closed areas are outside the A/P study area, but Core and Bogue Sounds and several small embayments are affected. In the A/P Study area, approximately 36,000 acres are closed to the harvest of shellfish. Roughly another 15,000 acres in the Study area are subject to temporary closures due to contaminated stormwater runoff, an indication of continued localized water quality degradation. (These areas have been closed temporarily at least 10 times in the past 5 years.)

Temporary closures since 1980 have increased (G. Gilbert, Shellfish Sanitation, pers. comm.). The closures related to runoff from agriculture and urban/residential development have increased since 1980 (Rader In Press). Closures to shellfish harvest due to marina developments have also increased (G. Gilbert, Shellfish Sanitation, pers. comm.). Under present management guidelines, as development expands and the coastal plain becomes more populous, the amount of shellfishing areas closed to fecal contamination will likely increase. As of July 1989, in the counties surrounding the Albemarle-Pamlico estuarine system, the acreage of closed shellfishing waters that have historically supported shellfish harvesting are: Dare County = 15,200 acres (3% of the total estuarine acreage); Hyde County = 2,600 (<1%); Beaufort County = 42,900 (60%); Pamlico County = 16,500 (12%); Craven County = 19,800 (70%), and Carteret County = 7,400 (2%) (Shellfish Sanitation Branch Unpublished Data).

A final major water quality concern associated with fisheries production in the Albemarle-Pamlico estuarine system is the discharge of toxic substances. Toxicants are discharged into the Albemarle-Pamlico from a variety of sources, both point and nonpoint. Point sources include industrial complexes and municipal wastewater treatment facilities, while examples of nonpoint sources are agricultural and silvicultural lands.

Relatively high metal concentrations have been found in the sediments of tributaries of the Albemarle-Pamlico estuarine system which receive both point discharges and heavy agricultural runoff (S. Riggs et al. 1989). The highest use of pesticides per unit of cropland for any estuarine drainage area in the United States occurs in the Albemarle Sound area (Pait et al. 1989). Pamlico Sound has the fifth highest pesticide use per unit of cropland of all estuarine drainage areas in the United States. Pesticides have been found in both the Tar-Pamlico and Neuse rivers (North Carolina Division of Environmental Management 1986). DDT, chlordane, lindane, and PCPs were found in fish tissue at several locations in the Neuse and Tar Rivers; however, the levels found were determined to present no problems in these systems. Significant quantities of dioxin have been found in fish near industrial discharges located along one tributary of Albemarle Sound and an advisory concerning fish consumption was issued by the DEM in 1990 and 1991.

Toxins may affect fisheries production both directly by impacting fish stocks and indirectly through impacts on the aquatic environment. Toxins can kill fish acutely or chronically through deleterious effects on basic life history functions, such as reproduction and feeding. Lipophilic toxins, for example, would be expected to concentrate in egg tissue and so could be toxic to early developmental stages, yet not be hazardous at such concentrations to larger individuals. High levels of toxins in fish can make them unmarketable. Toxins are thought to cause environmental stress which may result in tumors and ulcerative diseases in fish (Malins et al. 1984). Toxins also can have sub-lethal effects on fish such as impeded growth (Sindermann 1979).

The potential effects of human-related environmental factors on the fishery resources of the Albemarle-Pamlico estuarine system merit concern. Similar concerns have been examined for several finfish resources along the Atlantic Coast (Schaaf et al. 1987; Summers et al. 1987; Polgar et al. 1985). The ability to distinguish the effects of individual anthropogenic activities will be difficult due to the large variability of fish stock abundance and the migratory nature of most economically valuable estuarine fishes (Schaaf et al. 1987). Efforts should begin with obtaining better estimates of fish abundance and directing research efforts towards some of the major water quality concerns.

B. CRITICAL FISHERIES HABITATS

The productive fisheries habitats of the Albemarle-Pamlico estuarine system provide fishery resources not only for this estuarine system but for other areas of North Carolina and the Atlantic Coast as well. Although all areas in the estuarine system are important for overall fisheries production, five general habitat types are especially critical for fisheries production. These habitats include: (1) estuarine nursery areas, (2) anadromous fish areas, (3) shellfish areas, (4) submerged aquatic vegetation beds (SAV), and (5) wetlands. Each habitat contributes uniquely to overall fish production, and each is a critical component of the estuarine complex as a whole. In addition, the sounds themselves are extremely important to the overall fishery production.

B. 1. Estuarine Nursery Areas

Nursery areas are those areas in which juvenile development occurs. The entire estuarine system is a major nursery area for many economically important species. Though virtually every portion of the estuarine system serves as a nursery area for some species, two special categories of estuarine nursery areas are officially recognized -- primary and secondary nursery areas.

Estuarine primary nursery areas are generally located in the upper portions of the tributaries and in embayments around the sounds and rivers. These areas are usually shallow, bordered by marsh, and have soft, detritus-rich mud bottoms. Larvae typically arrive in these areas from oceanic or near-inlet spawning grounds throughout the year; spawning times depend on individual species' life histories, however, most species enter nursery areas during the winter and spring. Larval transport mechanisms in the sound are generally believed to be related to wind-induced tides and currents combined with larval behavior (Miller et al. 1984). Primary nursery area utilization for most species lasts through the early summer; by mid-summer most winter/spring-spawned organisms are large enough to emigrate to the secondary nursery areas. Primary nursery areas in North Carolina were first defined and identified by the NC Marine Fisheries Commission (MFC) regulations in 1977. Approximately 19,000 acres of primary areas have been defined and officially designated in the Albemarle-Pamlico estuarine system. The ten most abundant species occurring in primary nursery areas of the A/P Study area in descending order of abundance in 1988 were: spot, bay anchovy (Anchoa mitchilli), Atlantic croaker, pinfish (Lagodon rhomboides), brown shrimp (Penaeus aztecus), Atlantic menhaden, blue crab, pink shrimp (P. duorarum), pigfish (Orthopristis chrysoptera), and silver perch (Bairdiella chrysoura). Table IV-3 shows the species composition in primary nursery areas as determined by the DMF estuarine trawl survey during 1988. Figure IV-2 shows the legally adopted primary nursery areas of the A/P Study area. Numerous fisheries surveys have been conducted in the estuarine system; many were aimed specifically at documenting the organisms which utilize the nursery areas (Tagatz and Dudley 1961; Turner and Johnson 1973; Spitsbergen and Wolff 1974; Hester and Copeland 1975; Purvis 1976; Wolff 1976; Carpenter 1979; Ross and Carpenter 1980; Ross and Carpenter 1983; Currin et al. 1984; Ross and Epperly 1986; Hettler 1989; and Noble and Monroe 1991). The majority of the primary nursery areas in the A/P Study area, especially those in mesohaline zones, are characterized by tremendous numbers of individuals, but relatively low finfish/crustacean species diversity.

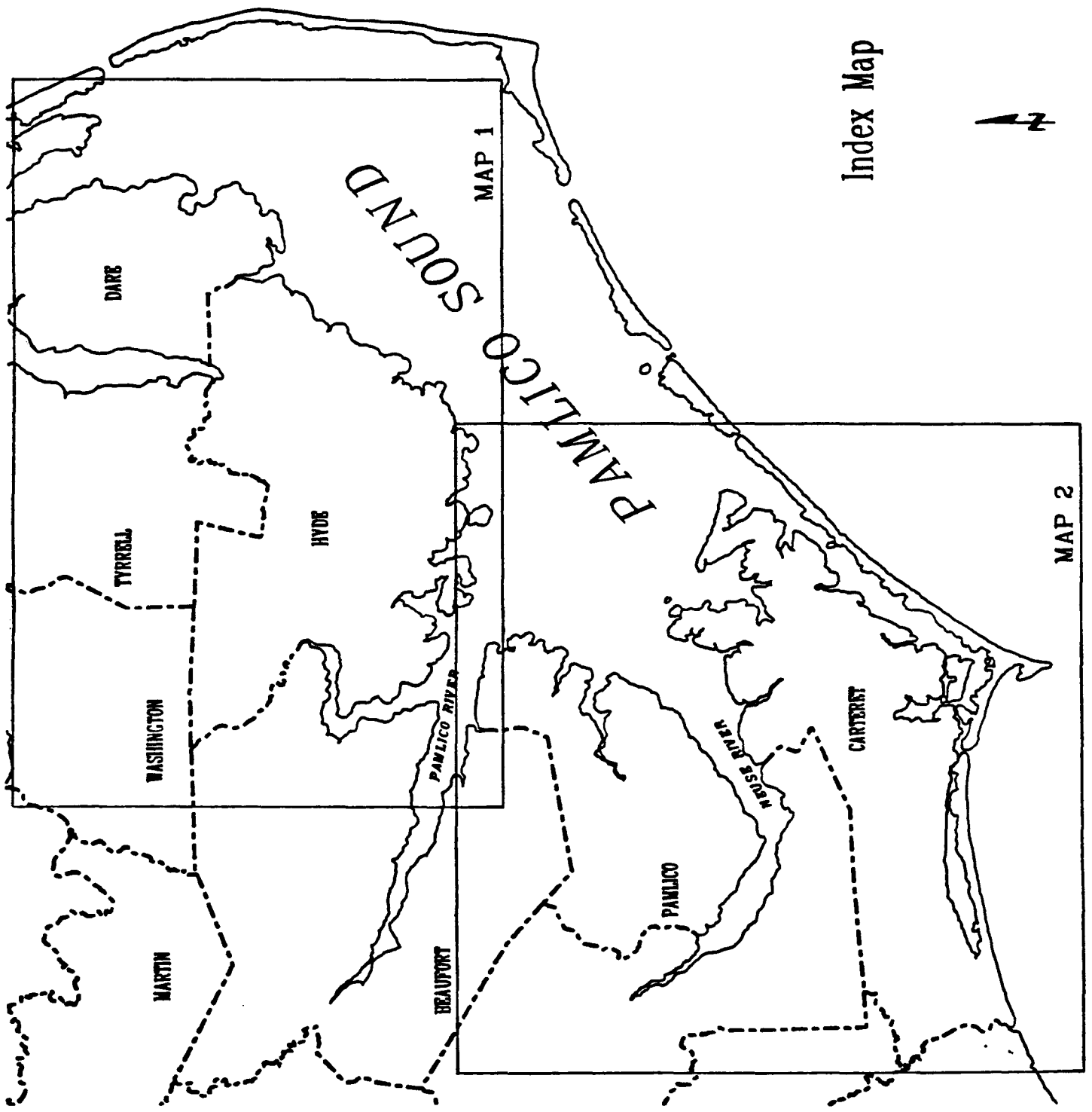
Those habitats immediately downstream from primary nursery areas are considered to be secondary nursery areas. Secondary nursery areas are legally designated in a manner similar to primary nursery areas and are also shown in Figure IV-2. They are generally larger, deeper bodies of water which contain great numbers of mixed sizes of organisms. Most juvenile organisms leave the primary nursery areas during the summer, occupying the secondary nursery areas until they migrate off-shore with declining temperatures in the fall. The species composition in the secondary nursery areas is similar to that of the primary nursery areas. The ten most abundant species noted in trawl surveys during 1988 in the A/P Study area were (in order of abundance): spot, bay anchovy, Atlantic croaker, blue crab, brown shrimp, shore shrimp (Palaemonetes spp.), Atlantic menhaden, silver perch, southern flounder, and pinfish (Table IV-4). In addition, larger adult fish are usually found in the secondary areas.

Table IV-3. Species composition of primary nursery area trawl survey, Albemarle-Pamlico estuary, 1989 (NC Division of Marine Fisheries).

| Common name | Species | Number | Pct. Total |
|-------------------|---------------------------------|---------|------------|
| Spot | <u>Leiostomus xanthurus</u> | 70,060 | 47.6 |
| Bay anchovy | <u>Anchoa mitchilli</u> | 39,604 | 29.6 |
| Atlantic menhaden | <u>Brevoortia tyrannus</u> | 8,212 | 5.6 |
| Atlantic croaker | <u>Micropogonias undulatus</u> | 6,137 | 4.5 |
| Brown shrimp | <u>Penaeus aztecus</u> | 6,124 | 4.2 |
| Pinfish | <u>Lagodon rhomboides</u> | 3,750 | 2.5 |
| Blue crab | <u>Callinectes sapidus</u> | 3,424 | 2.3 |
| Silver perch | <u>Bairdiella chrysoura</u> | 1,179 | 0.8 |
| Southern flounder | <u>Paralichthys lethostigma</u> | 1,050 | 0.7 |
| Pigfish | <u>Orthopristis chrysoptera</u> | 1,027 | 0.7 |
| Others | | 6,719 | 4.2 |
| Total | | 147,286 | 100.0 |

Table IV-4. Species composition of secondary nursery area trawl survey, Albemarle-Pamlico Estuaries, 1989 (NC Division of Marine Fisheries).

| Common name | Species | Number | Pct. Total |
|-------------------|---------------------------------|---------|------------|
| Spot | <u>Leiostomus xanthurus</u> | 145,995 | 48.5 |
| Bay anchovy | <u>Anchoa mitchilli</u> | 83,666 | 27.8 |
| Atlantic croaker | <u>Micropogonias undulatus</u> | 29,266 | 9.7 |
| Blue crab | <u>Callinectes sapidus</u> | 14,211 | 4.7 |
| Brown shrimp | <u>Penaeus aztecus</u> | 10,908 | 3.6 |
| Atlantic menhaden | <u>Brevoortia tyrannus</u> | 4,089 | 1.4 |
| Silver perch | <u>Bairdiella chrysoura</u> | 2,111 | 0.7 |
| Weakfish | <u>Cynoscion regalis</u> | 1,657 | 0.5 |
| Southern flounder | <u>Paralichthys lethostigma</u> | 1,540 | 0.5 |
| Pinfish | <u>Lagodon rhomboides</u> | 1,025 | 0.3 |
| Others | | 6,617 | 2.2 |
| Total | | 301,085 | 100.0 |



Index Map

MAP 1

- Primary Nursery Area
- ▲ Secondary Nursery Area

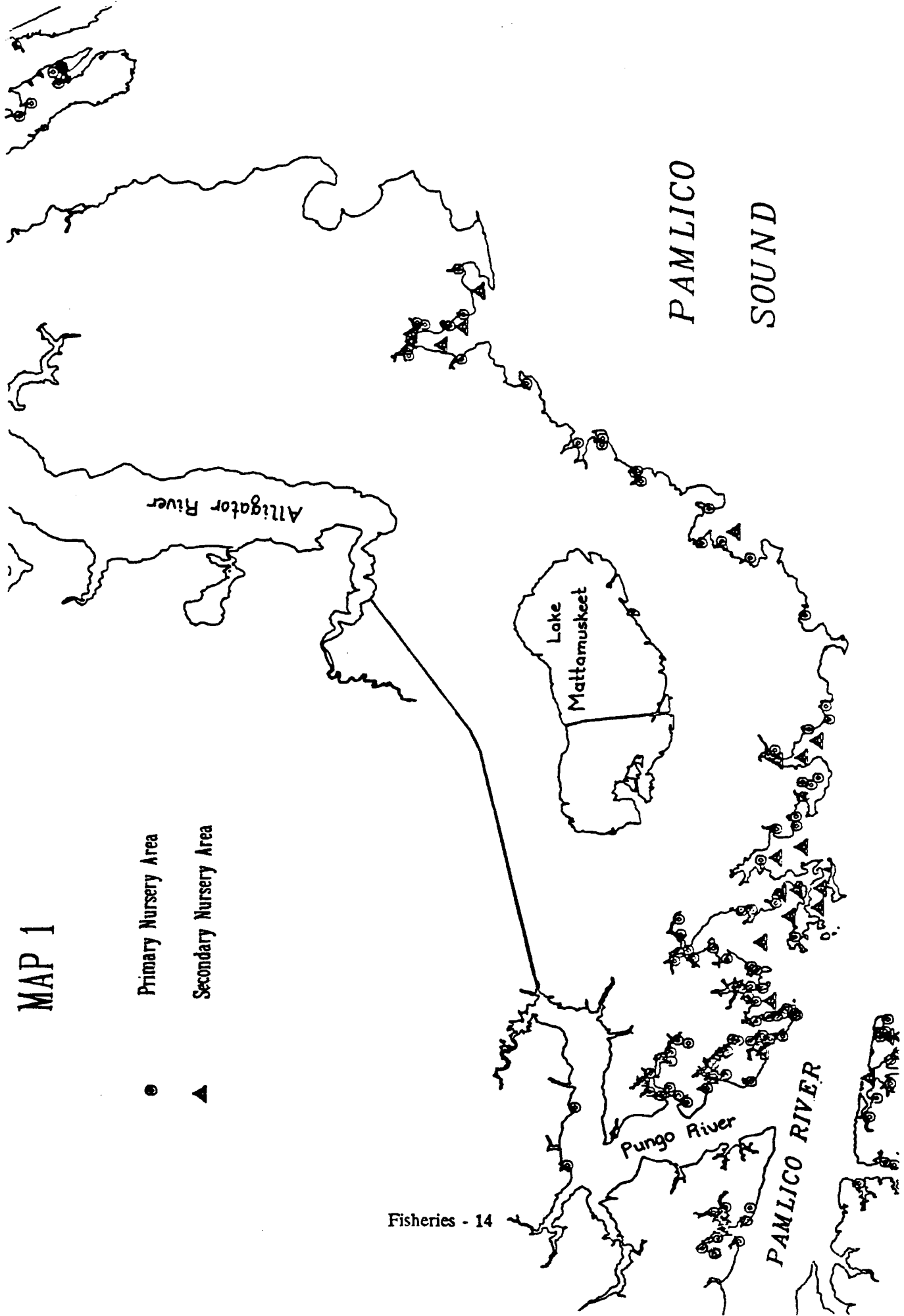


Figure IV.2 (h) Primary and Secondary Nursery Areas: Northern Pamlico Sound and the Pamlico River

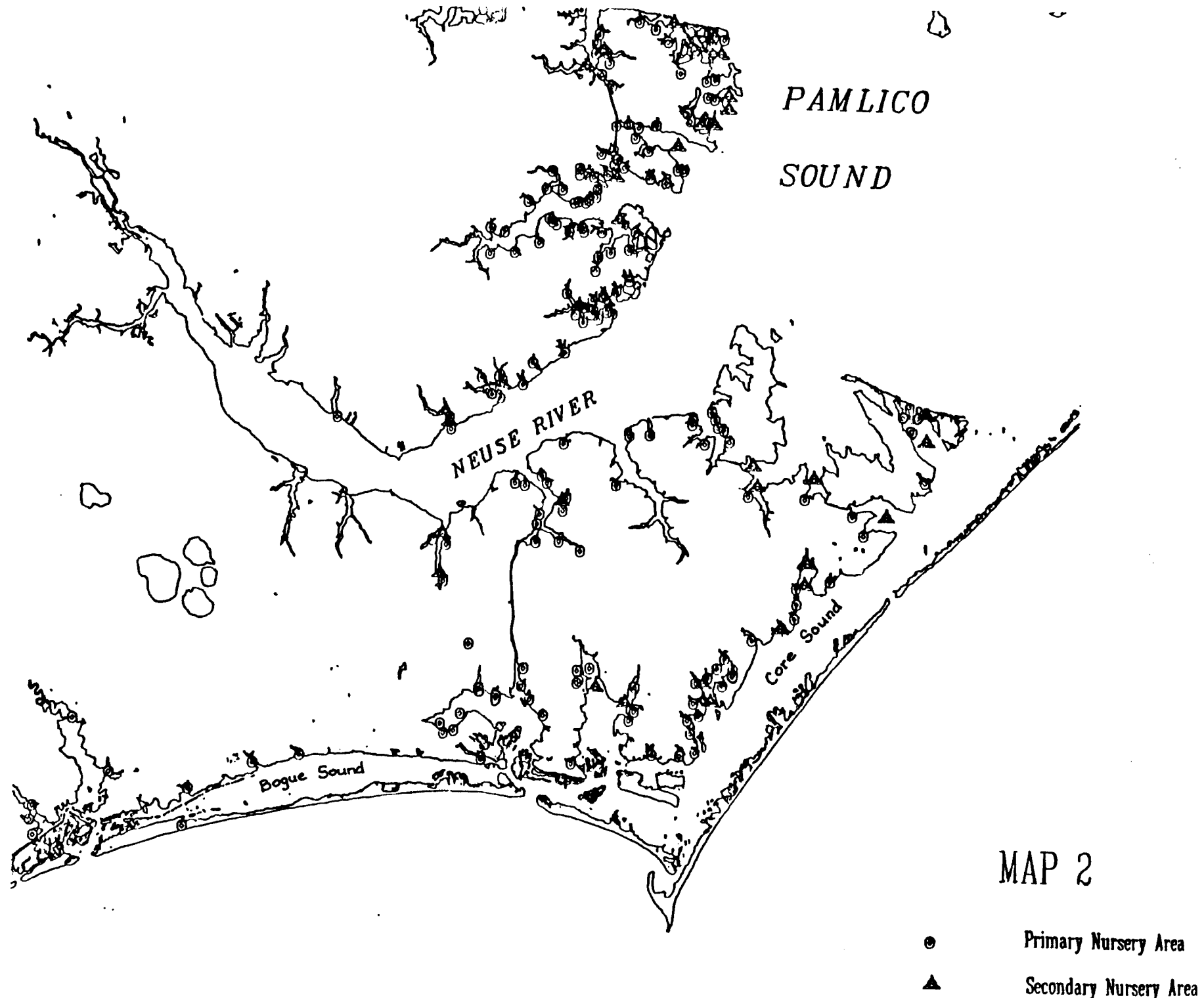


Figure IV-2 (c). Primary and Secondary Nursery Areas: Southern Pamlico Sound, Neuse River,

B. 2. Anadromous Fish Areas

Anadromous fish species have historically formed a significant component of the fishery resources of the Albemarle-Pamlico estuarine system. Spawning and early development must occur in freshwater and the upper reaches of the estuaries. The anadromous species found in the area include blueback herring, alewife, hickory shad, American shad, striped bass, and Atlantic sturgeon (Acipenser oxyrinchus). These species utilize the major drainages around the estuarine system and especially the major rivers, including the Chowan, Roanoke, Tar-Pamlico, and Neuse. Numerous life history studies have been conducted on the anadromous species in the estuary (Walburg 1957; LaPointe 1957; Cheek 1961; Pate 1971; Tyus 1971; Manooch 1972; Street and Hall 1973; Kornegay and Humphries 1975; Pate 1975; Street and Pate 1975; Johnson et al. 1977; Loesch et al. 1977; Marshall 1977; Sholar 1977; Johnson et al. 1988; Hawkins 1980; Hassler et al. 1981; O'Rear 1983; Winslow et al. 1983; Winslow and Johnson 1984; Creed 1985; Rulifson 1985; Winslow et al. 1985).

All anadromous species in the area spawn during the spring. Critical habitats utilized by sexually mature adults for spawning are also necessary for egg development. The preferred habitat varies depending on the species. For example, striped bass spawn in the main stem of major rivers such as the Roanoke, while blueback herring prefer flooded swamps adjacent to rivers or small tributaries.

Anadromous fish nursery areas are those areas downstream from the spawning areas where juvenile development occurs. These areas often include the upper estuarine area, especially in Albemarle Sound, including the shallow waters along the shoreline as well as the deeper, open-water areas.

B. 3. Shellfish Areas

Critical shellfish habitats are those which contain high densities of oysters, bay scallops, and hard clams or those areas capable of producing oysters, scallops, and clams. Scallops occupy beds of seagrasses -- these are discussed briefly in the next section and in detail in Chapter II. E. 1. Oyster resources are found throughout the Pamlico and Core Sounds, while clams are found predominantly in eastern Pamlico Sound and throughout Core Sound (Figure IV-3). A survey of the distribution of oyster-producing areas was conducted by Winslow (1889). Coker (1907) conducted experiments in oyster farming or culture in Pamlico Sound. The state worked to rehabilitate oyster areas after hurricane Ginger in 1971 (Munden 1975). These rehabilitation efforts of planting clutch material each year continue as a major aspect of DMF's oyster program. Shellfish area criteria are currently being developed, and a shellfish mapping survey is being conducted by the DMF to locate specific resource areas. Also, planting sites and natural beds of oysters are being sampled through an oyster shoal survey in Pamlico Sound and its tributaries; these data help identify the most productive oyster areas. Shellfish habitats are discussed in more detail in Chapter II, Critical Areas.

B. 4. Submerged Aquatic Vegetation Beds (SAVs)

"Grassbeds" are highly productive areas which serve as nursery areas for a number of important organisms and are critical to the life history of some species, such as bay scallops (Thayer et al. 1984; Fonseca et al. 1984; Thayer et al. 1979; Ferguson et al. 1989; and Orth et al. 1984). Two major types of SAVs occur in the Albemarle-Pamlico estuarine system. High salinity seagrass meadows, characterized by eelgrass (Zostera marina) and shoalgrass (Halodule wrightii), are located throughout Bogue Sound, Core Sound, and eastern Pamlico Sound. Brackish water grassbeds containing species such as wild celery (Vallisneria americana), widgeongrass (Ruppia maritima), and Eurasian watermilfoil (Myriophyllum spicatum) are found in the upper estuarine zones of the Neuse and Pamlico Rivers, and in Albemarle and Currituck Sounds (Davis and Brinson 1976; Davis and Brinson 1983; Davis et al. 1985). Abundance of the brackish water species has declined greatly since the mid-1970s, especially in the Tar-Pamlico

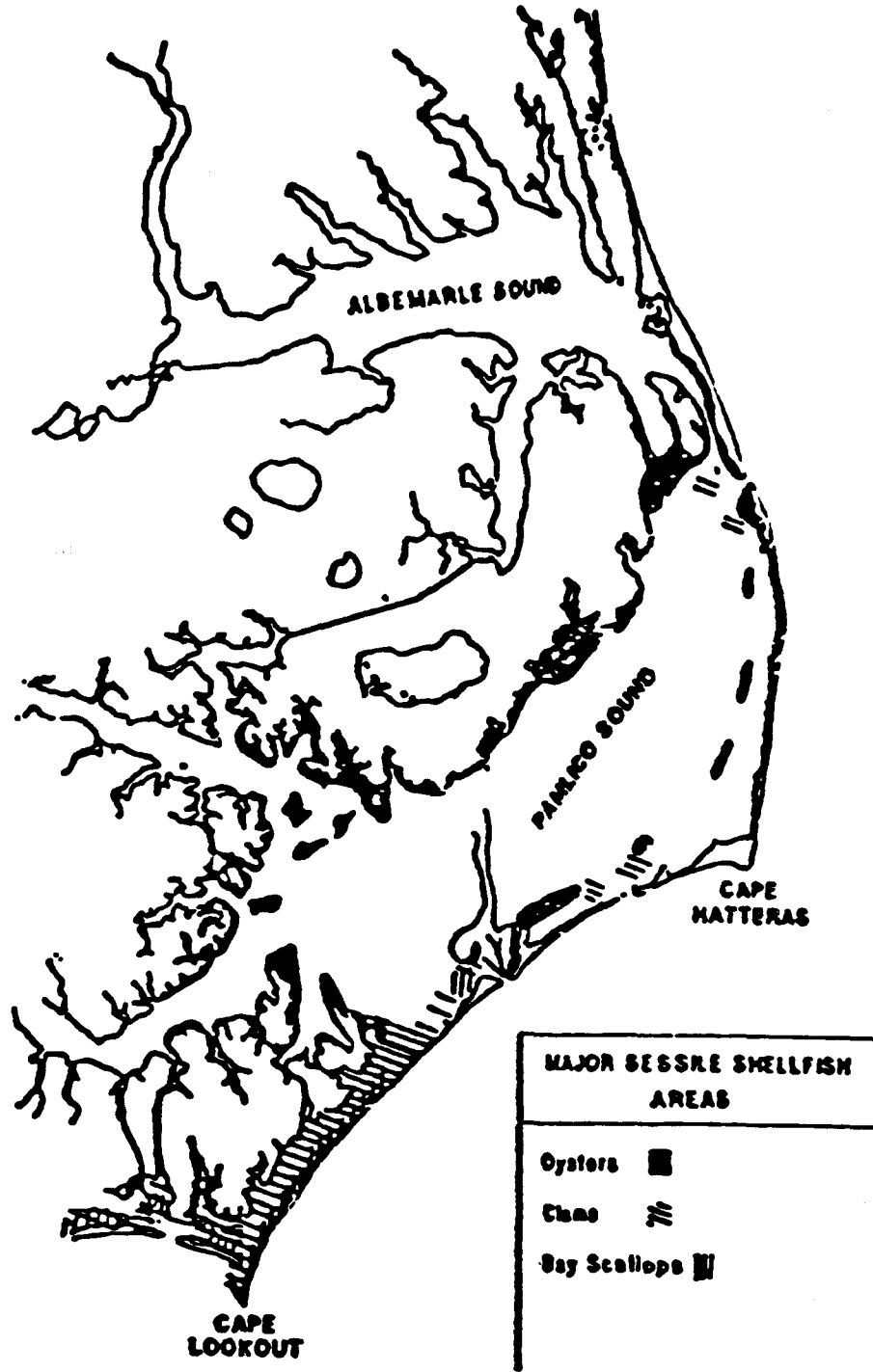


Figure IV-3. Major Shellfish Areas in the Albemarle-Pamlico Estuarine System. From Epperly and Ross (1986).

River (Davis et al. 1985). Submerged aquatic vegetation habitat is discussed in more detail in Chapter II, Critical Areas.

B. 5. Wetlands

Wetlands, located at the land/water interface, are an integral ecological part of the estuarine system and are critical for fish production. Wetlands provide direct benefits by serving as habitat for aquatic organisms and indirect benefits by helping to maintain water quality and contributing nutrients and detritus crucial for biological productivity. Wetlands also play an important role in modifying hydrologic events. The Albemarle-Pamlico estuarine system is surrounded by many wetland types, including vast marshes composed of black needlerush (*Juncus roemerianus*), smooth cordgrass (*Spartina alterniflora*) (Hettler 1989), and saltmeadow hay (*S. patens*). Large areas of riverine bottomland hardwoods are found along the major rivers, especially the Chowan, Roanoke, Tar-Pamlico, and Neuse rivers. Nontidal freshwater swamps are especially common in the Albemarle Sound area. Each wetland type contributes to the maintenance of the overall fisheries production of the estuarine system. Wetlands provide the basis for biological productivity in most of the A/P area and are discussed in more detail in Chapter II, Critical Areas.

C. STATUS OF MAJOR SPECIES

Well over 100 species of finfish, crustaceans, and shellfish contribute to North Carolina's commercial and recreational fisheries each year. Both commercial and sport fishermen in the Albemarle-Pamlico estuarine areas generally seek the same species, such as striped bass, white perch, Atlantic croaker, spotted seatrout, flounder, blue crabs, shrimp, and hard clams. A few species are of importance almost exclusively to commercial fishermen, including river herring, Atlantic menhaden, harvestfish, and eels. Similarly, anglers have a predominant interest in a few estuarine species, including tarpon and red drum.

The 14 species with the highest commercial landings in the Albemarle-Pamlico estuarine system are discussed below. Commercial landings data for these species is shown in Table IV-5. Data are from the DMF/NMFS cooperative statistics program. Comparable recreational data do not exist, as previously discussed.

C. 1. River Herring

Blueback herring and alewife, collectively known as river herring, ascend North Carolina's coastal rivers each spring to spawn in freshwater creeks and swamps. Millions of fish, principally in the Chowan River, are harvested for processing to yield salted herring, specialty products, and roe (Wynns 1967). River herring are also highly valued as bait for striped bass sport fishing, for blue crabs in the south Atlantic area, and for crayfish in Louisiana.

Domestic landings declined sharply during the 1970s as foreign fleets made large catches in the ocean, exceeding previous domestic landings. Ocean landings essentially ended when foreign fishing was controlled by enactment of the Federal Fisheries Conservation and Management Act of 1976. Landings, however, remained depressed into the early 1980s. Some recovery occurred in North Carolina in 1985, but landings have declined since then to the lowest on record. The fisheries in Virginia and Maryland declined along with those in North Carolina and have remained severely depressed.

Table IV-5. Landings of principal commercial species from the Albemarle Sound, Pamlico Sound, and Core Sound areas of North Carolina combined, 1972-1990 (in thousands of pounds). (DMF Data)

| Year | S P E C I E S | | | | | | | | | | | | | |
|------|---------------|-----------|----------|---------|----------|-----------|------------|-------|--------------|-------------|--------|-----------|-----------|---------|
| | River herring | Blue-fish | Cat-fish | Croaker | Flounder | Weak-fish | Amer. shad | Spot | Striped bass | White perch | Shrimp | Blue crab | Hard clam | Oysters |
| 1972 | 11,237 | 405 | 2,375 | 755 | 779 | 341 | 402 | 1,978 | 429 | 201 | 3,125 | 13,112 | 77 | 275 |
| 1973 | 7,926 | 477 | 1,888 | 2,608 | 898 | 767 | 289 | 3,723 | 642 | 145 | 2,827 | 11,659 | 134 | 380 |
| 1974 | 6,210 | 1,195 | 1,739 | 3,804 | 1,868 | 833 | 349 | 4,152 | 511 | 309 | 6,234 | 12,861 | 40 | 383 |
| 1975 | 5,949 | 936 | 1,654 | 6,775 | 1,696 | 1,639 | 218 | 6,767 | 716 | 289 | 2,988 | 10,783 | 13 | 302 |
| 1976 | 6,401 | 809 | 1,500 | 6,677 | 1,672 | 1,835 | 158 | 8,769 | 704 | 184 | 4,666 | 11,411 | 8 | 214 |
| 1977 | 8,523 | 813 | 2,068 | 8,207 | 672 | 4,781 | 106 | 2,790 | 480 | 268 | 4,494 | 11,903 | 533 | 266 |
| 1978 | 6,606 | 482 | 1,734 | 7,974 | 1,327 | 3,098 | 364 | 3,090 | 532 | 499 | 1,744 | 22,044 | 471 | 164 |
| 1979 | 5,031 | 739 | 1,512 | 11,006 | 1,822 | 3,261 | 201 | 5,570 | 366 | 361 | 2,596 | 25,154 | 688 | 433 |
| 1980 | 6,217 | 1,101 | 1,447 | 12,637 | 3,077 | 5,340 | 150 | 5,372 | 433 | 105 | 6,632 | 32,987 | 777 | 489 |
| 1981 | 4,611 | 765 | 1,716 | 8,080 | 2,102 | 3,290 | 192 | 2,729 | 358 | 395 | 1,646 | 36,202 | 652 | 315 |
| 1982 | 9,428 | 1,008 | 1,167 | 7,815 | 1,803 | 2,662 | 270 | 4,368 | 244 | 665 | 4,196 | 35,866 | 873 | 352 |
| 1983 | 5,868 | 622 | 1,050 | 5,587 | 2,377 | 2,178 | 377 | 2,373 | 306 | 498 | 3,754 | 33,042 | 723 | 497 |
| 1984 | 6,505 | 773 | 1,330 | 4,506 | 2,178 | 2,464 | 502 | 2,492 | 497 | 440 | 2,201 | 31,484 | 859 | 563 |
| 1985 | 11,548 | 977 | 1,279 | 4,166 | 1,841 | 1,922 | 309 | 2,775 | 280 | 701 | 9,601 | 28,562 | 886 | 393 |
| 1986 | 6,774 | 832 | 1,181 | 3,961 | 2,465 | 2,129 | 265 | 2,196 | 188 | 672 | 1,572 | 22,898 | 814 | 528 |
| 1987 | 3,176 | 1,044 | 1,228 | 3,181 | 2,519 | 1,771 | 272 | 1,649 | 262 | 792 | 2,901 | 31,509 | 617 | 1,210 |
| 1988 | 4,172 | 1,005 | 1,122 | 3,928 | 2,780 | 2,384 | 228 | 2,237 | 115 | 586 | 5,121 | 33,775 | 516 | 746 |
| 1989 | 1,491 | 472 | 812 | 3,983 | 3,123 | 829 | 272 | 2,140 | 100 | 295 | 6,230 | 33,630 | 690 | 293 |
| 1990 | 1,147 | 524 | 983 | 4,660 | 2,434 | 1,404 | 250 | 2,547 | 105 | 156 | 5,429 | 36,794 | 681 | 154 |

Area fishermen feel that weather conditions and pollution from a pulp mill in Virginia which discharges into Chowan River just upstream from the North Carolina/Virginia border together reduced fish landings from 1986 to 1990 and that adequate fish stocks were available but were not entering the nets due to those conditions (Winslow 1989). Examination of catch effort data (Winslow 1989; Winslow et al. 1985; Winslow et al. 1983; Johnson et al. 1981) indicates that pound net effort in the Chowan River during 1987, 1988, and 1989 was among the highest on record while catches and catch-per-unit-effort were the lowest on record. It has been suggested that water quality problems in spawning and nursery areas have inhibited stock recovery. Blue-green algae blooms during late spring may also affect early juveniles by releasing toxins into the water column (Winslow et al. 1985).

C. 2. American Shad

During the early 1900s, American shad was the most commercially important species in North Carolina. Landings declined from more than 8 million pounds in 1896 and 1897 to the 1-million-pound range and below in the 1930s. The lowest landings on record occurred during the mid-1970s. Some improvements occurred during the early 1980s, but landings have declined again since then (Winslow 1989). American shad, anadromous fish, enter coastal streams in the spring to spawn. Shad stocks all along the Atlantic Coast have been affected by loss of spawning areas due to construction of dams on coastal rivers, industrial and municipal pollution of rivers, and over-fishing of some stocks. Changed consumer habits have resulted in reduced market demand for shad, although seasonal demand remains high in some areas. Intensively managed shad stocks in New England are increasing with habitat improvement, stocking, fishway construction, and regulation of the fisheries. Such management has not been attempted in North Carolina. The major commercial fisheries for American shad is the gill net fishery in Albemarle Sound. Gill net fisheries are also present in Pamlico Sound, Neuse River, and Pamlico River, but have declined in the last ten years. The principal angling areas of the Albemarle-Pamlico region are the Neuse River, Tar River, and Chowan River. Recreational fishermen also use drift gill nets in the Neuse and Tar Rivers. The DMF has conducted extensive research on American shad since the early 1970s but has been unable to determine causes of apparent population declines.

C. 3. Bluefish

Bluefish are very important to both sport and commercial fishermen. Long haul seines, pound nets, and gill nets account for most of the commercial catch in the estuarine system. Most of the total catch comes from the near-shore ocean by trawls and gill nets. Recreational harvest of bluefish usually exceeds commercial harvest. Bluefish are one of North Carolina's most popular recreationally caught fish, ranking among the top three in numbers caught, and consistently ranking number one in total pounds landed. Most recreational catches are taken by trolling and surf casting. A stock assessment program sampling bluefish has been in place in North Carolina since 1981. Abundance was high all along the Atlantic coast from the mid-1970s through the mid-1980s, making bluefish one of the few species consistently available to all fishermen.

Bluefish have been found to carry varying amounts of contaminants. Recent data from NMFS indicate that the total recreational catch along the Atlantic coast has fallen dramatically (from roughly 80 million pounds to roughly 40 million pounds) from 1986 to 1989 (NMFS 1987, 1988, 1989). A coastwide fisheries management plan for bluefish has been prepared (Mid-Atlantic Fishery Management Council 1989) and was implemented early in 1990, particularly restricting recreational catches. Some large bluefish from various Atlantic coastal sites, including North Carolina, contained PCB concentrations exceeding the federal action level of 2 parts per million, however, a recent federal study of PCB's indicates that there is no general hazard to the public.

C. 4. Catfish

In the A/P Study area, channel catfish and white catfish are taken principally in western Albemarle Sound, Chowan River, and Roanoke River in pound nets, gill nets, and catfish pots. Landings have varied, generally trending downward since the mid 1970s. Certain species of catfish, including the white catfish, black bullhead, yellow bullhead, brown bullhead, and flat bullhead, are quite tolerant of degraded water quality, especially low oxygen levels. The channel catfish and other catfish of commercial value are however, not tolerant. A decline in water quality may, therefore, result in changing species assemblages towards more tolerant species. Catfish are susceptible to red sore disease, a bacterial infection prevalent in the Albemarle Sound area during the 1970s. As with most diseases, outbreaks of red sore disease in catfish are often manifestations of stress due to poor water quality. Little biological research has been conducted on catfish in the Albemarle area (Mauney 1969; Keefe and Harriss 1981) and no cause can be stated for the apparent decline in landings.

C. 5. Atlantic Croaker

Atlantic croaker is one of North Carolina's most important finfish for both commercial and recreational fishermen. Some large year classes were produced during the mid and late 1970s, which provided record landings from 1976 to 1980. During this period, relatively large numbers of three- and four-year-old fish were taken. Recreational fishing in Pamlico Sound was so good, that the term "croaker boats" was used to describe the large fleets of 16-25 ft recreational fishing boats which fished in Pamlico Sound during that period, regardless of their target species. Oceanic trawl and estuarine long haul seine catches dominated landings through 1980; since 1984, oceanic gill net catches accounted for most of the Atlantic croaker harvest (Ross 1991). Pound nets also harvest considerable numbers of Atlantic croaker. Data collected from the major commercial fisheries by DMF stock assessment surveys since 1981 indicate that Atlantic croaker are "growth over-fished", i.e., that average sizes of landed individuals have become smaller (Ross 1991). Reasons for the increase from 1976 to 1980 are unknown but are probably related to favorable changes in environmental conditions in ocean spawning areas and estuarine nursery areas. Croaker spawn principally during fall, winter, and spring; extreme winter conditions may cause mortality of eggs, larvae, or early juveniles.

C. 6. Spot

Spot is usually one of the most abundant estuarine fishes of North Carolina and is very important to recreational fishermen, it ranked first in numbers caught recreationally from 1987 to 1989. Landings and presumably population levels fluctuate wildly. The long haul seine fishery harvests most of the spot landed in North Carolina. According to DMF stock assessment data, populations show little indications of growth over-fishing in North Carolina. Fluctuations are thought to be primarily controlled by environmental conditions or other aspects of spot's life history, such as predation.

C. 7. Flounder

Two species of flounder primarily support one of North Carolina's most important commercial finfish fisheries, as well as very important recreational fisheries. Summer flounder is the most commercially important species, composing approximately 56-70% of the total flounder landings in North Carolina. The oceanic trawl fishery harvests most of the summer flounder. Landings of summer flounder along the Atlantic coast were nearly constant from 1979 to 1990, when they fell nearly 60%. North Carolina landings have gradually declined since 1984, with 1990 landing the lowest since the early 1970s. Presently summer flounder appear to be over-fished.

The harvest of southern flounder is restricted almost entirely to estuarine waters; it is reaped primarily by pound nets and gill nets. Stock assessment data show that the size of southern flounder harvested have become smaller (Ross 1991). Landings of southern flounder have increased in recent years.

Minimum size limits were increased for flounder in 1988 and tailbag (codend) sizes for oceanic trawls enlarged during 1990 in response to heavy fishing pressure. Both species spawn in the ocean off North Carolina during the winter, and the young utilize estuarine nursery areas. Summer flounder utilize the higher salinity open water for nurseries, while southern flounder utilize the lower salinity creeks and bays. The Albemarle-Pamlico estuarine system is a major flounder nursery area, possibly the most important summer flounder nursery area for the entire Atlantic Coast (see section IV-G).

C. 8. Weakfish

Generally called "grey trout" in North Carolina, weakfish utilize estuarine waters for spawning and as nursery areas. Pamlico Sound and its tributaries serve as the major nursery areas for weakfish in North Carolina; the area is also an important nursery area for the entire Atlantic coast. Weakfish is one of North Carolina's most valuable commercially landed finfish. Commercial catches reached their peak between 1978 and 1984, with most of the increased catch coming from the oceanic gill net and trawl fisheries. Most of the estuarine harvest is taken with long haul seines and pound nets in the Pamlico Sound area. Commercial landings have fluctuated widely all along the coast. Landings from northern areas have fallen recently (Unpublished information, Atlantic States Marine Fisheries Commission, December 1988), while North Carolina landings remained quite high until 1990 when they declined sharply to 5.8 million pounds, the lowest volume in 20 years. North Carolina lands approximately 70% of the total weakfish harvested along the Atlantic Coast. The historic centers of abundance appear to be Pamlico Sound and Chesapeake Bay. Reasons for the wide variations in abundance historically are unknown. Presently, DMF stock assessment data show that weakfish are being growth over-fished. The Atlantic States Marine Fisheries Commission (ASMFC) Weakfish Board has recently determined that weakfish are in an over-fished status.

C. 9. Striped Bass

Striped bass populations are found in all of North Carolina's major coastal river basins (Cape Fear River, Neuse River, Tar-Pamlico River, and Roanoke River-Albemarle Sound). In addition, the Atlantic Coast migratory stock of striped bass utilizes offshore wintering grounds which generally extend from Cape Hatteras north to the mouth of the Chesapeake Bay. The Roanoke River-Albemarle Sound complex is an excellent example of a system in which changes to the flow regime may have had a major negative effect on living resources. Historically, the Roanoke River-Albemarle Sound complex was one of the most productive striped bass spawning areas on the east-coast, ranking third only to the Chesapeake stocks and the Hudson River population (US Department of Interior and US Department of Commerce 1987). During periods of high abundance, this stock probably contributes to the Atlantic migratory population which over-winters off North Carolina and migrates north along the coast to New England during the summer. Annual landings, however, decreased from about 15 to 20 million pounds in the mid-1960s and early-1970s to less than 300,000 pounds in the late 1980s, a decline of over 80 percent in 20 years (Manooch and Rulifson 1989).

Historically, the Chesapeake Bay population has made up the preponderance of the Atlantic Coast migratory stock. However, reproductive failure of this stock after the early 1970s, combined with over-harvest, resulted in a severe population decline. This situation led to a cooperative interstate approach to management of the migratory stock. A management plan has been prepared by the Atlantic States

Marine Fisheries Commission (ASMFC), an interstate compact created by the US Congress in 1942. Implementation of this plan required severe restrictions and moratoria on fishing in some areas from 1985 to 1989. These measures have helped the Atlantic coast migratory population recover to such a point that very restricted fishing began in 1990 in ocean waters north of Cape Hatteras and in estuarine waters from Chesapeake Bay northward.

Similar to the Chesapeake Bay stock, reproductive failure has plagued the Albemarle-Roanoke stock since 1977 (Manooch and Rulifson 1989), although fishing restrictions have been less severe in North Carolina's estuarine waters than further north. Reasons for poor reproduction appear to be related to over-harvest, poor water quality, and, perhaps most importantly, instability of river flows during spawning and nursery seasons (Manooch and Rulifson 1989).

Several factors have strongly linked striped bass declines to changes in the Roanoke River-Albemarle Sound flow and circulation regime. (1) Although reliable information on landings prior to the mid-1960s is unavailable, striped bass declines occurred after the completion of a series of reservoirs on the upper Roanoke in 1963. (2) Time-series analysis has shown strong correlation between reservoir release schedules and the yearly juvenile abundance index (JAI), an indicator of spawning success (Manooch and Rulifson 1989). (3) There has been no apparent decline in the number of eggs spawned, but egg viability has decreased and juvenile mortality has increased (Manooch and Rulifson 1989). (4) There is some indication that, over the last 30 years, significant changes in bathymetry (and thus perhaps circulation) have occurred in western Albemarle Sound, the historical nursery area for striped bass larvae.

The importance of flow processes on striped bass is evident at a number of key stages in the early-life cycle of the fish. Transport and mixing processes: (1) control the rate of egg transport downstream -- eggs should remain suspended and within the channel (not the floodplain); (2) determine the location at which eggs hatch -- hatching should occur in a region with an adequate food source and moderate flows; (3) affect larval feeding success and mortality -- larvae should be transported to historical nursery grounds in the estuarine mixing zone; and (4) govern water quality. Transport and mixing processes also affect the supply of phytoplankton and zooplankton available to larval fish and appear to be modifying the bathymetry and so the circulation in the historical nursery areas (Rulifson unpublished data).

An ad hoc multi-agency committee was formed in 1987 to review the water flow situation and its possible relationship with spawning success. This group recommended river flow changes in 1988 and as a result, juveniles were somewhat more abundant. In 1988, the JAI rose from the previous year's value of 0.08 to 4.09 (Manooch and Rulifson 1989). Unfortunately, full implementation of the committee's recommendations for a flow regime could not be accomplished in 1989 due to heavy rains and resulting high flows. The high flows were, however, quite stable during the spawning and nursery seasons. The 1989 JAI was 4.27, the second consecutive year of improvement. Unfortunately, the JAI declined sharply in 1990 to 1.41.

The commercial and recreational fisheries for striped bass have been supported, to some degree, by stocking of hatchery fish in the winters of 1981 and 1983 to the present. The DMF tagging program substantiates favorable returns to both commercial and recreational harvesters, but most importantly, to the residual spawning stock utilizing the Roanoke River. The total spawning stock, natural and surviving hatchery fish combined, however, remains extremely depressed. The striped bass fishery in the Pamlico River has become virtually non-existent.

Commercial and recreational landings throughout the Atlantic coast have declined due to greatly reduced abundance of fishable year classes and severe regulatory measures imposed by all states from North Carolina to Maine, under the ASMFC. The ASMFC interstate fishery management plan has recently been amended by Amendment #4, which allowed reopening of very limited fisheries in 1990.

The US Congress, in re-authorizing the Atlantic Striped Bass Conservation Act in 1988, included an amendment directing the federal government, in cooperation with state agencies, to undertake an additional study of the Roanoke-Albemarle population and to report their recommendations within three years. In North Carolina, DMF and the North Carolina Wildlife Resources Commission, in cooperation with the US Fish and Wildlife Service, are preparing a cooperative plan to meet the requirements of Amendment #4. All of these planning efforts are directed toward managing the North Carolina stock in concert with the Atlantic Striped Bass Conservation act to restore the stock to sustained fishable levels.

C. 10. White Perch

A slow-growing fish related to striped bass, white perch has replaced striped bass as a target species for many Albemarle Sound commercial and recreational fishermen. White perch are sought by gill net fishermen in Albemarle Sound, leading to problems in taking striped bass as by-catch (Henry 1987, 1989). White perch spawn in the lower Roanoke River and throughout the Chowan River, and they utilize most of the Albemarle Sound area as a nursery. They are especially susceptible to red sore disease, which may be responsible for the extremely low landings of 1980. Commercial landings from 1985 to 1988 were among the highest on record. Landings declined sharply in 1989-1990, possibly because of gill net restrictions designed to conserve striped bass. Little research on white perch has been conducted (Conover 1958; Keefe and Harriss 1981); thus, status of the stock is unknown.

C. 11. Shrimp

Brown, white (*P. setiferus*), and pink shrimp all contribute to North Carolina's shrimp harvest. Brown shrimp comprise the majority of the landings (69%). North Carolina is the largest producer of brown shrimp on the Atlantic Coast. Most shrimp are harvested with trawls in the estuarine waters of North Carolina, with Pamlico and Core Sounds serving as major fishing grounds. Brown shrimp support the major summer fishery, especially in Pamlico Sound. As an annual crop, shrimp abundance depends principally on annual environmental conditions, especially the salinity and temperature of nursery areas (Hunt et al 1980; Jones and Sholar 1981; and Hettler and Chester 1982). Thus, landings fluctuate widely from year to year. Especially critical for brown shrimp are nursery area conditions during April and May of each year. Examples include the record harvest of 6.4 million pounds of brown shrimp in 1985 during warm, dry conditions versus the poor harvest of approximately one million pounds during the relatively cool, wet conditions of 1984. The strong correlation ($r^2 > 0.9$) between the number of juvenile shrimp captured in the DMF shrimp trawls and the number of adults harvested, allows good estimates of the annual crop to be made early in the season (DMF, unpublished data). Pink shrimp production is very dependent on water temperatures, since juveniles over-winter in the relatively shallow waters of Pamlico and Core Sounds. For example, pink shrimp landings dropped from approximately 3 million pounds in 1989 to approximately 1.5 million pounds after relatively cold periods during the winter of 1989-90. Recreational shrimpers probably take significant quantities of shrimp, but the amount is unknown (Pate 1977). The DMF is able to assess annual production of brown shrimp through an intensive assessment sampling program for juveniles that has been in place since 1972.

C. 12. Blue Crabs

In terms of total harvest, value, numbers of fishermen, amount of gear, processing plants, and employment, blue crabs support North Carolina's most important commercial fishery. Landings increased steadily since the mid-1970s, reaching all time peaks during the early 1980s, before declining through 1986. Landings increased again between 1987 and 1990, reaching the third highest value on record (36.9 million pounds). Pamlico Sound is the center of the fishery, although contributions from

Albemarle and Core Sounds have increased. North Carolina is the third largest producer of blue crabs on the Atlantic coast, accounting for 23% of the total landings. Currently, crab pots account for over 95% of North Carolina's crab landings, while historically, crabs were primarily harvested with trawls. Effort, in terms of the number of pots fished, has increased dramatically since the early 1970s, with hundreds of thousands of pots in use. Blue crabs are essentially an annual crop like shrimp, so annual environmental variations probably dictate population size. Controlling factors, however, are not known. An assessment program for blue crabs in North Carolina has recently been initiated by the DMF to aid in determining efforts of harvest. As with shrimp, there are large, but unquantifiable recreational landings.

C. 13. Hard Clams

Hard clams supported a minor fishery in North Carolina (<300,000 pounds of meat), principally in the southern coastal area, until the extremely severe winter of 1976-77 adversely affected the northeastern United States. Landings rose rapidly from 1976 through 1979. Since 1979, North Carolina landings have averaged approximately 1,400,000 pounds per year. Clams are harvested by hand with rakes and tongs, and mechanically with hydraulic dredges and "kick" boats (using the propeller wash to dislodge the clams and "kick" them into trawls pulled behind the vessel). Present trends in total landings suggest that, in spite of increasing effort, clams are fully exploited. Demand from northern markets has driven the price steadily upward, resulting in significant regulatory and enforcement problems. It is especially difficult to control clam harvest in areas polluted by sewage and in grass beds and oyster rocks which are productive habitats for other species such as crabs, shrimp, bay scallops, and oysters. The "red tide" algal bloom of 1987-88 resulted in the closure of most clam harvest areas and caused considerable hardship among fishermen. Although it is believed that the red tide did not kill hard clams as it did bay scallops, low availability of the smaller sizes of market clams during 1988-89 suggests that small hard clams may have been affected by the red tide. Little assessment data are available on the clam resource in North Carolina.

C. 14. Oysters

North Carolina possesses thousands of acres of potentially productive oyster bottoms, especially around the perimeter of and within Pamlico Sound. Oysters can tolerate the wide variety of conditions found in the area as long as they have the proper bottom type. In the early 1900s, North Carolina supported a very productive oyster industry, landing several million bushels annually. The major harvest area was Pamlico Sound. By 1962, however, landings had declined to 192,000 bushels, probably as a result of fishing pressure and declining water quality. While fluctuating widely, oyster landings from the Pamlico Sound generally increased from the 1960s to 1988, due largely to a DMF management program which plants roughly 300,000 bushels of shell annually in Pamlico Sound to serve as oyster substrate. In 1988, the pathogens Minchinia nelsoni (MSX) and Perkinsus marinus (Dermo or dermocystidium), both fatal to oysters but harmless to people, were documented in Pamlico Sound. Drought conditions during 1987-88 evidently resulted in high salinity levels during the summer, which combined with warm water to provide favorable growing conditions for both disease organisms. Large mortalities of oysters were noted in areas where pathogens were observed, especially Dermo. Landings have continued to decline since 1988, and reached the lowest level on record during the 1989-90 season (52,000 bushels). The declines appear to be due to continued intense harvest pressure, loss of habitat through poor water quality, and mortality through disease. Decreasing salinity and episodes of decreasing oxygen may be the reasons that some oyster rocks in western portion of Pamlico Sound are no longer productive. Hypoxia is widespread in certain areas; in 1985, for example, several hundred square miles of Neuse River, Pamlico Sound and Pamlico River bottoms were virtually devoid of oxygen for three days, resulting in reported oyster mortalities in some areas.

The DMF has conducted spatfall surveys since 1978 to monitor recruitment and has initiated shoal surveys in Pamlico Sound for stock assessments. The DMF's oyster management activities are being adjusted to avoid spreading MSX and Dermo through transplanting. Emphasis is being placed on locating disease-free areas and planting shell in such areas to provide resources for future harvest. The DMF has established a program to monitor MSX and Dermo with the assistance of North Carolina State University School of Veterinary Medicine. Intensive management measures have been undertaken to maintain and enhance stock status.

D. STATUS AND TRENDS OF MAJOR FISHERIES

D. 1. Introduction

D. 1. a. Trends In Fish Stocks. Long-term trends in abundance of stocks of a few species can be discussed but only in very general terms because of limitations in sampling data. As discussed previously, limitations in amount and quality of data greatly restrict the ability to determine actual trends in stock abundance. Commercial landings data, when combined with biological data, can often provide insight regarding general trends in the fisheries, provided that certain assumptions are made and the limits of the data are understood.

One critical factor influencing landings data is consistency of collection methods. Prior to 1950, the federal government collected annual landings data on a sporadic basis in North Carolina. Beginning in 1950, the federal government collected North Carolina landings data every year. Partial data on landings by waterbody are available, starting in 1959. Monthly landings data have been collected since 1956. Prior to 1978, one or two federal employees collected the data through a voluntary program. Coverage of certain species, areas, and seasons was limited. Beginning in 1978, DMF and NMFS established a cooperative program with a total of six (now seven) port agents and support staff. Interviews are conducted by the port agents or by DMF biologists to collect effort data for several fisheries. It is apparent that landings data have not been collected consistently in North Carolina since the 1880s, but data collected since 1978 are consistent for virtually all species and fisheries. For some species (Atlantic menhaden, shrimp, and probably a few others), data collected prior to 1978 may also be used with confidence. For most species, use of data collected prior to 1978 for other than examining gross changes must be done cautiously.

Another factor concerns species identification. For example, historically the statistics category "flounder," as published, included five or six species, some of which never use the estuary. The DMF currently collects the data by species. Prior to 1979, all flounder were listed as "unclassified." Biological information has been utilized to improve precision of data reported for various species of porgies, snappers, groupers, and tunas. Clearly, confidence in species identifications is greater at present than in earlier periods. In order to improve the quality of landings data (commercial and recreational), Street and Phalen (1990) have recommended several changes in fisheries licensing and data collection.

The vast majority of the DMF's biological data for adults comes from sampling commercial and recreational landings. This fishery-dependent sampling provides relatively large samples at much lower unit cost than if DMF personnel conducted their own labor-intensive fishing activities. Fishery-dependent biological sampling assumes the fisheries harvest the stock in relation to its availability by area, season, size, and sex. This assumption may not be met for a variety of reasons, including regulations (size limits, seasons, area closures, gear restrictions), weather, and market conditions.

D. 1. b. Trends in Juvenile Abundance. The best data available are for juveniles. Juvenile fish abundance is monitored within the Albemarle-Pamlico estuarine system by several historical and ongoing fishery-independent surveys. These include the DMF primary and secondary nursery area surveys, red drum nursery area survey, Pamlico/Albemarle Sounds survey, juvenile anadromous fish survey, and the striped bass nursery area survey. Data from these surveys are intended for use in developing long term indices of year class strength for various species. Trend data are available only from the primary, anadromous fish, and striped bass nursery area surveys. The red drum and Pamlico/Albemarle Sounds surveys have only recently been established (<4 yr), and the secondary nursery area survey has had recent gear changes, making long term continuous indices unavailable from these data.

The primary nursery area surveys are conducted in shallow (0.1-1.2 m) upper reaches of creeks or bays where initial post-larval development occurs. These areas have been sampled, using a 3.2 meter two-seam trawl, for several months each year since the survey methods were standardized in 1979 (DeVries 1985). Data used to generate year class strengths were restricted to those collected at stations within the Albemarle-Pamlico Study area. Indices have been developed for Atlantic croaker, spot, southern flounder, weakfish, and brown shrimp.

No significant trends for any of these species are indicated during the past 12 years (1979-1990). Years of relatively high abundance were 1982 and 1986 for southern flounder, 1981 and 1986 for weakfish, 1983 for Atlantic croaker and 1985 for brown shrimp. The spot index showed one relatively poor year, 1980. Other than these few highs and lows, catch-per-unit effort values remained relatively constant with only minor fluctuations. The absence of downward trends indicates that any stress on these species (such as over-fishing) is not great enough to cause a decline in relative juvenile production. Fluctuations are most likely due to yearly variations in environmental parameters, such as temperature, salinity, weather patterns, and/or currents. These factors all affect larval transport and survival. The brown shrimp index has been shown to reflect true annual abundance by exhibiting similar trends to those found in the brown shrimp commercial landings ($r^2 > 0.9$) (DeVries 1985) and commercial catch-per-unit-effort (CPUE) data (DMF unpublished data).

The anadromous fish nursery area survey provides an index of juvenile abundance of blueback herring in Albemarle Sound extending back to 1972. This survey consists of 11 stations sampled monthly (June-October) using an 18.3 meter bag seine. Stations are located in the western Albemarle Sound area which has been identified as an anadromous fish nursery area. Catches among years are highly variable. Trends in juvenile blueback herring abundance are not readily apparent from the index. Even with relatively high and low CPUE values, differences are hard to quantify or verify due to high sampling variance (DMF unpublished data). The data indicate the 1986-1990 seasons showed relatively low juvenile abundance. Further analyses of landings and biological data and additional years of juvenile abundance data are needed to determine if a trend exists. The ASMFC, in cooperation with DMF and other states, conducted a stock assessment of river herring along the Atlantic Coast.

The striped bass nursery area survey is the longest juvenile abundance index available in the Albemarle-Pamlico estuarine system. Dr. Hassler, along with North Carolina State University personnel, conducted the survey from 1955 to 1987. The DMF adopted the same methods in 1984 and conducted a comparative survey through 1987, when the NCSU survey ended. DMF has maintained the survey to continue the historic index of juvenile abundance. Sampling is conducted twice a month, from July through October, at seven fixed stations in western Albemarle Sound using a 5.49 meter balloon trawl.

The index of juvenile striped bass abundance shows fluctuations among relatively high and low years between 1956 and 1977 (Figure IV-4). Starting in 1978 and continuing through 1987 the survey indicates that year class strength was severely depressed. This trend was also reflected in landings (Table IV-5). Some possible reasons for the low juvenile CPUE are that: (1) adult mortality became so high that recruitment was affected, and/or (2) some factor(s) caused failure in reproduction and/or larval survival. The 1988 year class index was the highest of the last 12 years. Preliminary data indicate that the 1989

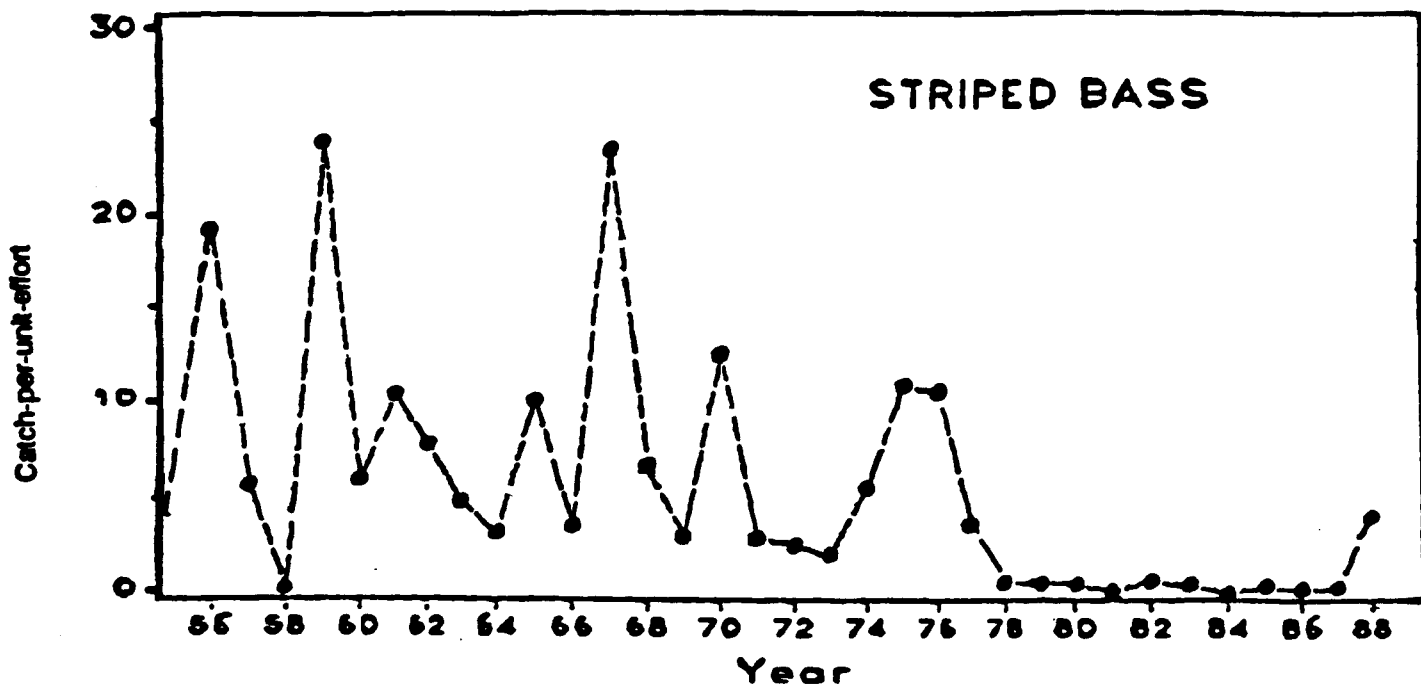


Figure IV-4. Catch-per-unit-effort for Young-of-the-year Striped Bass from Western Albemarle Sound, 1956-1990 (DMF).

index may be similar to the 1988 value. It is unclear whether future recovery is indicated by this two-year trend in juvenile abundance.

D. 1. c. Trends in Adult Abundance. Because no long term fishery-independent sampling is conducted for adult fish in the Albemarle-Pamlico estuarine system, reliable trends in abundance of adult fishes are difficult to determine with any degree of precision. Striped bass and menhaden are two examples of finfish for which data are available to estimate abundance (Data are available for other species, as discussed in the species sections).

Because the database extends back to the 1950s for juvenile abundance, spawning success, spawning stock estimates, catch and effort in Roanoke River, and some other parameters, general stock trends for striped bass in the Albemarle Sound area can be discussed. Current data are available from continuing sampling by personnel from DMF, the North Carolina Wildlife Resources Commission, and East Carolina University. Data are available from Hassler et al. (1981), Hassler and Taylor (1986), Harriss et al. (1985), Winslow and Harriss (1986), Winslow and Henry (1986, 1988, 1989), Mullis (1989), and Rulifson et al. (1986, 1988). Dominant year classes were produced in 1956, 1958, and 1967 (Figure IV-4). Landings generally increased in Albemarle Sound during the two years following production of a dominant year class. Unfortunately, age composition data are not available for the 1950s and 1960s, so year classes produced during that period cannot be followed in the fishery. Age composition data have been collected by DMF since 1971-72. Hassler and Taylor (1986) reported spawning stock estimates from 1956 to 1985. Landings data are not comparable to earlier data because of restrictive seasonal and size regulations. Unfortunately, effort data are not available for the commercial fishery in Albemarle Sound. Based on examination of available data, it is apparent that the Albemarle-Roanoke stock of striped bass is much smaller at present than during the peak period from the 1960s through the mid-1970s.

Menhaden do not support major fisheries in the Albemarle-Pamlico estuarine system; however, the area is a major nursery area for menhaden harvested in the ocean off North Carolina and elsewhere. Several million pounds of menhaden are harvested annually from the Albemarle-Pamlico system for reduction to fish meal and oil and for bait. Since only one company fishes for reduction, data are confidential. Much of the bait landings (menhaden caught as bait) come from by-catch (incidental catch) of the long haul seine and summer pound net fisheries, although some purse seine sets are made for bait, especially in Core Sound. Vaughan and Smith (1988) recently completed a stock assessment for Atlantic menhaden of the entire Atlantic coast. The authors concluded that the stock has recovered from poor reproduction and over-fishing that occurred from the mid-1960s through the mid-1970s. Population sizes at present compare favorably with those estimated for the late 1950s.

D. 2. Commercial Fisheries

The Albemarle-Pamlico estuarine system currently yields about 62 million pounds per year of commercial landings which represent about 54% of the total North Carolina catch of edible seafood. Table IV-6 shows the catch for the three sound areas (Albemarle, Pamlico, and Core) for the 19 year period of 1972-1990. The area probably produces far more seafood, which is harvested all along the Atlantic Coast. Tagging studies on croaker, summer flounder, and Spanish mackerel, among other species (Ross et al. 1986; Monaghan et al. 1989), demonstrate that the Albemarle-Pamlico estuarine system contributes to harvests in a number of other areas. Producing 32% of the state's total landings, the Pamlico Sound area was the most productive, while the Albemarle area accounted for 14%, and Core Sound, almost 9%. The commercial fishing industry in the area is dependent upon a diversity of species and fisheries. Few fishermen depend on only one fishery or a limited geographic area. Most fishermen vary their practices depending on the season, market conditions, and other factors (Maiolo et al. 1980; Street and McClees 1981; Maiolo et al. 1985a). For example, a summertime shrimp trawler may fish for crabs in the spring and fall and for oysters in the winter. This diversity of fisheries accounts for the resiliency and the viability of the industry by allowing for flexibility in fishing practices and target species.

Table IV-6. Total commercial landings for principal fishing gears by sound area for 1974-1990 (in thousands of pounds). (DMF, unpublished data).

| | <u>Long haul seines</u> | | | <u>Pound nets</u> | | | <u>Gill nets</u> | | | <u>Crab pots</u> | | | <u>Shrimp trawl</u> | | |
|-----------------------|-------------------------|--------|-------|-------------------|-------|-------|------------------|-------|-------|------------------|--------|-------|---------------------|-------|-------|
| | Albml | Pmlco | Core | Albml | Pmlco | Core | Albml | Pmlco | Core | Albml | Pmlco | Core | Albml | Pmlco | Core |
| 1974 | 553 | 3,370 | 5,844 | 7,119 | 845 | 696 | 1,388 | 837 | 391 | 1,812 | 6,833 | 2,239 | 44 | 3,871 | 2,949 |
| 1975 | 666 | 8,680 | 6,666 | 6,632 | 1,267 | 424 | 1,467 | 732 | 325 | 1,190 | 4,730 | 1,679 | 0 | 2,245 | 1,316 |
| 1976 | 603 | 6,421 | 2,422 | 7,219 | 3,412 | 419 | 1,697 | 644 | 80 | 813 | 5,036 | 1,854 | 0 | 3,792 | 1,448 |
| 1977 | 234 | 9,925 | 2,994 | 9,253 | 1,519 | 285 | 1,404 | 467 | 263 | 1,046 | 7,059 | 1,181 | 0 | 4,168 | 1,097 |
| 1978 | 175 | 14,159 | 2,204 | 6,493 | 2,463 | 298 | 3,983 | 1,544 | 649 | 2,798 | 11,274 | 2,757 | 4 | 1,954 | 1,315 |
| 1979 | 1,678 | 17,559 | 3,290 | 5,570 | 1,900 | 840 | 2,059 | 1,937 | 764 | 2,683 | 13,886 | 2,580 | 0 | 3,584 | 2,065 |
| 1980 | 1,359 | 16,277 | 4,800 | 7,265 | 6,501 | 586 | 2,188 | 1,525 | 1,349 | 1,888 | 22,730 | 2,629 | 49 | 7,010 | 2,454 |
| 1981 | 388 | 11,887 | 2,345 | 4,902 | 4,418 | 435 | 2,460 | 1,415 | 807 | 3,774 | 23,043 | 2,741 | 5 | 2,340 | 986 |
| 1982 | 1,576 | 11,277 | 2,497 | 9,197 | 4,545 | 353 | 3,047 | 1,134 | 512 | 6,076 | 21,884 | 2,335 | 15 | 4,947 | 1,867 |
| 1983 | 1,108 | 8,737 | 3,291 | 5,505 | 2,486 | 448 | 3,140 | 1,323 | 648 | 6,033 | 20,808 | 1,667 | 62 | 3,582 | 2,388 |
| 1984 | 1,035 | 8,470 | 2,171 | 5,616 | 3,216 | 713 | 3,855 | 1,584 | 935 | 2,620 | 21,760 | 2,098 | 73 | 1,241 | 1,881 |
| 1985 | 318 | 6,337 | 2,187 | 11,925 | 3,999 | 302 | 3,086 | 1,560 | 864 | 5,576 | 18,812 | 2,323 | 101 | 9,666 | 1,593 |
| 1986 | 628 | 6,795 | 2,602 | 7,519 | 2,276 | 500 | 2,517 | 1,927 | 989 | 8,001 | 11,936 | 1,070 | 2 | 4,057 | 1,689 |
| 1987 | 377 | 5,339 | 2,136 | 4,193 | 4,466 | 509 | 2,934 | 1,972 | 760 | 10,501 | 17,896 | 1,439 | 0 | 1,903 | 1,631 |
| 1988 | 440 | 6,273 | 2,405 | 3,825 | 5,276 | 1,217 | 3,513 | 2,245 | 1,043 | 6,118 | 24,131 | 1,764 | 0 | 3,901 | 2,155 |
| 1989 | 318 | 6,664 | 1,660 | 1,751 | 3,959 | 963 | 2,635 | 1,457 | 702 | 10,307 | 19,752 | 1,687 | 14 | 5,180 | 1,912 |
| 1990 | 172 | 8,378 | 2,583 | 1,720 | 3,449 | 841 | 4,053 | 1,299 | 942 | 7,702 | 24,924 | 1,183 | 6 | 5,137 | 903 |
| Mean | 684 | 9,205 | 3,064 | 6,217 | 3,293 | 578 | 2,673 | 1,383 | 707 | 4,643 | 16,265 | 1,955 | 22 | 4,034 | 1,744 |
| Percent of Area Total | 4.9 | 25.2 | 33.6 | 45.3 | 8.6 | 5.6 | 17.2 | 3.7 | 7.3 | 27.0 | 41.2 | 21.3 | 0.2 | 10.4 | 18.8 |

The diversity of fishing gears also greatly complicates the task of relating harvest data to actual stock abundance.

Commercial fishermen of the Albemarle-Pamlico estuarine system rely predominantly on five types of gear: long haul seine, pound net, gill net, crab pot, and shrimp trawl. These gears produce, on average, about 95% of the catches in the Albemarle Sound area, 89% of the Pamlico Sound area catches, and 87% of the Core Sound area catches. Table IV-6 gives the landings by these gears from each area from 1974 to 1990. While certain species, such as blue crabs, are important throughout the region, each area contains characteristic fisheries. Albemarle Sound, for example, produces about 99% of the river herring, 93% of the catfish, 68% of the striped bass, and 95% of the white perch caught statewide. Pamlico Sound produces 45% of the croaker, 42% of the shrimp, 78% of the blue crabs and 59% of the oysters commercially landed in North Carolina. Fifty percent of the hard clams in the state are harvested from Core Sound. This difference in fisheries is due to the difference in habitat types. Generally, Albemarle Sound has low salinities; Core Sound is a shallow, high salinity area; and Pamlico Sound contains broad expanses of moderate salinity.

Almost all of the commercial landings from the Albemarle Sound area come from fixed gear: pound nets and gill nets for finfish, and pots for crabs. Pound nets and gill nets have become increasingly important in taking finfish in the Pamlico and Core Sounds area, while long haul seines, a moveable gear, have become relatively less important. Long haul seines now harvest only limited amounts of finfish in the eastern portion of the area, however, while declining, long hauls are still the single most important finfish gear in the Pamlico-Core area. Crab pots account for the highest landings of any gear in the Albemarle-Pamlico estuarine system, especially in the Pamlico Sound area, the center of the blue crab fishery. The shrimp trawl, a moveable gear, accounts for about 95% of the shrimp harvest in the Albemarle-Pamlico area, as well as a substantial finfish by-catch, which is usually discarded at sea.

The use of various fishing methods is controlled by a variety of factors, principally natural conditions. Moveable gears require large, unobstructed areas. Areas containing fixed gear generally preclude the use of moveable gear. In order to maintain use of trawls and long haul seines and availability to the public (of their products), state regulations restrict crab pots to specified areas during much of the year. On a local basis, fishermen usually determine use of areas among themselves, although conflicts do occur.

The following is a brief description of the five major fisheries (Copeland et al. 1983; Copeland et al. 1984).

D. 2. a. Shrimp Trawl Fishery. The trawl fishery for shrimp began shortly after the turn of the century in the southern part of North Carolina. Although some trawling occurred in Pamlico Sound during the 1930s, it did not become significant until the late 1940s or early 1950s (Maiolo et al. 1980). The North Carolina shrimp fishery, unlike that of other states, is dependent on estuarine trawling (Street 1987). The Pamlico Sound area is the northernmost area with commercial quantities of penaeid shrimp and is the major shrimping area in the state (Calder et al. 1974) (Figure IV-5). Harvest occurs from May through September or October and depends primarily on brown shrimp, although pink shrimp and white shrimp are also caught. Pamlico Sound is unique among southeastern estuaries in that it consistently produces large shrimp (16-20 tails per pound or larger). Maiolo et al. (1980) described the socio-cultural aspects of the North Carolina shrimp fishery. Other shrimp studies in the estuary have centered around biological and fishery management investigations (Broad 1950; Williams 1964; McCoy 1968; Purvis and McCoy 1972; Purvis and McCoy 1974a,b; Purvis et al. 1977; Hunt et al. 1980; Wicker et al. 1988). The resident shrimp trawl fleet often trawls for crabs and flounder in the estuary during the fall, winter, and spring.

Three general types of vessels normally fish in the Pamlico Sound shrimp fishery: (1) large vessels (50-90 ft) which fish part of the year in Pamlico Sound and the rest of the year in other southern areas (North Carolina and other states), mostly for shrimp; (2) large vessels, usually constructed of steel, which

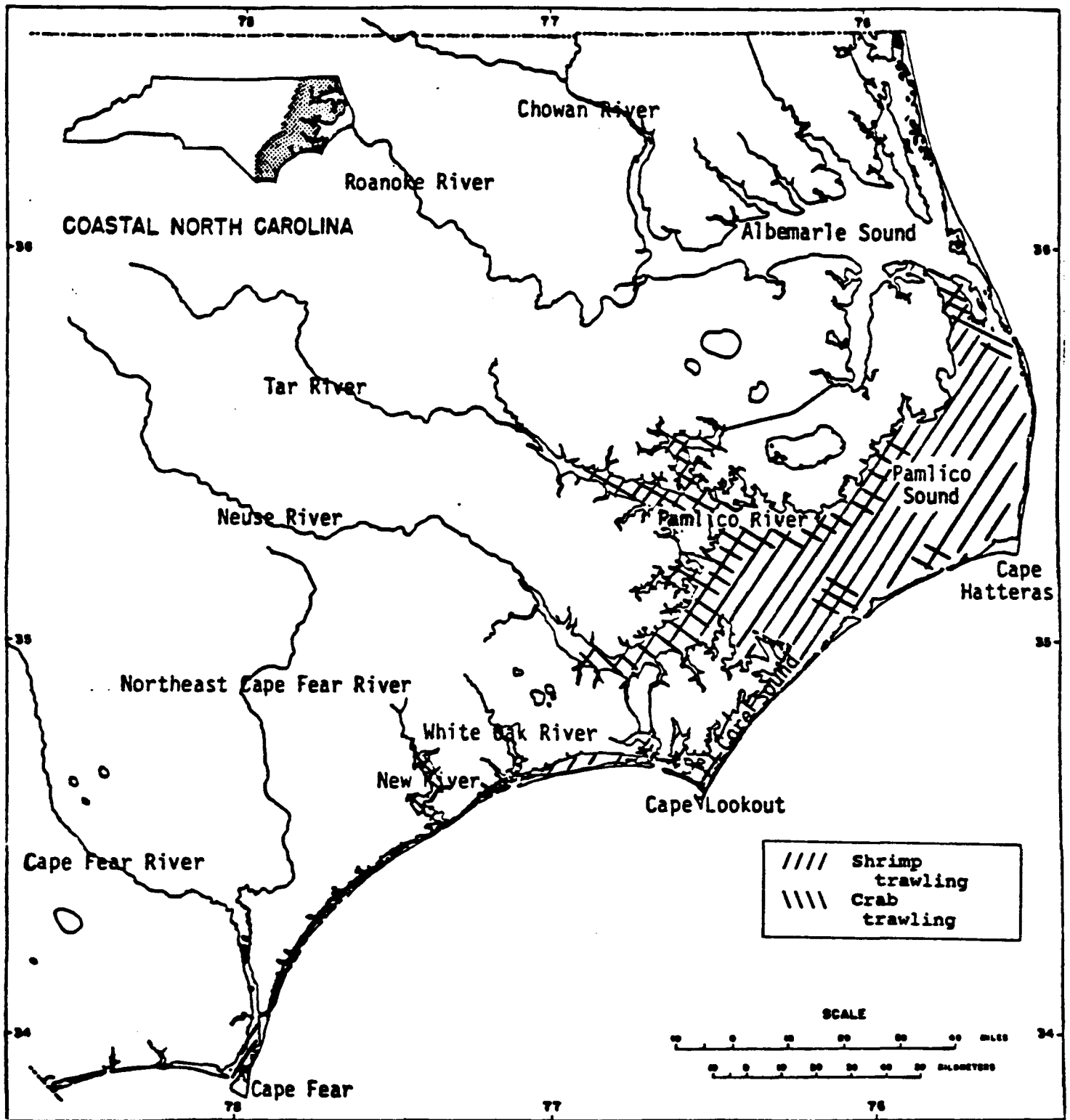


Figure IV-5. Shrimp and blue crab trawling areas in North Carolina's estuarine waters.

work most of the year in the mid-Atlantic and New England areas for finfish and/or sea scallops, shrimping in Pamlico Sound only at the peak of the season; and (3) small vessels (40 ft or less) which fish the entire year in Pamlico Sound, primarily trawling for shrimp, but often converting to oyster dredging, crab trawling, or other fisheries. The large vessels generally remain on the fishing grounds several days at a time, while the small vessels usually make one-day trips.

Shrimp trawling is also of major importance to the Core Sound area but is of little importance to the low salinity Albemarle Sound area. Most Core Sound vessels are small and work only at night. In Pamlico Sound, shrimping is usually conducted around the clock.

Because of the high use of fixed gear, all trawling is illegal in Albemarle Sound to minimize user and fishing gear conflicts; directed trawling in the Pamlico and Core Sound areas is restricted to shrimp, blue crabs, and flounder (while crab trawling). Shrimp provide the vast majority of the landings in this fishery. Catches vary widely from year to year since they depend on three annual species whose abundance is controlled by environmental factors. Technological advances in the shrimping industry have significantly increased the catching effort of larger boats, particularly in Pamlico Sound. Most boats in the 1940s and 1950s pulled a single trawl; presently, the majority of boats in Pamlico Sound are "four-barrelled" (they utilize four nets).

D. 2. b. Long Haul Seine Fishery. The long haul fishery is unique to the Albemarle-Pamlico estuarine area. It began in the Neuse River and Albemarle Sound area in the early to mid 1800s (Goode 1887). At that time the nets were limited in size to about 80-100 yards because they were hauled by sail skiffs. By 1925, the methods of long hauling from engine-powered boats had become almost identical to today's practices (Higgins and Pearson 1928). The modern-day seine, approximately 1,500 yards long, is pulled between two boats (long hauling) or from one boat (swipe netting) to a shoal area where the net is brought together around a stake. The fishermen "foot" the net while they are overboard. Methods of footing the net in deep water (up to 18 feet) have been developed and are now used by some fishing crews in northern Pamlico Sound and Croatan Sound. Guthrie et al. (1973) described in detail the methods used. In addition to an early study by Higgins and Pearson (1928), the DMF has been conducting studies since the 1970s to characterize the long haul fishery and to monitor the catch composition of the long haul fishery (Sholar 1979; DeVries 1980; DeVries 1981; DeVries and Ross 1983; Ross and Moye 1989; Ross et al. 1986). Harvest generally occurs from April through October and catches primarily Atlantic croaker, spot, weakfish and Atlantic menhaden. As shown in Table IV-7, these four species comprised over 87% of the long haul catch sampled by DMF in 1987. Table IV-6 indicates an average catch exceeding 9 million pounds for long hauls in the Pamlico Sound area, while they account for about one-third of Core Sound's total landings. The fishery generally occurs throughout the estuarine system (Ross et al. 1986).

The long haul seine fishery operates from Bogue Sound to Croatan Sound (Figure IV-6) and has been present in North Carolina since the early 1900s. This fishery peaked during between 1977 and 1983 when roughly 50-60 different crews made landings (Ross et al. 1986). The harvest has declined from an average of 17 million pounds annually during that period, to about 9.5 million pounds annually between 1984 and 1988. By 1987-88, the number of fishing crews was down to fewer than 30 (West 1989). Probable reasons for the decline are complex but include competition for space with fixed gear (crab pots and pound nets) and an apparent reduction of availability of target species. As noted earlier, stocks of several important species probably peaked during the late 1970s and early 1980s; several of these species (croaker, weakfish, spot) are important to the long haul fishery.

The centers of activity for the fishery are in northern Pamlico Sound/Croatan Sound and southern Pamlico Sound/Core Sound. The southern fishery utilizes the traditional method of fishing in relatively shallow waters near shoals (4-9 feet) and harvests primarily spot. The northern fishery has developed

Table IV-7. Species composition and abundance for the long haul seine fishery, Albemarle-Pamlico Estuaries, North Carolina, 1987 (adapted from Ross and Moye 1989). (% Freq. of occur. is the percentage of long hauls containing this species).

| Common name | Species | Total number | % of total | % Freq. of occur. |
|--------------------|---------------------------------|--------------|------------|-------------------|
| Atlantic croaker | <i>Micropogonias undulatus</i> | 962,604 | 36.1 | 94.5 |
| Spot | <i>Leiostomus xanthurus</i> | 752,636 | 28.2 | 100.0 |
| Weakfish | <i>Cynoscion regalis</i> | 308,851 | 11.6 | 92.7 |
| Atlantic menhaden | <i>Brevoortia tyrannus</i> | 305,175 | 11.5 | 61.8 |
| Pinfish | <i>Lagodon rhomboides</i> | 168,401 | 6.3 | 72.7 |
| Silver perch | <i>Bairdiella chrysouara</i> | 44,872 | 1.7 | 57.3 |
| Pigfish | <i>Orthopristis chrysoptera</i> | 38,373 | 1.4 | 63.6 |
| Bluefish | <i>Pomatomus saltatrix</i> | 24,915 | 0.9 | 78.2 |
| Southern kingfish | <i>Menticirrhus americanus</i> | 12,084 | 0.5 | 50.9 |
| Spotted seatrout | <i>Cynoscion nebulosus</i> | 7,997 | 0.3 | 56.4 |
| Lookdown | <i>Selene vomer</i> | 4,791 | 0.2 | 17.3 |
| At. thread herring | <i>Opisthonema oglinum</i> | 3,211 | 0.1 | 10.0 |
| Blue crab | <i>Callinectes sapidus</i> | 3,674 | 0.1 | 63.6 |
| Crevalla jack | <i>Caranx hippos</i> | 2,665 | 0.1 | 10.9 |
| Flounder | <i>Citharichthys</i> spp. | 2,363 | 0.1 | 1.8 |
| Harvestfish | <i>Peprilus alepidotus</i> | 2,302 | 0.1 | 24.5 |
| Southern flounder | <i>Paralichthys lethostigma</i> | 2,241 | 0.1 | 35.5 |
| Summer flounder | <i>Paralichthys dentatus</i> | 2,018 | 0.1 | 28.2 |
| Atlantic spadefish | <i>Chaetodipterus faber</i> | 1,806 | 0.1 | 7.3 |
| Butterfish | <i>Peprilus triacanthus</i> | 1,574 | 0.1 | 10.9 |
| Others | | 12,338 | 0.5 | |

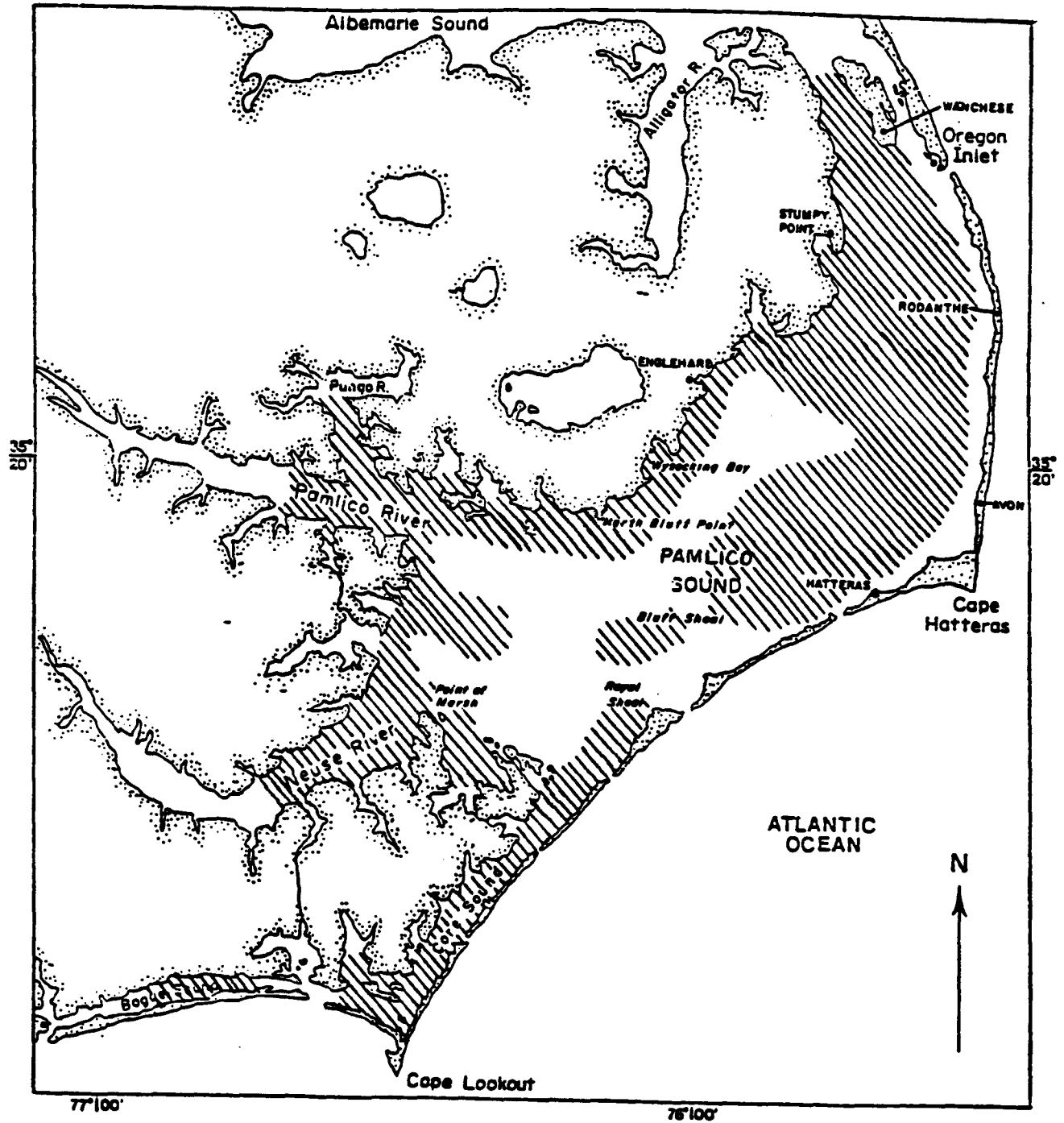


Figure IV-6. Fishing grounds (hatched areas) of North Carolina's long haul fishery.

the capability to fish the nets in relatively deep waters (12-18 feet) and harvests primarily Atlantic croaker.

The DMF has had an ongoing stock assessment program for the long haul seine fishery since 1981 (Ross et al. 1986; Ross and Mayo 1989). Examination of catch-per-unit-effort (CPUE) data for the period from 1981 to 1988 reveals no statistically significant trend for the fishery as a whole or specifically for spot, Atlantic croaker, or weakfish (Figure IV-7).

D. 2. c. Pound Net Fisheries. Pound nets are large stationary devices which lead and trap fish. Forms of pound nets made of hedging were used by coastal Indians and early settlers. In the Albemarle-Pamlico estuarine system there are three major pound net fisheries conducted in different areas, during different seasons, to catch different species of fish (Figure IV-8).

During the spring, a major fishery using pound nets occurs in the Albemarle Sound area, especially the Chowan River (Cobb 1906; Street and Pate 1975; Johnson et al. 1977; Winslow 1989; Winslow et al. 1983, 1985). This fishery is directed toward adult river herring migrating to spawning areas. Historically, the fishery was the largest fishery in the area with a large processing segment (Wynns 1967). Landings have become variable in recent years; roughly 11 million pounds were landed in 1985 compared to less than 1.2 million pounds landed in 1990 (Table IV-6). In addition to herring, pound nets catch catfish and white perch (Keefe and Harris 1981). On the average, pound nets account for about 45% of Albemarle Sound's total landings (Table IV-6).

Another major pound net fishery harvests migrating flounder in the fall. This fishery occurs in eastern Albemarle Sound, in eastern Pamlico Sound behind the Outer Banks, and throughout Core Sound (Wolff 1977; Epperly 1984). The fishery is directed at southern flounder migrating from the estuary to the ocean. Although they are the major species landed in North Carolina, relatively few summer flounder are caught in the estuarine pound net fishery.

The third major pound net fishery occurs in the deeper waters of Pamlico Sound during the warmer months. This fishery primarily targets estuarine migratory species, including Atlantic croaker, spot, and weakfish. Numerous other species are also taken, including Atlantic menhaden, bluefish, harvestfish (*Peprilus alepidotus*), Spanish mackerel, and butterfish (*Peprilus triacanthus*) (Higgins and Pearson 1928; Ross and Moye 1989; Ross et al. 1986; Sholar 1979).

The pound net fishery for river herring in the Chowan River has experienced greatly reduced catches since its peak in the late 1960s and early 1970s (Street 1988). Area fishermen maintained that fish were available between 1986 and 1988 but that weather and conditions hurt the fishery (Winslow 1989). Juvenile abundance data indicate considerable variability from 1972 to 1988, with poor year classes from 1986 to 1988. However, landings are comprised mostly of fish four to six years of age (Winslow 1989), so a paucity of juveniles during 1986-88 would not affect the landings for several years. DMF data (unpublished) indicate that landings in 1989 were the lowest on record.

The flounder pound net fishery in the fall has experienced fairly stable or somewhat increased landings in recent years (DMF unpublished data). This fishery depends on southern flounder, a different species from that comprising the bulk of winter landings from the ocean. An assessment program for this fishery began in 1989 to provide data to guide its management. An increase in the minimum size limit for flounder in North Carolina (from 11 to 13 inches) effective in late 1988, should improve the yield in this fishery, as well as in the ocean fishery for summer flounder. Working with fishermen, DMF developed a modification to the pound net gear with a larger mesh size which can release undersize flounder, thereby reducing waste.

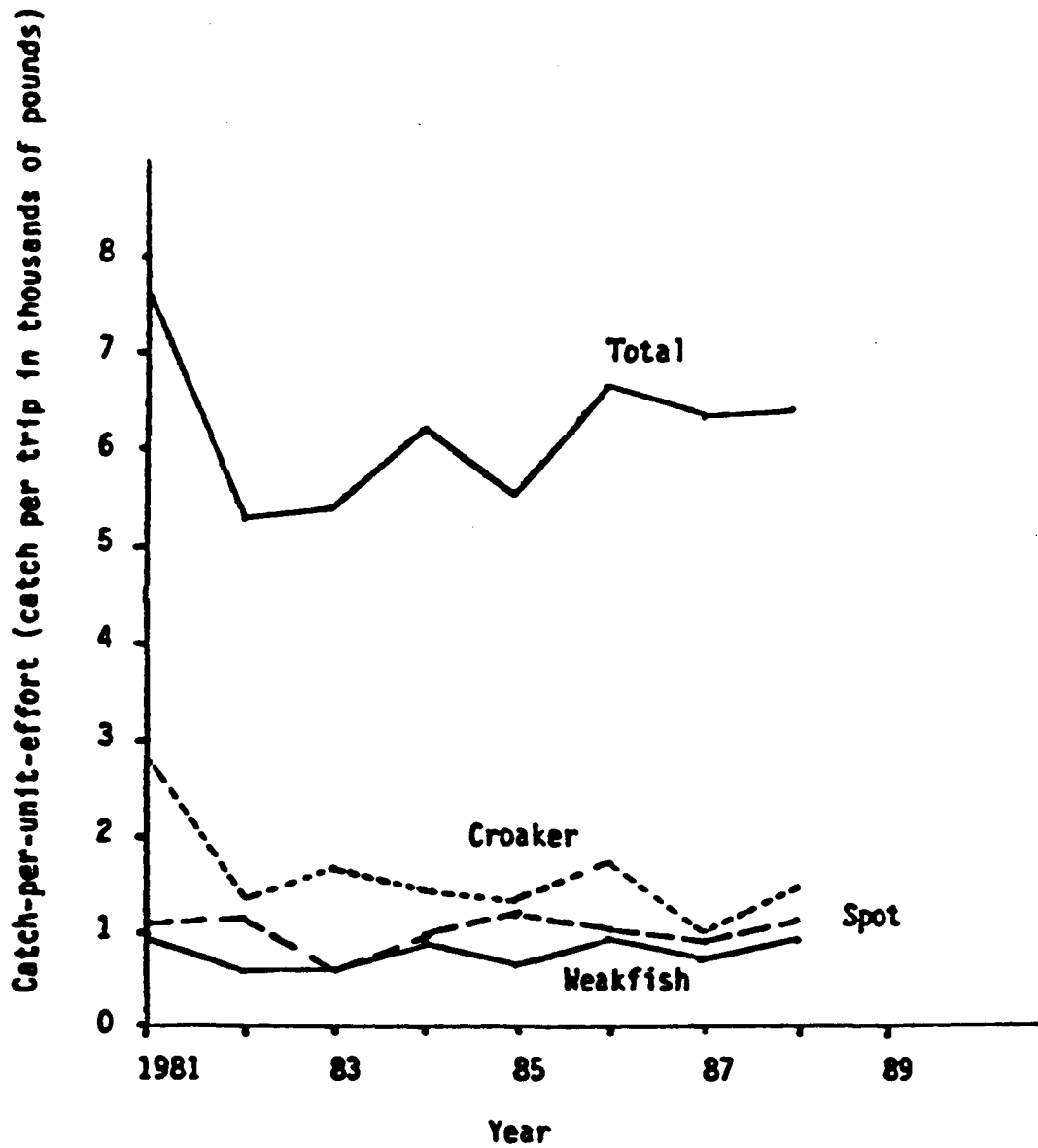


Figure IV-7. Catch-per-unit-effort (CPUE) for North Carolina's Long Haul Seine Fishery, 1981-1990 (DMF).

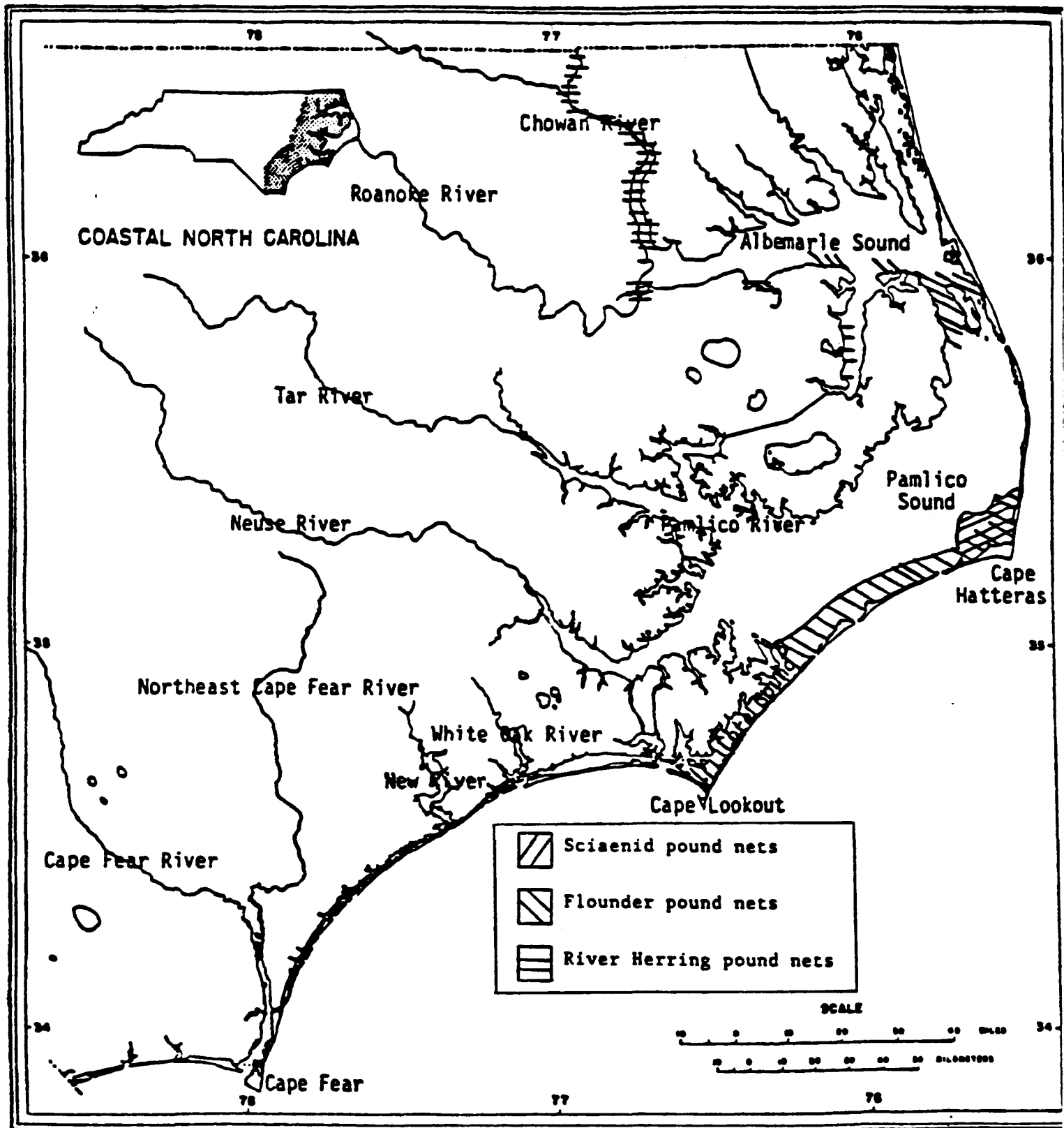


Figure IV-8. Fishing areas for North Carolina's three pound net fisheries: sciaenid, flounder, and river herring.

The summer pound net fishery, which targets spot, Atlantic croaker, weakfish (sciaenids), and harvestfish, has been a major commercial fishery in Pamlico Sound since the 1920s. The number of summer pound nets has fluctuated widely since the 1920s (Higgins and Pearson 1928). Sciaenid pound nets are no longer used in the Pamlico and Neuse River. The numbers in Pamlico Sound have decreased from a high of 30 stands in 1928 to 12-14 stands in 1987 (Ross et al. 1986; Ross and Moye 1989).

The DMF has had an ongoing stock assessment program for the sciaenid pound net fishery since 1982. Catch-per-unit effort data indicate that Atlantic croaker catches have not decreased, spot catches decreased but have become stable, and weakfish catches have decreased since 1982 (Table IV-6).

D. 2. d. Gill Net Fisheries. The estuarine gill net fisheries employ stationary nets of various mesh sizes, depending on target species. Estuarine gill nets produce about 17% of the annual Albemarle Sound landings (Table IV-6). Gill nets are the most widely used gear in the Albemarle Sound area and are the principal gear used for striped bass. Gill nets are used to catch anadromous species during their spring spawning runs, as well as mullet (*Mugil cephalus*), white perch, and southern flounder (Keefe and Harris 1981; Epperly 1984). Gill nets are used in other areas of the estuarine system to catch most other estuarine species, especially southern flounder. Large numbers of gill nets are also used by recreational fishermen to catch fish for home consumption.

Gill nets are set in much of the Albemarle-Pamlico estuarine system without being targeted at a specific species, especially during the summer when much of the gillnet effort is by recreational fishermen. The fishery is most directed in Albemarle Sound during the fall for white perch, during the winter for striped bass, and during the spring for American shad. Directed shad and southern flounder fisheries also occur in the Neuse and Pamlico Rivers and Pamlico Sound each spring. As noted earlier, the Albemarle-Roanoke stock of striped bass is depressed and landings have declined greatly, due both to reduced abundance and restrictive regulations designed to promote stock recovery. The Albemarle Sound gill net fishery has shifted to other species, especially in the fall. In recent years near-drought conditions have increased the salinity level in much of Albemarle Sound, bringing in species such as croaker, weakfish, and bluefish. As a result, total gill net landings have been relatively stable in Albemarle Sound (Table IV-6).

D. 2. e. Crab Pot Fishery. Blue crabs are the single most important commercial species in the estuary in terms of pounds landed, number of people involved in the fishery, processing volume, and total value. The Albemarle-Pamlico estuarine system produces about 95% of the blue crabs caught in the state, averaging over 25 million pounds per year. Pots catch around 95% of the crabs landed. Current estimates indicate that about 535,000 pots are in use (DMF unpublished data).

Limited studies have been conducted on the biology of, fishery for, and management of the blue crabs in the Albemarle-Pamlico estuarine system. Larval and juvenile abundance was investigated by Dudley and Judy (1971, 1973), and Wolff (1978). Fischler (1965) estimated the abundance of blue crabs in the Neuse River using catch-effort, catch data, and tagging. Tagging studies were also reported by Judy and Dudley (1970) and Sholar (1983). The blue crab fisheries were described by Pearson (1951), Wolff (1978), and DeVries (1981). In addition, Sholar (1982) described the Pamlico Sound area as "the major production area for the South Atlantic." Maiolo et al. (1985b) described the socio-economic aspects of the blue crab fishery in the estuary. Little stock assessment data exists for the crab pot or trawl fisheries.

The blue crab is North Carolina's most important species in terms of processed products. Table IV-8 indicates the number of processing plants and the processed products value by year for the Albemarle-Pamlico area. The decline from 1987 to 1988 was probably related to reduced catches and markets associated with the red tide episode of 1987-88. Although some other species and processes (river herring salting and canning, flounder filleting, and oyster shucking) are included in these figures, the majority of the value is attributable to blue crab processing.

Table IV-8. Seafood processing plants and processed product value for the Albemarle-Pamlico area, North Carolina, 1975-1988.

| Year | No. plants | Processed products value |
|------|------------|--------------------------|
| 1975 | 75 | \$21,351,000 |
| 1976 | 69 | 21,558,000 |
| 1977 | 67 | 22,835,000 |
| 1978 | 68 | 21,065,000 |
| 1979 | 80 | 35,115,000 |
| 1980 | 83 | 32,481,000 |
| 1981 | 86 | 43,756,000 |
| 1982 | 90 | 41,360,000 |
| 1983 | 93 | 50,107,000 |
| 1984 | 98 | 54,663,000 |
| 1985 | 97 | 59,197,000 |
| 1986 | 103 | 65,894,000 |
| 1987 | 103 | 76,955,000 |
| 1988 | 98 | 64,760,000 |

For management purposes, blue crabs, like shrimp, can be considered as an annual crop of which a high proportion of the available stock may be harvested without affecting future production. Historic landings data (Street 1988; Chestnut and Davis 1975) show high production during the 1960s, reduced landings from 1971 to 1977, record landings each year from 1978 to 1982, decline through 1986, and return from 1987 to 1990 to levels of the record period. Effort data are poor, both for actual numbers of pots and the effectiveness of individual pots. Estimates of the number of pots provided voluntarily by fishermen on their vessel license applications and through DMF's statistics program's annual operating units survey vary widely. Many crabbers work on a part-time or seasonal basis. In specific geographic areas exploitation of blue crabs is high. Between 1980 and 1982, DMF personnel tagged several thousand blue crabs in various tributaries of western Pamlico Sound. Return rates for some groups of tagged crabs greatly exceeded 50% (DMF unpublished data), indicating the intensity of the existing fishery. Fishing effort is probably even greater at the present time.

The fishery along the Outer Banks and in Core Sound harvests large numbers of females, including egg-bearing ("sponge") females, while the catch in the western Pamlico Sound area and Albemarle Sound takes males and females, but relatively few egg-bearing females. This situation is due to the biology of the species; males stay in low salinity areas, while females migrate after mating to the inlets, extruding egg mass en route. There is no biological evidence that harvest of females at any stage of maturity has any effect on future stock size. Sponge crabs are, however, considered undesirable by crab processors since crabs are purchased by weight and the dealers get no return for the weight of the egg masses they purchase, and since the meat of egg-bearing females is of poor quality relative to non-sponge crabs. Consequently, there are periodic efforts to regulate the harvest of sponge crabs.

Of particular importance is the growth of the crab pot fishery in the Albemarle Sound area (Table IV-6), from a minor fishery during the 1970s, to the highest landings of any given year since 1986. This increase is probably attributable to two factors characterizing the Albemarle area: increased exploitation of previously under-utilized blue crab stocks in much of the Albemarle Sound area, and probable increased abundance of blue crabs in the Albemarle area due to increased general salinity in the area, as

noted above in the "Gill Net Fisheries" discussion. Changes in the regulatory regime for finfish in the Albemarle Sound area have also encouraged some fishermen to change from finfish gill netting to crab potting.

As long as environmental conditions remain favorable for blue crabs (the controlling environmental factors are not known, specifically), the fishery will probably continue to be the most important in the coastal area. Conflicts will likely increase, however, as the presence of crab pots interferes with moveable gears (long haul seines and trawls) and as recreational boating continues to increase, and as the number of pots continues to increase. The DMF has recently initiated a blue crab stock assessment program to help determine harvest effects.

D. 2. f. Anadromous Fisheries. In general, populations of all anadromous species continue to decline in numbers throughout the A/P Study area (Table II-3). Over-harvest is one cause for decline of these populations, but degradation of available spawning habitat has contributed as well (Manooch and Rulifson 1989, Rulifson and Manooch 1990b). Only two species in North Carolina have undergone extensive stock restoration efforts through culturing. Striped bass and American shad, have been the focus of efforts by the US Fish and Wildlife Service and NC Wildlife Resources Commission, yet populations continue to decline.

During the late 1800s the North Carolina shad fishery reached its peak, at one time exceeding production in all other states (Smith 1907). In 1896 the Neuse River was regarded as the most important shad-producing stream between the James River, Virginia and the St. Johns River, Florida. After 1900, decline in numbers was attributed to over-harvest, so the NC Legislature enacted a law to protect shad from over-harvest.

Currently, commercial harvest of anadromous species is regulated by the State of North Carolina and the federal government. Regional fisheries councils have enacted management plans for the ocean harvest of anadromous alosids (shad and river herring) and striped bass. The shortnose sturgeon is protected as an endangered species; the Atlantic sturgeon management plan is currently underway. The NC Division of Marine Fisheries regulates commercial and recreational harvest of the estuaries, sounds, and 3 miles of coastal ocean. The NC Wildlife Resources Commission regulates recreational harvest in inland waters -- no commercial harvest is allowed in inland waters. North Carolina is the only Atlantic coast state that allows recreational harvest of striped bass in the spawning grounds. No comprehensive anadromous fish management plan exists at this time, but a cooperative agreement was reached in 1990 by the US Fish and Wildlife Service and two state agencies to manage striped bass in North Carolina.

D. 2. g. Other Commercial Fisheries. Many other commercial fisheries are also conducted in the area, including the oyster dredge fishery, the bay scallop dredge fishery, and the soft-shelled crab fishery. The economically productive bay scallop fishery was investigated by Spitsbergen (1979) and Kellogg et al. (1985). Another fishery, found principally in Core Sound, is mechanical clamming (Taylor et al. 1985). This fishery includes clam "kicking", which utilizes the wash from propellers and heavy trawls to catch buried hard clams, as described by Guthrie and Lewis (1982). Clams are also harvested with a variety of other gears in the Core Sound area including rakes, tongs, bull rakes, and hydraulic dredges.

D. 3. Recreational Fisheries

The recreational fisheries contribute substantially to the local economy in the form of pier use fees; charter fees; boat, bait, and tackle sales; marina use; and hotel and restaurant trade (Street and McClees 1981). In addition, the recreational fisheries are an important component of the overall fishery harvest. For a number of important species including bluefish, spotted seatrout, red drum, and Spanish mackerel, the recreational fishery harvest usually exceeds the commercial harvest. Recreational fishermen in the Albemarle-Pamlico estuarine system catch a wide variety of species (Table IV-9). The average number of

fish per angler trip for the Albemarle-Pamlico estuarine system was higher than the statewide catch per trip during 1988 (Table IV-10). Atlantic croaker was the fish caught most frequently by recreational anglers. Eight species (Atlantic croaker, pigfish (*Orthopristis chrysoptera*), summer flounder, pinfish, weakfish, spot, spotted seatrout and bluefish) comprised 81% of the total catch (Table IV-10). In addition to recreational hook-and-line fishing, pleasure fishermen also utilize commercial techniques and equipment to catch a variety of finfish and shellfish for personal consumption. These gears include gill nets, pots, and shrimp trawls and hand gears such as rakes, dip nets, gigs and tongs. Pate (1977) attempted to quantify the recreational catch of shrimp with trawls. Although statistical data on the harvest of the fishery resources by recreational fishermen are limited, they are thought to take substantial numbers of finfish, as well as blue crabs, oysters, clams, shrimp, and scallops with commercial equipment. "Pleasure" vessels, those which use commercial gear for personal consumption, form the largest category of commercially licensed fishing vessels in North Carolina. Since 1980, such vessels have comprised 53% of the total licensed commercial fishing vessels in North Carolina (Table IV-11). Recreational fishermen utilize the Albemarle-Pamlico estuarine system to harvest the same resources as commercial fishermen. As a result, occasional competition and conflict exist between commercial fishing and recreational fishing interests seeking similar harvest opportunities.

D. 4. Summary of Trends

Following are a number of trends in the commercial fisheries which are apparent from the preceding discussions. Recreational data are insufficient to indicate any long-term trends (1987-present).

1. Landings of the major finfishes, most of which have fairly similar life histories and are taken by the same fishing gears, reached historic peaks in the late 1970s and early 1980s and have since declined. Reasons for the peak are unknown. Weakfish, Atlantic croaker, and summer flounder landings have declined significantly. The landings of these species have also declined throughout the Atlantic coast. Weakfish and summer flounder have been determined to be in an over-fished status. Atlantic croaker are being growth over-fished (not maximizing yield).
2. Landings of anadromous fishes (fish which spawn in freshwater but spend most of their life in salt water -- striped bass, American shad, and river herring) have declined since the early 1970s, or before. The American shad fisheries in particular have declined in Pamlico Sound and the Neuse and Pamlico Rivers. The reasons for the decline of American shad in North Carolina are specifically unknown, however, Atlantic coast stocks have been affected by habitat degradation, loss of spawning areas, and over-fishing. River herring initially declined because of excessive catches by foreign vessels in the ocean, but recovery has probably been impeded by poor water quality in the Albemarle Sound spawning and nursery areas. Reproduction of striped bass in the Roanoke River has been unsuccessful since 1977, probably due principally to water quality and water flow problems. Reproductive success improved somewhat in 1988 and 1989, but fell in 1990 (DMF JAI data). Striped bass have continued to decline in the Pamlico River.
3. Shrimp landings fluctuate widely, depending on environmental conditions. The shrimp trawl fishery has developed more effective methods to harvest shrimp, such as the ability to use four nets per boat.
4. Landings of blue crabs, North Carolina's most important commercial species, reached peak levels in the early 1980s, declined, and have again increased. Factors controlling abundance are unknown. Blue crabs were harvested by trawls, but are presently harvested by pots. Effort, in terms of numbers of pots, has increased dramatically.

Table IV-9. Species Composition, Reported and Observed Catches by Area from the North Carolina Marine Recreational Fishery Statistical Survey, 1988. (Numbers indicate relative abundance of fish, but not the total catch for the area). (DMF)

| Common name | Scientific name | Total | Albemarle Sound area | | Pamlico Sound area | | Core Sound area | |
|---------------------|------------------------------------|-------|----------------------|----------|--------------------|----------|-----------------|----------|
| | | | Reported* | Observed | Reported* | Observed | Reported* | Observed |
| Croaker, Atlantic | <i>Micropogonias undulatus</i> | 3578 | 814 | 1124 | 428 | 964 | 94 | 154 |
| Pigfish | <i>Orthopristis chrysoptera</i> | 1345 | 20 | 29 | 152 | 47 | 245 | 852 |
| Flounder, summer | <i>Paralichthys dentatus</i> | 925 | 119 | 44 | 312 | 423 | 1 | 26 |
| Pinfish | <i>Lagodon rhomboides</i> | 552 | | | 40 | 5 | 435 | 72 |
| Weakfish | <i>Cynoscion regalis</i> | 529 | 64 | 85 | 17 | 234 | 8 | 121 |
| Spot | <i>Leiostomus xanthurus</i> | 468 | 1 | 10 | 140 | 200 | 20 | 97 |
| Seatrout, spotted | <i>Cynoscion nebulosus</i> | 408 | 2 | 40 | 20 | 142 | 42 | 162 |
| Bluefish | <i>Pomatomus saltatrix</i> | 326 | | 24 | 93 | 142 | 26 | 41 |
| Lizardfish, inshore | <i>Synodus foetens</i> | 273 | | | 211 | 4 | 57 | 1 |
| Mullet, striped | <i>Mugil cephalus</i> | 268 | | | 9 | 247 | 7 | 5 |
| Sea Bass, black | <i>Centropristis striata</i> | 190 | 5 | | 80 | 25 | 68 | 12 |
| Toadfish, oyster | <i>Opsanus tau</i> | 133 | 20 | | 67 | | 42 | 4 |
| Sheepshead | <i>Archosargus probatocephalus</i> | 105 | | 3 | | | 15 | 87 |
| Drum, red | <i>Sciaenops ocellatus</i> | 105 | | | 14 | 28 | 31 | 32 |
| Killifish, striped | <i>Fundulus majalis</i> | 98 | | | 30 | 68 | | |
| Puffer, northern | <i>Sphoeroides maculatus</i> | 89 | | | 33 | 10 | 21 | 25 |
| Kingfish, southern | <i>Menticirrhus americanus</i> | 71 | 7 | 6 | 1 | 36 | | 21 |
| Kingfish, northern | <i>Menticirrhus saxatilis</i> | 69 | | | | 2 | | 67 |
| Skates | Rajidae | 64 | 47 | | 15 | | 2 | |
| Mackerel, Spanish | <i>Scomberomorus maculatus</i> | 54 | | | 2 | 8 | 1 | 43 |
| Flounder, southern | <i>Paralichthys lethostigma</i> | 52 | | 3 | 5 | 44 | | |
| Bass, striped | <i>Morone saxatilis</i> | 43 | 32 | 11 | | | | |
| Searobins | Triglidae | 43 | | | 8 | | 32 | 3 |
| Perch, silver | <i>Bairdiella chrysoura</i> | 38 | | 7 | 6 | 4 | 3 | 18 |
| Flounder, lefteyed | Bothidae | 38 | | | 5 | | 21 | 12 |
| Searobin, northern | <i>Prionotus carolinus</i> | 25 | | | 22 | 1 | 2 | |
| Sharks | Squaliformes | 20 | 3 | | 5 | | 12 | |
| Stargazer, southern | <i>Astroscopus y-graecum</i> | 14 | 2 | | 12 | | | |
| Toadfishes | Batrachoididae | 12 | | | | | 12 | |
| Sunfishes | Centrarchidae | 12 | 12 | | | | | |
| Skate, clearnose | <i>Raja eglanteria</i> | 11 | | | 11 | | | |
| Puffers | Tetraodontidae | 11 | | | 11 | | | |
| Perch, white | <i>Morone americana</i> | 8 | | 8 | | | | |
| other species | | 69 | | | | | | |

* - Reported - Number reported by fishermen but unconfirmed by intercept agent.

x - Observed - Fish observed, identified, and recorded by intercept agents.

Table IV-10. Number of Interviews, Angler Trips, Total Fish Caught, and Mean Fish Per Angler Trip for the Albemarle, Pamlico and Core Sound areas, 1988. (Angler trips and Total fish represent only those included in the field samples and are not estimates of total trips or fish for the year). DMF, unpublished data.

| | Number of interviews | Angler trips | Total fish | Mean fish per angler trip |
|------------------------------------|----------------------|--------------|------------|---------------------------|
| Albemarle Sound area | 166 | 169 | 2,649 | 15.7 |
| Pamlico Sound area | 636 | 658 | 4,431 | 6.7 |
| Core Sound area | 241 | 292 | 3,080 | 10.5 |
| Albemarle-Pamlico Estuarine System | 1,043 | 1,119 | 10,160 | 9.1 |
| All State waters | 8,215 | 6,830 | 51,797 | 5.9 |

Table IV-11. Numbers of Licensed North Carolina Commercial Fishing Vessels by License Categories, 1980-1990. (DMF)

| Year | Commercial | | Pleasure and hire vessels | Total vessels |
|------|-------------------|-------------------|---------------------------|---------------|
| | Full-time vessels | Part-time vessels | | |
| 1980 | 3,792 | 8,162 | 13,282 | 25,236 |
| 1981 | 4,090 | 7,765 | 13,596 | 25,428 |
| 1982 | 4,217 | 7,283 | 14,599 | 26,099 |
| 1983 | 4,021 | 6,334 | 14,411 | 24,766 |
| 1984 | 3,950 | 5,913 | 11,277 | 21,140 |
| 1985 | 4,228 | 5,632 | 11,472 | 21,332 |
| 1986 | 4,159 | 5,671 | 11,366 | 21,196 |
| 1987 | 4,391 | 5,694 | 10,815 | 20,899 |
| 1988 | 4,566 | 5,746 | 10,216 | 20,659 |
| 1989 | 4,730 | 5,719 | 10,119 | 20,731 |
| 1990 | 4,780 | 5,402 | 10,017 | 20,199 |

5. The hard clam fisheries of Core Sound and other areas are probably producing near their maximum potential, given the existing regulatory controls and mix of harvest methods used.
6. Oyster landings have declined to the lowest levels on record. Harvest pressure, loss of habitat, the pathogens MSX and Dermo, and water quality degradation (as measured by fecal coliform and anoxic and hypoxic events) have contributed to the decline. Intensive management measures have been utilized to maintain/enhance the oyster resource.
7. Certain water quality associated concerns which have the potential to negatively affect fisheries in the A/P area are becoming more severe, such as fish and crab diseases and losses of shellfish habitat. Reports of fish kills, algal blooms, and hypoxia are becoming more frequent.
8. Downward trends in total commercial landings of edible finfish species continue and may indicate declining stocks. Current or increasing levels of fishing pressure on such stocks will likely lead to increased social conflicts among all fishermen (commercial and recreational) for access to the available resources, and resultant calls for the state to "solve" such problems.
9. Continuing stock declines, initially attributable to pollution, environmental conditions, or natural variations in abundance, will likely be magnified by fishing mortality caused by commercial and recreational fishermen. Such a situation will result in the need for restrictions on fishing. Such restrictions on harvesters, when biologically justified, are necessary and must be undertaken in concert with actions aimed at improving environmental conditions.

E. EFFECTS OF FISHING PRACTICES ON HABITAT

Virtually all of the current fishing practices of the Albemarle-Pamlico estuarine system have been used for generations. A brief history of commercial fishing in North Carolina was provided by Godwin et al. (1971). Pound nets were introduced in the Albemarle Sound area in 1870 (Earll 1887). This gear is similar to devices used by Indians and illustrated by John White of the Roanoke colony in the 1580s (Wilder 1963). Gill nets were in use by the latter third of the 19th century (Wilder 1963). Oyster dredges were extensively used in Pamlico Sound in the 1880s (Godwin et al. 1971). Long haul seines have been used in North Carolina since the early 1800s (Earll 1887). Trawls were first used in North Carolina before World War I, and have been the major gear for shrimp since at least 1918 (Chestnut and Davis 1975). In contrast to the older gears, crab pots were introduced from the Chesapeake Bay in the early 1950s and became the dominant gear by 1959 (Chestnut and Davis 1975). "Clam kicking" refers to the use of vessel propeller wash to dislodge hard clams so they can be caught by a heavily weighted trawl towed behind the boat. The practice began in the 1940s and changed little until the late 1960s or early 1970s (Guthrie and Lewis 1982) when a number of innovations were implemented. Hydraulic escalator dredges have been used to harvest clams since the 1960s. Various other gears are used for commercial fishing in the Albemarle-Pamlico estuarine system including hand gears such as rakes and tongs for clams and oysters, toothless dredges for bay scallops, channel nets (anchored trawls held open by the ebbing tide) for shrimp, and eel pots.

Fixed gears generally have little or no significant effect on the habitat. Such gears include gill nets, crab and eel pots, and pound nets. Pots may create some turbidity when dropped to the bottom or from interactions with bottom currents. Stakes and anchors used with gill nets may have very minor, temporary effects. Channel net anchors are similarly benign. Pound net stakes have a one-time impact during the setting procedure, with negligible habitat effect thereafter.

Movable gears are generally assumed to have greater impact on the habitat than fixed gears. As a conservation practice, most movable gears are banned from use by the MFC in designated primary nursery areas. For most of the gears, little or no information on effects is available. Hand rakes and tongs used to harvest oysters and clams dig into the bottom and stir surficial sediments. When rakes and tongs are used in seagrass beds, some vegetation is lost, however, effects are judged to be so minor that the MFC allows their use in primary nursery areas. Bay scallop dredges are toothless steel and netting devices dragged over seagrass beds to catch scallops. A leading bar prevents them from digging into the bottom, but considerable amounts of grass are broken loose. Fonseca et al. (1984) concluded that scallop dredges have a negative effect on eel grass meadows. Unfortunately, peak meat weight (thus, desirability for harvest), peak juvenile attachment, and low seagrass biomass occur at the same time. Research is underway on the effects of use of scallop dredges for adult harvest on juvenile bay scallops.

Long haul seines herd their catch as they are pulled across the bottom. While it depends on the bottom type and the weight of the bottom line (lead line) of the seine, this gear seems to have a minor effect on the bottom. In grass beds, some damage undoubtedly occurs. To the degree that the seine may dig into the bottom and/or catch in the grass, additional energy must be expended to haul the net, costing the fishermen time and money. The lead line must, however, stay very close to the bottom to prevent fish from escaping under the net. No research is known on the effects of long haul seines on the bottom.

Hydraulic escalator dredges are used in North Carolina and South Carolina for hard clams, in Maryland for soft clams, and in New York for oysters. These gears dig trenches of varying depths and widths in the bottom, so their use is strictly regulated by the MFC, with limited areas available only during the winter (December-March). Physical effects on the bottom and its infauna are probably similar to those of clam kicking (Peterson et al. 1987), but hydraulic escalator dredges do not appear to hurt hard clams. The DMF has regulated the use of hydraulic dredges in New River below the North Carolina highway 172 bridge since the mid-1970s. This area is quite unique, with depths of 12-18 ft, which are beyond the harvest ability of all but the largest hydraulic dredges. No research has been conducted on the effects of the fishery on the habitat in this area. The area is opened to harvest every other year. Harvest is intensive, with declining catches within a few weeks of the opening of the harvest. After "resting" for a season (actually about 18 months), abundance of harvestable clams has returned to that at the opening of earlier seasons. Thus, recruitment of hard clams does not seem to be hurt by this practice.

Clam-kicking is most prevalent in Core Sound, at the southern end of the Albemarle-Pamlico estuarine system study area. Although fairly shallow (depth not exceeding 10 ft), Core Sound is generally more than two miles wide. Due to prevailing winds and such an expanse of open area, the use of hand gears, such as tongs or bull rakes (used in Chesapeake Bay and New England in depths much greater than 10 feet), is extremely difficult, if not impossible. Thus, mechanical harvest gear is necessary if the clams are to be harvested in much of Core Sound. In order to minimize negative effects on habitat, only open sand areas are made available for mechanical harvest. Adjacent seagrass meadows (eelgrass and shoalgrass) are not opened to mechanical harvest. This management approach is supported by the research of Peterson et al. (1987). Illegal harvest does, however, occur in the grass beds, sometimes resulting in significant local impacts. The high unit price of clams provides an incentive for current harvest, regardless of consequences. The legal harvest of clams by mechanical gears probably has minimal negative effects.

The overall effect of mechanical clam harvest on the habitat is unknown and cannot be determined relative to the period prior to use of mechanical gear because virtually the entire Core Sound area was subjected to clam-kicking during the 1970s, before the MFC enacted restrictive rules. No data are available on the productivity of the area for the period prior to heavy use of kicking and hydraulic dredging, so comparisons of past productivity with present productivity cannot be made.

The use of trawls to harvest shrimp and crabs in Pamlico Sound has become very controversial in recent years. Shrimp trawls operate by dragging across the bottom behind a trawl vessel. Water pressure spreads the "doors" or "otter boards" which are attached to the leading edge of the funnel-shaped net, holding the net open. The bottom line (lead line) of the trawl maintains contact with the bottom. Usually a chain (tickler chain) is attached to the trawl doors ahead of the net. The tickler digs slightly into the bottom to cause the shrimp to jump off the bottom and so be captured by the trawl. Thus, the doors, tickler chain, and trawl leadline all stir the bottom to some extent. The larger the rig, the greater the resulting disturbance. Throughout the 1980s, North Carolina shrimp trawlers have converted their rigs from one or two large nets to four nets, which are believed to take less by-catch, and require less fuel.

Since 1918, trawls have been the principal gear for the harvest of shrimp in North Carolina, accounting for more than 96% of the harvest during recent years (unpublished DMF data), with an average dockside value exceeding \$13.6 million annually. On average, the Albemarle-Pamlico estuarine system accounts for about 70% of North Carolina's annual commercial harvest of shrimp (Street 1987). Thus, shrimp trawling is extremely important economically. Prior to the early 1970s, trawling was allowed anywhere within the estuary once the season opened in that area. Trawling occurred in marsh creeks small enough that the trawl boards were in the marsh grass on each side of the creek. As the DMF primary nursery area surveys were being conducted between 1970 and 1976, trawling was prohibited in the designated areas. Since 1977, MFC regulations have prohibited trawling in all designated Primary Nursery Areas. Trawling has been restricted in many estuarine bays since the late 1970s. Most of these areas were formally designated as Secondary Nursery Areas in 1986 by the MFC, with a prohibition on trawling. The Albemarle Sound area was also closed to trawling in 1987 by the MFC because of the overwhelming long-term use of fixed gears in that area. Trawling in the Albemarle-Pamlico estuarine system is generally restricted to the open waters of Pamlico Sound, Neuse River, Pamlico River, Bay River, and Core Sound.

Brown shrimp provide the majority of shrimp landings in North Carolina, generally comprising about two-thirds of the total. In Pamlico Sound, they are even more important (unpublished DMF data). In Pamlico Sound, brown shrimp grow to very large sizes, usually exceeding 165 mm in length by early fall, when large catches of shrimp in the "16-20" range (16-20 tails per pound) may be taken in the Sound. Brown shrimp of such a size are only rarely found elsewhere along the Atlantic coast, and are not found again until the Gulf of Mexico shrimping grounds off Louisiana and Texas.

No studies have been conducted in North Carolina to examine the effects of trawling on the estuarine habitat. A South Carolina study examined trawl effects on sediments and benthic organisms in two South Carolina estuaries with bottom types and fauna generally similar to those found in the Albemarle-Pamlico estuarine system. The authors concluded that shrimp trawling "did not have a significant adverse effect on the benthic community parameters measured" (Van Dolah et al. 1988). Those parameters included sediment composition, hydrographic conditions, and benthic community structure (diversity, evenness, and richness).

F. DISEASE PROBLEMS

F. 1. Introduction

Very little is known of the actual consequence of disease on populations of aquatic organisms, however, the potential damage that disease can inflict is considerable. Disease may be important in fisheries populations for several reasons. First, the potential impact of diseases upon the amount of biomass of the stock is great. An accurate determination of this value is of great concern to both fishery managers and fishermen, as it influences decisions about the amount of finfish or shellfish that can be harvested. With the sensitivity of present methods, usually only massive, catastrophic acute mortalities are detectable due to the wide degree of natural biological variation (Munro et al. 1983; Vaughan et al. 1986). It is the chronic deterioration in water quality, however, that may affect fishery stocks most significantly. Unfortunately, such chronic effects are often the most difficult to discern (Green 1984; Wedemeyer et al. 1984). Chronic problems are a major dilemma for fisheries managers, since the immediate impacts of the problem may be relatively small and, thus, may be considered relatively unimportant. By the time that the true impact of the pollutant has been fully realized, the population may already have suffered great harm.

Second, disease is important from the standpoint of aesthetics. This phenomenon may have more economic impact than previously thought. Visibly diseased fish are unsalable "in the round". If fillets are affected, they may be totally rejected, thus excluding them from the commercial fishery, regardless of the risk they pose to human health. In addition, people do not like to see sick fish or other animals in the wild. Thus, appearance may reduce the attractiveness of fishing in affected areas, and so could have considerable impact on the valuable recreational fisheries. Such problems often become politicized. Political pressure placed on managers may be somewhat beneficial, by focusing attention on these problems, but it can also be detrimental if it tends to emphasize short-term, stop-gap solutions that fail to recognize or address the problems' inherent complexity (Perry et al. 1987).

Third, is the potential relationship of aquatic animal health to human health. Fish exposed to contaminants such as carcinogens and other toxins often respond in a manner similar to that of mammals and develop neoplasia and other organ dysfunctions (Sindermann 1983). Toxin-producing phytoplankton can accumulate in the edible tissues of marine animals, especially bivalve molluscs, posing potential risk to humans. Also, some pathogens that cause disease in fish (e.g., certain *Vibrio* bacteria) can be pathogenic to humans. Thus, it is never advisable to consume any animal having lesions that may have high concentrations of such pathogens.

Finally, fish health may be an indicator of general ecosystem health (Sindermann 1988). In aquaculture, high levels of disease are frequently a reflection of sub-optimal environmental conditions that allow pathogens to overwhelm a population's defenses (Plumb 1984; Wedemeyer et al. 1976). It is tempting to extrapolate such findings to natural aquatic populations, but such cause and effect relationships have not been proven.

F. 2. Finfish Diseases

Epidemic disease was first reported in the Albemarle-Pamlico estuarine system in the 1970s, when there were massive kills of largemouth bass (*Micropterus salmoides*), white perch, and other species in the Albemarle Sound area (Esch and Hazen 1980a). Dying fish frequently had extensive skin lesions, which were referred to as "red-sores" (DEM et al. 1976). During certain periods of the summer of 1975, 50% of all the commercially harvested fishes in Albemarle Sound were found to be affected with red sore disease (DMF 1975).

In the 1970s, epidemics of red-sore disease were also reported in a number of freshwater lakes in North Carolina (Miller and Chapman 1976) and in other parts of the southeastern US (Esch and Hazen 1980b). Unfortunately, the term "red-sore" soon became synonymous with any red lesion seen on fish in North Carolina. General use of this term added considerable confusion to the attempts to determine the true cause of these lesions, since red skin lesions on fish can be caused by many factors.

True red-sore disease has been described as a skin infection due to the presence of both a bacterium, Aeromonas hydrophila, and a protozoan, Epistylis (also known as Heteropolaria). Huizinga et al. (1979) stated, based upon experimental infection studies, that the presence of a skin ulcer having only A. hydrophila should be considered as a diagnosis of "red-sore." The utility of this criterion may, however, be questionable since A. hydrophila is probably the most common secondary invader of skin wounds in freshwater fishes and so, more often than not, can be isolated from any skin wound regardless of its cause.

During the massive fish kills in Albemarle Sound and the Chowan River, the affected fish apparently had red skin lesions (DMF 1976). Presumably, many of these fish had Aeromonas-Heteropolaria infections, although the true prevalence of such pathogens in the lesions was never documented. However, based upon the serious fish disease problems being experienced in the Albemarle drainage, a series of studies was initiated by Esch and Hazen (1980b) to study the microbial ecology of A. hydrophila. Using monthly sampling, they found a positive correlation between A. hydrophila concentrations and the levels of fecal and total coliforms, dissolved oxygen, turbidity, chlorophyll a, pheophytin a, sulfate, ammonia, total Kjeldahl nitrogen, total phosphorus, phosphates and total organic carbon.

In previous studies, Esch, Hazen, and co-workers had correlated the increased prevalence of red-sore disease in Par Pond, a freshwater reservoir in South Carolina, with high temperature. An attempt was made to equate hematological parameters of physiological stress to body condition of largemouth bass sampled from Par Pond (Esch and Hazen 1980a). Based upon these previous studies in Par Pond, they concluded that lowered body condition of fish, an indicator of poor health and a result of various stressors in the water: (1) perturbs parameters of physiological stress in the fish, thereby increasing their susceptibility to and the occurrence of red-sore disease, and (2) increases the abundance of the causative agent, A. hydrophila.

The model that Esch and Hazen (1980b) presented relating water quality, A. hydrophila densities, and the stress-related occurrence of red-sore disease is intuitively appealing, especially since high levels of organic matter have been felt to increase the risk of infection by A. hydrophila (Wedemeyer et al. 1976). However, their conclusions largely rested on inference, not on definitive research. Esch and Hazen's (1980b) studies in the Albemarle drainage area focused entirely on the relationship between water quality and bacterial densities. There was no examination of how these two parameters related to the prevalence of fish disease. Instead, they studied the prevalence of red-sore lesions in a body of fresh water (Par Pond) and then attempted to extrapolate this work to an estuarine system (Albemarle Sound). Aside from the inherent dangers in making any such extrapolations, a comparison of these two systems is especially questionable, since the most common pathogens in marine environments are not the same as the ones most commonly found in freshwater systems, even though many may appear clinically similar.

For example, there is some question as to whether Esch and Hazen (1980b) were accurately measuring A. hydrophila densities, since the medium they used for enumeration, Rimmeler-Shotts, does not differentiate between A. hydrophila and Group F or EF6 vibrios (Kaper et al. 1981), bacteria which are widely distributed in estuarine environments. Thus, many of the bacteria being counted as A. hydrophila may actually have been Vibrio species. The actual importance of A. hydrophila in the pathogenesis of skin lesions in the Albemarle drainage area is also in question due to the more recent studies which demonstrated that early skin lesions from largemouth bass in the Chowan River had a

variety of bacteria present (Noga 1986b). A. hydrophila was not the predominant organism (as defined by colony type) in most cases, and no other bacterium was consistently predominant. Microscopic examination revealed that 31% of all early lesions were associated with Lernaea cruciata infection. This copepod was the most commonly identified agent in early skin lesions. Over 60% of all lesions had no identifiable pathogens, but the histological appearance of most lesions was similar to that seen in L. cruciata infection, suggesting that this parasite may be the primary initiator of skin lesions in largemouth bass of the Chowan River. Examination of other species from the Chowan River and Albemarle Sound also revealed that "red-sore" lesions were associated with many other pathogens, including monogenean trematodes, digenean trematodes, fungi and (rarely) Heteropolaria (Noga 1986b; Noga Unpublished Data). Most of the lesions examined were small, presumptively early stages of disease.

Between November 1986 and May 1987, an epidemic of severe ulcerations of the tongue and buccal cavity of largemouth bass was seen in Currituck Sound (Noga et al. 1990). No other external clinical signs were present. Reports from fishermen suggested that as many as 90% of large bass (over 300 mm) were affected at certain times. Older fish were the most commonly affected. The leech Myzobdella lugubris was consistently present on or near the lesions. Lesions were heavily infected with several different bacteria that were apparently secondary invaders. Stressfully high salinity or an interruption in the normal migratory cycle of the parasite were considered as possible causes for the condition.

Recently, other types of diseases have been recognized in Pamlico Sound and its tributaries. In the winter of 1981, the North Carolina DMF investigated lesions on southern flounder from the Pamlico and Pungo Rivers that had been captured by the estuarine winter trawl fishery. Affected individuals appeared predominantly in the tributaries between Blount's Bay and Rose Bay. The prevalence of flounder with lesions appeared to significantly decrease when water temperatures increased during spring. From November 1983 to March 1984, more flounder with skin lesions were seen. Exhaustive water quality sampling failed to reveal any obvious abnormalities. Although a virus was isolated from some fish (McAllister et al. 1984), subsequent studies failed to reproduce the disease with this agent.

One of the most common diseases presently affecting fishes in the Albemarle-Pamlico estuarine system is ulcerative mycosis (UM), a fungal infection primarily affecting Atlantic menhaden. This disease was first reported in April 1984. First seen in the Pamlico River, it was also reported in the Neuse River as well, with isolated reports from the New River and Albemarle Sound.

Since 1984, repeated outbreaks of UM have occurred that in some instances has resulted in up to 100% infection rates in randomly sampled schools of Atlantic menhaden in the Pamlico River (Levine et al. 1990(b)). In North Carolina, outbreaks are most common in the Pamlico River. The severity of epidemics in other estuaries in the state, like the Neuse River, appears to parallel the severity of the condition in the Pamlico River. During especially virulent episodes, millions of fish may die of the infection (J. Hawkins, DMF, Personal Communication).

The overwhelming majority of fish that acquire the UM infection are young-of-year (age 0) Atlantic menhaden. A similar disease has been observed on southern flounder, striped bass, weakfish, Atlantic croaker, spot, silver perch, gizzard shad (Dorosoma cepedianum), hickory shad, hogchoker (Trinectes maculatus), pinfish, and bluefish (Noga et al. 1991). The prevalence of skin lesions on these other species seems to be greatest during the peaks of the menhaden epidemics (Levine et al. 1990(a)).

In the Pamlico River, where UM has been best studied, outbreaks exhibit a bimodal annual cycle, with peaks in disease prevalence usually occurring between April and June and again between September and December (Levine et al. 1990(b)). The highest prevalence rates occur in low to moderate salinity (about 2-8 ppt). Observations of lay-observers and empirical evidence from sampling surveys (Levine et al. 1990a, 1990b) strongly indicate that the fish are probably acquiring the infection in parts of the estuary exhibiting this salinity range. This conclusion is also supported by the spatial shifting of the focus

for high concentrations of infected fish from downriver in the spring-summer epidemic, to farther upriver during the fall-winter peak, corresponding to rising salinities late in the year (Noga et al. 1989a).

UM has several characteristic features that help to distinguish it from other diseases that cause sores on fish. First, and most obvious, are very deep, penetrating, aggressive lesions which commonly perforate the body wall and expose internal organs. Once dead tissue sloughs off, a crater-shaped lesion is left. Lesions are commonly infected with many different types of bacteria and protozoa. The large numbers of microorganisms present in advanced cases probably contribute to the death of the fish.

The fungi in UM lesions are water molds of the genera Aphanomyces and Saprolegnia (Noga and Dykstra 1986; Dykstra et al. 1986; Dykstra et al. 1989). These organisms have previously been considered to be almost exclusively freshwater pathogens and have rarely been reported to cause disease in estuarine fishes. These water molds or "oomycetes" are common freshwater inhabitants that usually form fuzzy, cottony growths on the skin of freshwater fishes. In contrast with UM, typical oomycete-caused lesions usually do not penetrate deeply into the body. Fishes' inflammatory response to UM is unusually severe; this may reflect the aggressive fungal growth into the tissue. The disease appears to have a high mortality rate, since few fish with evidence of previous infection are seen after an outbreak subsides.

The growth of an Aphanomyces sp. isolated from Atlantic menhaden with ulcerative mycosis was enhanced in the presence of low concentrations of salt (Dykstra et al. 1986). Such growth is very unusual, for this type of water mold is usually inhibited by salt. This finding, however, correlates with the highest prevalence of the disease in waters of low to moderate salinity. Salinity tolerance may also explain how these fungi penetrate deep into fish tissue, which has a high salt content. The tissue of freshwater fish also has a high salt content. While fungi are consistently present in UM lesions, there is now evidence that a bacterium or some other infectious agent is also needed to cause UM (Noga et al. 1989b).

While UM is by far the most common disease affecting Atlantic menhaden in the Pamlico River, many other diseases have been seen in lower prevalence since 1984 (Table IV-12). Among the most important of these problems is an ulcerative disease of American eels (Anguilla rostrata) caused by the bacterium Aeromonas salmonicida (Noga et al. 1989a). The only feature that all of these maladies have in common is that an infectious agent is involved, which is often an opportunistic pathogen. Neoplasia (i.e., cancer) is extremely rare.

Kills of fish without obvious gross lesions are also common in the Albemarle-Pamlico estuarine system, especially in the Pamlico River during late summer and fall. The cause of the majority of these kills is unknown, but where causes have been determined, hypoxia is by far the most important factor (Rader et al. 1987). Hypoxic conditions are usually created by salinity stratification, however, it now appears that hypoxic conditions can develop in unstratified waters (Noga, Markwardt, Berkhoff 1989). Toxins produced by algae have also been suspected of causing mortalities in flounder and other fishes (Paerl 1987). Evidence accumulated through the statewide fish kill monitoring network suggest that more fish may die in acute mortalities in the Albemarle-Pamlico estuarine system than in the rest of North Carolina combined. The number of kills may be increasing (Rader et al. 1987).

Finfish diseases do not appear to be a problem in Core Sound, as evidenced by the lack of observations of diseased finfish by both fishermen's reports and the DMF state-wide trawl survey for juvenile fish and crustaceans, which notes general skin diseases on individuals.

F. 3. Shellfish Diseases

While lesions on finfish have been most intensively studied in the Albemarle-Pamlico estuarine system problems with shellfish have also recently become a concern. In the summer of 1987, fishermen in the Pamlico River began to report blue crabs with shell disease (McKenna et al. 1990). During the course of the outbreak, up to 90% of crabs in individual crab pots were affected (S. McKenna, DMF, Personal Communication). Since crabs with significant amounts of shell disease are unsalable, there is considerable worry among commercial fishermen.

Shell disease (also known as rust disease, black spot, or brown spot) is a common syndrome in both freshwater and marine decapod crustaceans (Johnson 1983). It is considered an infectious disease, and a number of pathogens have been found in the lesions. The most commonly isolated pathogens are gram-negative bacteria, including *Vibrio* and *Pseudomonas* (Johnson 1983). *Vibrio* and *Pseudomonas* were among the pathogens isolated from shell disease lesions in Albemarle-Pamlico estuarine system blue crabs (McKenna et al. 1990). Other agents including mycobacteria, psychrophilic luminescent bacteria, and fungi have also been associated with some cases.

The lesions seen in the Pamlico River blue crabs are a very aggressive form of shell disease that frequently penetrates the carapace or causes massive disintegration of the shell (Engel and Noga 1989). These lesions are much more severe than those classically described by Rosen (1970).

In June 1987, DMF sampling of crab pots of commercial fishermen suggested that the highest prevalence of shell disease was on the south side of the river between Durham and South Creeks near the Texasgulf, Inc. phosphate mine. This conclusion was supported by the observation of the same distribution after a trawl survey of 60 stations between Mauls Point and Indian Island (McKenna et al. 1990).

Clinically normal crabs obtained from Rose Bay were placed in cages in the river in order to determine if there was any increased risk of developing shell disease in certain areas. Cages were placed at Core Point, Indian Island, Long Point, and adjacent to the Texasgulf, Inc. phosphate mine. Crabs that were wounded by scraping the carapace developed what the authors considered to be early stages of shell disease (i.e., punctiform brown marks with reddish-brown depressed centers) as soon as one day after wounding. While shell disease lesions developed from the wounds of most crabs at all locations, crabs at Long Point and Texasgulf developed lesions significantly ($p < 0.05$) faster (mean = 4.2 days) than crabs at Core Point and Indian Island (mean = 8.1 days).

McKenna et al. (1990) speculated that toxic sediments originating from Texasgulf, Inc. may be responsible for the increased risk of disease development, since the Division of Environmental Management had determined that cadmium and fluoride, both of which might affect skeletal integrity, were highest on the south side of the river at the Texasgulf, Inc. facility.

Problems have also recently been reported in oysters. During the annual DMF oyster shoal survey of fall 1988, high mortalities were observed in Core and Pamlico Sounds. Examination revealed that many oysters were infected by *Dermocystidium* (*Perkinsus marinus*) or MSX (*Minchinia nelsoni*), two diseases that can be highly fatal to oysters. These two pathogens were later found throughout much of North Carolina's oyster stocks (DMF Unpublished Data).

Toxic dinoflagellate blooms in the fall of 1987 resulted in considerable mortalities of bay scallops (Summerson and Peterson In Press).

F. 4. Evaluation of Trends in Diseases

There is a very limited temporal database on the prevalence of disease in the Albemarle-Pamlico estuarine system. Before 1974, investigations of fish diseases had been sporadic and short-term. Since 1974, North Carolina has had an extensive coastal finfisheries monitoring program conducted by DMF. It includes sampling of several hundred estuarine stations up to 10 times per year (currently March through November) as well as sampling of commercial catches year-round. The field survey is directed at determining the relative abundance of juvenile bottom fishes and crustaceans, such as sciaenids, flounders, and shrimp, but incidentally includes pelagic species, such as menhaden and anchovies. Temperature and salinity are recorded at each station, and dissolved oxygen is measured at some locations. Presence of diseased fish is routinely recorded on data sheets. In 1986, a more comprehensive diseased fish recording system for skin disease problems was instituted that included detailed data on the types of lesions seen (Noga 1986a). Representative samples of all lesions are preserved for later histological diagnosis. All disease data are stored on computer files for future retrieval and analysis. While potentially useful in health monitoring, the ground fish survey is biased towards juvenile bottom fishes and often does not efficiently collect the pelagic fish populations (Atlantic menhaden) that are most heavily affected by disease at the present time.

Based on data from this survey, sampling by the North Carolina Wildlife Resources Commission, and fishermen's reports, the prevalence of disease in the Albemarle Sound estuary appears to be considerably less than during the epidemics of the mid- to late- 1970s. The last major epidemic of skin lesions appears to have been in 1982 (H. Johnson, J. Kornegay, DMF, Personal Communication). Since that time, the prevalence of skin lesions appears to have declined. Interestingly, decreased disease has coincided with a noticeable reduction in the number and severity of blue-green algae blooms that were also prevalent during this time. On average, from 1983 to 1988, salinities have been higher than the average in the Albemarle drainage area, due to lesser rainfall. In 1982, the Chowan River basin was designated as nutrient-sensitive by the North Carolina Environmental Management Commission as part of an effort to improve water quality of the river.

Prevalence of fish disease in the Pamlico River estuary has increased dramatically since 1984. Based on data from the DMF trawl survey and fishermen's observations, ulcerative mycosis (UM), which is the most common problem, was not seen before 1984. However, since its dramatic appearance, it has remained highly prevalent. While comparable data are not available for all years, it appears that the largest disease outbreaks occurred in 1984, 1989, and possibly, 1988. Interestingly, 1984 and 1989 were unusually wet years, resulting in depressed salinities in the Pamlico River, indicating the relatively greater importance of nonpoint sources of pollution.

Prospective studies to determine possible water quality conditions that may be responsible for fish disease were initiated in the Pamlico River in 1985. An intensive field survey examined the prevalence of UM in the Pamlico River from May 1985 to April 1987. Temperature, salinity, and dissolved oxygen (DO) were measured simultaneously at monthly intervals, in concert with a trawl survey to determine disease prevalence (Noga et al. 1989a). None of the water quality factors measured showed a correlation with UM. However, a more intensive cast net survey of UM prevalence that focused on the high-risk (low salinity) area of the Pamlico River demonstrated that there was a positive correlation between UM and temperature and bottom DO during the fall 1988 outbreak (Levine et al. 1989). This finding was supported by the observation of several hypoxic episodes in the same area just prior to the UM outbreak (Noga et al. 1989b). Also, large diurnal fluctuations in DO and pH were common. These fluctuations were similar in magnitude to seasonal fluctuations that had been reported previously (D. Stanley, ECU, Personal Communication).

A data management program known as the Ulcerative Disease Regional Database (UDRDB) was developed to both retrospectively and prospectively determine the relationships between water quality parameters and the presence of ulcerative lesions on fish in the Pamlico River estuary (Levine et al.

1987). The data bank combined fisheries, physical, and water quality data with skin ulcer prevalence. Values for more than 20 water quality and sediment parameters monitored by the North Carolina Division of Environmental Management were compared with UM prevalence. The monthly proportion of fish affected was regressed on total nitrogen, phosphorus, temperature, dissolved oxygen, BOD, pH, chloride, and heavy metals. No significant relationship was observed between these parameters and the occurrence of disease. Statistical evaluation was limited by the lack of available historical water quality data. During or preceding three outbreaks of UM, however, total nitrogen concentrations were elevated at one station. Similar concentrations were observed at a second site during two outbreaks. Chloride levels were also elevated during three outbreaks. Minimal changes in phosphorus levels were evident during or preceding UM outbreaks. In 1985 and 1986, disease appeared to increase following periods of dry weather and decline during periods of rainfall (Levine et al. 1987; Noga et al. 1989a).

Fish disease does not appear to be a major problem in Core Sound, although the importance of bivalve pathogens such as MSX or Perkinsus (Dermo) are uncertain. In general, there is considerably more knowledge about the disease problems affecting the finfish populations of the Albemarle-Pamlico estuarine system than those affecting invertebrate species.

F. 5. Cause of Disease Problems: Current Status of Knowledge

An overall assessment of the number and magnitude of diseases affecting the finfish and shellfish populations of the Albemarle-Pamlico estuarine system suggests that the populations are being exposed to abnormally high stresses. Whether such stresses are due to pollution or are entirely natural events has yet to be scientifically proven. There are several lines of evidence, however, that suggest that these problems are not entirely due to natural phenomena.

First, is the very high prevalence (and possibly incidence) of many different diseases. For example, overall prevalence of UM in the Pamlico River was 15% from May 1985 to April 1987 (Levine et al. 1990a; Levine et al. 1990b); during outbreaks, prevalence frequently exceeded 90% of sampled populations. In the Chowan River, some studies, designed to be representative of the population at large, have shown that over 50% of the largemouth bass population can have skin lesions during the summer (Noga 1986b). Disease prevalence in fish populations in unpolluted environments rarely exceeds 10% (Brown et al. 1977; Couch 1985).

While shell disease does not appear to affect more than 5% of the Pamlico River crab population (McKenna et al. 1990), the extremely aggressive lesions on affected animals suggest that the mortality rate may be especially high, compared to other blue crab populations that usually have been reported to have a milder form of the disease (Rosen 1970). High (and probably rapid) mortality is characteristic of UM. These features suggest that the incidence of these diseases (i.e., the number of new cases of disease developing at any particular time) would be great and make their impact more severe than less virulent problems with a similar prevalence.

Second, many of the most common diseases are often associated with polluted environments. Skin ulcers, for example, are considered to be one of the best pathological indicators of pollution (Sindermann 1983). Shell disease is increasingly being considered as the invertebrate analogue of finfish skin ulcers as an indicator of environmental quality (Sindermann 1989). Shell disease has been reported in many natural populations of crustaceans (Sindermann 1989), but the prevalence has usually been very low. Stressful environments, however, seem to increase the risk of disease.

Third, the tremendous number of affected species from diverse habitats and niches is indicative of widespread environmental perturbation.

The overwhelming majority of diseases facing the fishery populations of the Albemarle-Pamlico estuarine system have some infectious component. No strong evidence linking any infectious disease in wild fisheries populations to a specific pollutant currently exists, due largely to the myriad of possible variables ("contaminants") which may influence fish health. Factors which lead to the development of an infectious disease can be very complex. Exposure to a pathogenic organism will not result in disease unless the proper conditions in the host are met (i.e., suppressed immune system). The conditions responsible for this immunosuppression may not be easily determined.

If a toxin responsible for reducing immunity accumulates in host tissues, determination of body burdens in affected individuals may provide clues to the cause of the problem. Infectious diseases may also, however, be initiated by environmental factors which leave no detectable residues. Perturbations, such as increased nutrient levels, alterations in salinity gradients, or changes in suspended solids may not be directly toxic to aquatic animals. Instead, their second and third order consequences (e.g., changes in dissolved oxygen or carbon dioxide due to eutrophication) may stress fish (Plumb 1984). The rather ephemeral and temporally variable nature of such factors make them especially difficult to study. Thus, it is important to realize that infectious diseases are secondary manifestations of physiological and/or environmental changes that allow infectious agents to colonize a host. The need to identify those primary effects ultimately responsible makes research very complicated.

F. 6. Information Needed for Developing Management Strategies

Determining the factors that are responsible for an epidemic in a fishery population requires close examination of the three principal components that interact to produce disease: the host, the pathogen, and the environment (Snieszko 1974). It should be recognized that disease is a normal process in any animal population. Thus, we are concerned not so much with the presence of disease, but instead, with the anthropogenic factors that may affect its prevalence.

Many diseases can look very similar to the naked eye and thus may mistakenly be lumped into one category (Table IV-12). It is important to differentiate and identify the most important disease problems because distinct risk factors are associated with the development of different diseases. Once putative pathogens have been isolated, the disease must be successfully induced in the laboratory, and then the same organism must be re-isolated. The meeting of such criteria, termed Koch's Postulates, is essential because reproducible induction of a disease provides an experimental model which can be used to determine which environmental conditions are most influential on disease development.

It is also necessary to determine factors that may influence the pathogenicity of the infectious agent causing the disease. Many fish pathogens, such as water molds and many bacteria, are capable of a free-living existence in water and do not require a fish host for survival. Temperature, dissolved gases, salinity, pH, and various nutrients may influence the abundance and, possibly, the virulence of such agents.

There always exists the possibility that newer, more virulent strains of pathogens may be responsible for an epidemic. The introduction of new agents into susceptible host populations has frequently resulted in catastrophic effects, however, this is unlikely to be responsible for problems in the Albemarle-Pamlico estuarine system fisheries, since there are so many different agents causing lesions.

Field studies should include identification of zones of high and low risk for infection in an effort to focus on those sites in which fish are becoming infected. Correctly identifying such sites is critical to determining which water quality parameters may be responsible for the disease. One approach is to narrow the suspected region of high risk by using progressively more precise methods of detection.

Table IV-12. Pathogens associated with skin diseases ("red-sore") from fishes in the Albemarle-Pamlico Estuarine System (from Noga 1986b and Noga et al. In Press).

VIRUSES

Lymphocystis

BACTERIA *

Aeromonas hydrophila

Aeromonas salmonicida

FUNGI

Saprolegnia spp.

Aphanomyces spp.

PARASITES

Henneguya sp.

Heteropolaria sp.

Monogenean trematodes

Digenean trematodes

Argulus sp.

Lernaeid copepods

NOTE: Only skin pathogens associated with grossly evident inflammatory lesions are included. Many of these pathogens are also found asymptotically on healthy skin.

* Numerous other bacteria which have been identified from lesions and which do not appear to be primary pathogens are not included.

At the same time, one must try to correlate specific water quality factors with high and low risk sites. The success of this stage of study depends upon the ability to precisely identify high risk sites for infection. At present, there is very little information about the relationship between water quality and infectious disease development in natural environments. However, experience with disease problems in aquaculture situations can be helpful in formulating a list of probable risk factors. Two major types of factors should be considered. First, are those environmental conditions universally essential to fish health: dissolved gases (oxygen, carbon dioxide, etc), salinity, temperature, nitrogenous compounds (ammonia, nitrite, nitrate), and pH. Deciding which to examine depends upon their past variability in the particular system under study. Second, are toxins (heavy metals, etc.) that may be present above "normal" limits. With the myriad of possible factors that may affect fish health, this list should also be based upon any historical trends of anthropogenic inputs into the system. The time scale of monitoring to be performed will obviously depend upon the range of system variability for the water-quality criteria examined (Livingston 1982). For example, previous studies in the Pamlico River indicate that monthly water quality sampling is insufficient to accurately assess the actual water quality changes that are occurring (Levine et al. 1989; Noga et al. 1989b).

As mentioned previously, most pollution-disease investigations have focused on the possible cause and effect relationship between an anthropogenic substance and its effect on aquatic animal health. A direct causal relationship, however, may not exist. Instead, the pollutant may act indirectly on fish health by causing other changes in environmental quality. More difficult to assess, yet potentially very important, are ecological changes that may affect trophic dynamics, and thus food quality or quantity or the presence of various chemical constituents in the water (toxins, etc.).

In summary, while many factors have the potential of making fish more susceptible to disease, there needs to be a rational prioritization of the factors that are most likely to be responsible. While such a list may vary somewhat depending upon data available on the disease, it should focus on most probable conditions based upon data from more well-studied systems (e.g., aquaculture). Cost is always an important consideration, and thus an attempt should be made to use indicators that will provide the most information about a broad range of conditions. Once correlates are found, the study should become progressively more focused as more specific variables are identified.

In the Albemarle-Pamlico estuarine system, conditions which appear to merit special consideration as possible risk factors for fish disease include low dissolved oxygen, demonstrated to be responsible for acute mortalities of both finfish and shellfish in the Albemarle-Pamlico estuarine system, and phytoplankton-produced toxins, potentially able but never proven to cause mortalities. The presence of such acute effects suggests that sub-lethal effects leading to increased disease susceptibility may also be operative. If this is true, changes in the quality and/or quantity of phytoplankton communities will require further investigation. Physical-chemical factors which might be important in influencing these end results include the volume and temporal-spatial distribution of water entering the estuary. Depressed salinities appear to increase the risk of disease outbreaks, although other factors are probably also required.

A final step required in proving that certain water quality conditions are responsible for a disease is to reproduce the disease using the specific water quality risk factors. If differences in water quality have been detected between high- and low-risk sites, one must decide which of those differences are most likely to be causing the disease. This decision implies that reliable information exists on factors influencing fish health in natural systems. Unfortunately, environmental requirements for fish health are based mainly on studies of a few species, primarily salmonids and catfishes. Even in these species, the relationship between specific environmental conditions and disease resistance is poorly understood. Nonetheless, one must demonstrate that specific water quality features increase the risk of disease under experimental conditions in order to prove a cause-and-effect relationship.

The ultimate goal of these studies is to present to managers the major water quality factors that are responsible for the development of the disease. With this information and a knowledge of the anthropogenic contributions to a pollutant's loading, an administrative decision can be made concerning acceptable levels of that pollutant in the environment. It is important to realize that the acquisition of this information requires a long term effort. Since not all the data that are desired will be acquired at once, new information should be incorporated into management plans.

Thus, adaptive management should be encouraged, allowing managers to proceed with the best available information and to implement corrective actions as research produces new information. An assessment also needs to be made of the true impact of these diseases on the Albemarle-Pamlico estuarine system. This assessment should include not only catch data, but also less tangible effects such as socio-economic effects of the disease. At the same time, attempts should be made to determine how causes of fish disease may also be linked to other deleterious changes in the environment (loss of submerged aquatic vegetation, increased noxious algae blooms, etc.), which may also have adverse effects on fishery productivity. Thus, there needs to be a commitment to determining the impact of these diseases on the Albemarle-Pamlico estuarine system, so that rational judgments can be made before irreversible changes occur.

F. 7. Summary

Fishes in the Albemarle-Pamlico estuarine system have a very high prevalence of skin diseases. The only apparent similarity among the diseases is an infectious component (i.e., virus, bacterium, fungus, or parasite). Although diseases are very common in this estuarine system, there are insufficient data to support or refute pollution as their cause. One unknown, but crucially important, variable is the influence of natural environmental perturbations on the expression of these diseases. Disease is certainly not restricted to fish populations in polluted environments, and significant disease outbreaks have been documented in fish populations far from any pollutant sources.

One must first determine the major environmental factors that increase the risk of the fish population to disease before specific pollutants can be implicated. Thus, the question of "pollutant" or "natural stressor" is initially irrelevant; instead, the focus should be on those factors most important to fish health. It is important to understand how natural environmental fluctuations may affect the susceptibility of fish to disease. Only with this knowledge can we understand how anthropogenic activity can influence and accentuate those environmental stressors.

Finding those risk factors requires a multifactorial approach that includes examining the host, the pathogen and the environment. It is obvious that this task is not easily done, but will require considerable effort with no guarantee that answers will be found. The decision to attempt such undertakings will ultimately depend upon the economic and intrinsic value which we place on our fishery resources.

G. FISHERIES MANAGEMENT ISSUES

For various species, regulations of the North Carolina Marine Fisheries Commission (MFC) directly control seasons, gear parameters, size limits, and quantity of daily harvest. The Coastal Resources Commission (CRC) regulations help maintain estuarine habitat and water quality. Rules promulgated by the North Carolina Environmental Management Commission (EMC) are designed to maintain water quality. Because North Carolina has a federally approved coastal zone management plan, the activities of federal agencies which may affect coastal fisheries or habitat are subject to review for consistency with that plan. Many species of importance in the Albemarle-Pamlico estuarine system spend a portion of their life in the federal Exclusive Economic Zone (EEZ), that area extending from the state's three-nautical mile Territorial Sea to 200 nautical miles offshore. Some of these species, such as summer flounder, are harvested in the EEZ and so the fisheries are subject to federal fishery management plans and regulations under the Fisheries Conservation and Management Act (FCMA). Many other species migrate in the near-shore ocean and are harvested principally in areas under the control of the coastal states. Under the auspices of the Atlantic States Marine Fisheries Commission (ASMFC), coastal states may join together to prepare fishery management plans for such species, implementing needed regulations under their individual authorities. Some of the species for which such plans have been prepared and implemented include Atlantic menhaden, bluefish, striped bass, river herring and shad, weakfish, spotted seatrout, and red drum.

The responsibility for regulation of the fisheries in the estuary (inland waters) lies with the MFC under General Statute 143B-289.3. This 15-member body, created by the North Carolina General Assembly and appointed by the Governor, is delegated the responsibility "to manage, restore, develop, cultivate, conserve, protect, and regulate the marine and estuarine resources of the State of North Carolina" (NCGS 143B-289.4). The MFC and the management agency, the Division of Marine Fisheries (DMF), deal directly with fishery conflicts (people problems) and stock problems (biological issues). In approaching these types of problems, the DMF seeks to promote conservation of the fisheries resources

for the long term. In this context, conservation means "wise use." Management is not intended to seek short-term economic or social benefits at the expense of long-term benefits to the resources and those who use the resources.

The fisheries resources cannot be directly controlled by regulations. Regulations affect the fishermen utilizing the resource by controlling gears, seasons, areas, size limits, and quantities harvested. Most efforts of DMF involve the collection of statistical information, monitoring the various stocks, conducting needed research, and enforcing fishing regulations. In addition, some enhancement efforts, such as planting oyster clutch material for spat settlement and construction of artificial fishing reefs, occur within the estuary.

It is important to note that the MFC has no direct authority to regulate or control activities which affect the overall fisheries habitat or water quality, except those impacts resulting from use of fishing gears. Although DMF works closely with agencies with environmental regulatory authority and comments on habitat alteration permits, the agency which is responsible for managing the fisheries has no direct authority to protect that habitat from adverse environmental impacts. Habitat and water quality degradation are believed to be major threats to the long term fishery productivity of the estuary. Strong actions by all responsible state agencies is requisite.

A fishery management issue which needs immediate attention concerns the collection, assimilation, and analysis of the fisheries database to determine the true status and trends of the fisheries resources. As mentioned earlier, landings statistics are often improperly used to indicate resource trends. Unfortunately, they do not accurately reflect the true stock trends over time. As a result, differing opinions arise over the true status of the resources in the estuary. Much alarm has been raised in recent years about declines in the fishery resources. It is unclear, however, whether the resources have, in fact, declined. No doubt certain species, valuable to the estuary, have declined, such as striped bass. In many cases, individual fishermen's catches have decreased due to a number of factors, some of which may be competition from other fishermen and increases in total fishing effort. However, no comprehensive analyses have been conducted to accurately determine the overall status of the stocks. Until improved information and analyses are available to determine the status and trends of the fisheries resources, there will be constant debate about what direction management actions should take. Clearly, an effort must be made to determine the true status of the resources.

Compared to other states, North Carolina allows a wide variety of fishing activities with relatively little regulation. Access to the resource is not only unlimited, but in many respects is encouraged. As a result, the Albemarle-Pamlico estuarine system is fished very intensively, often resulting in conflicts over resource utilization or fishing space. Large numbers of people fish both commercially and recreationally for a wide variety of species utilizing diverse types of gear. In addition, many people fish commercially on a part-time basis to supplement their regular income. All of this activity occurs in an estuary which also serves as a highly productive nursery habitat for fisheries resources. Such intense utilization, combined with the need to protect essential habitats and resources, can result in highly volatile management situations, both perceived and real.

As discussed earlier, the principal fisheries in the estuary involve both fixed gears, such as crab pots, pound nets, and gill nets, and movable gear, such as shrimp trawls and long haul seines. Intense use of crab pots in an area precludes trawlers or seines from working the same area. Often, prime fishing with different gear for different species involves the same area; this often results in conflicts over allocation of the space available to each fishery. Towed gear has been displaced in some areas by fixed gear and fixed gear is occasionally destroyed by towed gear; real conflicts have ensued. As utilization of the estuary increases, these conflicts will probably intensify. Efforts to resolve gear conflicts center around negotiating with the user groups rather than imposing new regulations. When necessary, however, regulations to separate gears spatially with areal restrictions have been enacted by the MFC.

User conflicts sometimes occur among different commercial harvesting sectors of the same fishery. Crab potters compete with crab trawlers for the same resource, while conflicts among shrimp trawlers sometimes involves competition between large boats and small boats for both resource and area. Such conflicts are also likely to become more numerous as the use of the estuary increases. This situation leads to a growing concern over how many users and how much effort can be supported by the estuary's resources. Very few restrictions or limits are placed on the various commercial gears used and, for a modest fee, commercial access to the resource is unlimited. There are no fees at all for recreational fishing with hook-and-line. Can the estuary continue to support an ever-increasing level of fishing effort and still produce economically viable harvests and quality recreational experiences? Clearly, limits on the amount of gear or effort, or possibly limited entry to commercial fisheries, must be considered for the future.

There is a growing conflict between recreational and commercial fishermen. As noted earlier, recreational fishermen and commercial fishermen fish for many of the same species. Recreational interests are becoming concerned over the large harvests by commercial fishermen and over the use of fishing methods which may negatively affect the habitat as well as. Conflicts between fishing groups and property owners or businesses have also intensified in recent years. Citizens have complained that fishing gears near their property impede access to their property, damage their property, or decrease aesthetic values. Piers and docks, on the other hand, may take space formerly utilized for commercial or recreational fishing. As use of the coastal area increases, these conflicts will intensify.

Public policy-makers must recognize that, like agriculture, commercial fishing is a basic food producer, providing products for consumers and productive employment for thousands of North Carolinians and, like agriculture, commercial fishermen are being severely impacted by environmental degradation, loss of productive areas, and economic factors. Specific policies have been developed at the state and federal levels addressing protection and maintenance of the "family farm." Similar policies may be appropriate for North Carolina's commercial fishermen, especially those who rely so heavily on the estuarine resources. If developed, such policies must consider the needs of the recreational sector and ensure fair allocation of fishing opportunities.

North Carolina's estuarine system can continue to produce resources for sport and commercial fishermen alike, but harvest quantities and access may have to be restricted. Tourists flock to coastal seafood restaurants to eat "fresh local seafood." Without clean, productive waters fished by local commercial fishermen, "fresh local seafood" will not be available to consumers. To maintain commercial fishing and its way of life, commercial fishermen must adopt modern technology to harvest target species and release non-target fish. Policy-makers must seriously consider limiting entry to the commercial fisheries in order to ensure: (1) the availability of stocks for harvest by all fishermen, (2) the economic viability of commercial fishing, (3) the continued supply of seafood for consumers, and (4) allocation of fishing opportunities and resources for anglers. Commercial fishermen will have to approach their work much more as regulated small businessmen, realizing that success cannot be guaranteed in a competitive environment. At the same time, recreational fishermen must emphasize the sporting aspects of their avocation and place less importance on harvesting large numbers of fish. Catch-and-release and quality aspects of fishing will have to become more important.

North Carolina's appointed and elected officials must critically examine the coastal fisheries in the very near future and make informed, conscious decisions on the future of the fisheries. Change is underway, and, if not guided, will likely result in future conditions which do not satisfy commercial fishermen, anglers, consumers, or government officials.

Another major management issue involves the use of fishing gears such as trawls, clam kicking, long haul seining, and dredging, which may damage or degrade the habitat and/or result in significant by-catches. Towed gear sweeps the bottom and suspends sediments, potentially impacting benthic organisms. Methods, such as oyster and clam dredging and clam kicking, dig directly into bottom

sediments, disturbing the bottom habitat, especially such habitats as seagrass meadows. Regulations of the MFC prohibit use of dredges and kicking gear in grass beds, but enforcement is extremely difficult. The catch by such methods is largely non-selective and can produce large amounts of by-catch if care is not taken. The by-catch issue has been studied for many years (Higgins and Pearson 1928; Lunz et al. 1951; Roelofs 1950; Fahy 1965a,b; Brown and McCoy 1969; and Wolff 1972). In estuarine areas, the by-catch may be composed largely of juvenile fish and crustaceans utilizing the estuary as a nursery area. Fish naturally suffer high mortality as larvae and juveniles, and the impact on overall stock levels of mortality of juveniles from fishing is unknown. Stationary methods of fishing, such as gill nets and pound nets, generally have a by-catch component, as well. Mounting public concern will require that these issues receive careful consideration; fishing practices will have to become more selective and reduce by-catch.

An important concern of managers and fishermen alike is the ability of the fisheries habitats to sustain production of the resource. Clearly, without such productive habitats the fisheries would not exist. Another problem concerns identifying the major factors controlling overall production of the resources. Fishermen (both commercial and recreational) are relatively easy to regulate and are often blamed for problems with the resource. Fishermen, in turn, often contend that pollution and other habitat and environmental problems are responsible for declines in the fisheries. Yet, eliminating sources of pollutants throughout the 30,000 square mile watershed is extremely difficult, expensive, and time-consuming. All users must assume responsibility for their actions and be willing to take necessary steps to limit their impacts rather than continuing unproductive "finger pointing."

H. CONCLUSIONS AND RECOMMENDATIONS

H. 1. Habitat Protection

A healthy productive habitat is absolutely essential for providing fisheries resources for commercial and recreational harvesters alike. The North Carolina Marine Fisheries Commission (MFC) is responsible for harvest regulations, while the North Carolina Coastal Resources Commission (CRC) and the North Carolina Environmental Management Commission (EMC) regulate land use and water use, respectively, which determine the quality of the aquatic habitat. In order to ensure that CRC and EMC policies and regulations contribute to a healthy coastal environment, formal coordination among the three commissions should be established on a continuing basis. Similarly, formal coordination to protect and improve coastal habitat should be initiated among the three state agencies which conduct the day-to-day work of the three commissions: Division of Marine Fisheries (DMF), Division of Coastal Management (DCM), and Division of Environmental Management (DEM).

H. 2. Data Collection

Analysis of the DMF data gathering programs by Street and Phalen (1990) indicates that DMF conducts strong programs to collect biological fisheries-dependent data. Environmental data collection is minimal. Collection of fisheries-independent data is increasing with the survey in the Albemarle-Pamlico estuarine system and the cooperative interstate SEAMAP program in the ocean. Landings statistics are probably adequate at the state level for commercial data, but are weak at the waterbody level, the level of accuracy often needed for analysis. Reliable data for the marine recreational fishery, on a coast-wide basis, have been collected since 1987. The survey primarily directs sampling efforts at marine anglers and, as a result, sampling in upper estuarine areas, such as the Pamlico River, Neuse River, and Albemarle Sound, is very limited. Collection of effort data is improving for both commercial and recreational fisheries.

Changes in commercial licensing would greatly improve collection of statistically valid data at every level. Licenses or permits for specific quantities of gear would provide much-needed estimates of effort. Use of trip tickets for all initial landings sales by commercial fishermen (with copies sent to the DMF) would provide accurate data on catch, water body, gear, and effort. Initiation of gear licenses or permits and commercial trip tickets are recommended and are within the authority of the MFC.

A recreational license would provide a reliable sampling frame for the general recreational survey and for special surveys aimed at specific fisheries not adequately sampled by the general survey. Institution of an individual recreational permit or license for hook-and-line recreational fishing and personal use of commercial gear is also recommended, but would require legislative action.

H. 3. Stock Status

Most of the requisite data for stock assessments are collected (Street and Phalen In Press), the DMF data management system adequately processes the data, and computerized analytical programs are available through the Statistical Analysis System (SAS). The DMF should produce, on a continuing basis, a series of reports on the status of the species of principal concern to recreational and commercial interests in North Carolina for which adequate data do exist. Assessment programs should begin on those important species where data are lacking (blue crabs, white perch, hard clams, etc.).

H. 4. Nature of Commercial Fishing

As total pressure on the habitat and fisheries resources increases, each harvester's potential share of the finite resources diminishes. Commercial fishing is more than a means of making a living for most commercial fishermen; it is a way of life handed down through many generations. Marine recreational fishing has become a major economic factor in the coastal area, as well as an integral part of the lifestyle of a large segment of North Carolina's population. Conflicts between the two segments are growing, along with conflicts within the segments. Both groups must recognize their shared need for healthy habitats and stocks. Commercial fishermen must recognize the angler's need for access to fishing grounds and accept as reasonable his expectation of a quality fishing experience. Anglers must recognize that commercial fishermen must make reasonable economic returns on their investments of time and equipment in order to support their families and that consumers demand a choice of fishery products in the marketplace.

Commercial fishermen need to emphasize product quality and efficiency, and eliminate waste in their harvest practices. They must conduct themselves as small, independent businessmen. In recognition of the importance of commercial fishermen as basic food producers for consumers, similar to farmers, the General Assembly should consider enacting policies to protect commercial fishermen and commercial fishing, similar to those protecting family farmers.

For most fisheries, the effort employed probably greatly exceeds that needed to harvest the amount a given stock can annually produce and still remain productive. Such over-capitalization potentially endangers the biological integrity of the stocks and are economically inefficient. Because commercial fishermen have no guarantee of future stock availability, they often seek short-term harvest advantages with little or no consideration of the future. Conflicts and economic hardship are the inevitable result. The General Assembly should grant the MFC the authority to institute licensing regulation, including systems for limiting entry into selected fisheries in order to promote stock stability, economic stability, and reasonable allocation among competing commercial and recreational fishing interests.

Imposition of limited entry would be a drastic approach to solving various problems within target fisheries. Other, more conventional means should be utilized prior to use of limited entry, such as size limits, creel limits, quotas, seasonal closures, gear restrictions, and areal closures.

H. 5. Selective Fishing

Neither the fish stocks nor the harvesters can afford wasteful harvest practices. Excessive by-catch represents economic waste in harvesting, handling, energy use, and wear-and-tear on gear and vessels. To an unknown degree, excessive by-catch also represents biological and economic waste in that some portion of the discarded catch could have been captured later when larger in size and/or could have contributed to stock maintenance or growth through reproduction. In cooperation with commercial fishermen and the University of North Carolina Sea Grant College Program, DMF should institute a long-term program aimed at development of fishing gear which captures target species and sizes while releasing unharmed non-target species and/or sizes of fish. Work is needed on trawls, gill nets, pound nets, long-haul seines, and pots.

H. 6. Recreational Fishing

Just as commercial fishermen must change their historic behavior patterns in light of the realities of stock availability, environmental conditions, the needs of other resource users, and changing economic conditions, so, too, must anglers change some of their approaches to their sport and methods of fishing. The "sport" of fishing must receive greater emphasis among all anglers. Assuming commercial fishermen are placed under the types of controls discussed above, anglers must accept their share of the responsibility for maintenance of stocks and habitat. Their numbers, both of individuals and vessels, greatly exceed those of commercial fishermen. Collectively, recreational fishermen probably have greater impacts on many stocks and habitats than any other group. Success in harvesting fish will have to receive less emphasis, while catch-and-release fishing should receive much greater emphasis.

Sale of their catch by many recreational fishermen creates competition and ill-will among many commercial fishermen. Recall again the food-producing role of commercial fishing and farming, and recognize that hunters are not allowed to sell game in competition with livestock and poultry farmers. Hunters do not recoup costs of their recreation through sales; neither should anglers be allowed to do so.

H. 7. Aquatic Resource Education

Some public schools provide brief introductions to marine science at various grade levels. The North Carolina Aquariums provide excellent programs at their three facilities for visitors from the general public and organized groups, they hold workshops for teachers, and they conduct some other outreach activities. The staff of the North Carolina Maritime Museum also conducts educational activities in their area of expertise. The most ambitious aquatic resources work is the new education program of the North Carolina Wildlife Resources Commission (WRC), designed to encompass a number of activities aimed at school children, resource users, and the general public. However, coastal resources are not emphasized. The DMF published a bimonthly newsletter, presents educational displays at the annual North Carolina State Fair, and assigns staff to give talks to various groups on request. There is, however, no coordination in presentation of educational services concerning coastal resources.

The DMF should initiate a coordinated, coherent aquatic resources education program emphasizing coastal resources. The program should include activities aimed at resource users and the general public, including displays, videos, pamphlets, and slide programs. Assistance should be provided to the WRC,

the Aquariums, and the Maritime Museum to enhance the existing education programs aimed at teachers and students.

For all target groups, emphasis is needed on conservation, ethics, man's impacts on natural resources, impacts of solid waste and pollution on the habitat, and similar topics.

H. 8. Fishery Management Plans

The DMF and MFC conduct their management work on a very wide range of species and problems. Many decisions are made in short time frames with much less information available than the DMF and MFC would like to have. Although the various DMF research and monitoring programs are quite comprehensive, information is not always available in a timely manner or presented in a comprehensive fashion. The reasons for regulatory actions of the MFC and the DMF are frequently controversial, and seem unjustified to various interest groups. The roles of various state and federal agencies are frequently unclear to the public. Neither the MFC nor the DMF has issued general statements of goals and objectives for overall management, nor for any specific fishery or species.

In order to bring together coherent statements of goals, objectives, available and needed information, problem definition, and regulatory needs, the DMF and MFC should conduct a continuing program of preparing, publishing, and revising state fishery management plans for the species of importance to North Carolina's commercial and recreational fishermen.

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V. HUMAN ENVIRONMENT

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A. INTRODUCTION

Estuaries are important natural resources. In addition to supporting a wide range of wildlife, fish species, and complementary resources, they contribute in important ways to the economy of the coastal region. The Albemarle-Pamlico estuarine system is one of North Carolina's most dynamic regions. Many of the counties within the study area are undergoing tremendous changes in population, economic structure and land use. Some of these changes are positive. For example, historically "depressed" regions have experienced an increase of economic activity (e.g., tourism, or resort development). However, many of these alterations have caused serious environmental degradation to the resource base of the Albemarle-Pamlico ecosystems. The majority of these environmental problems arise from human activities in and around these systems. Human activities affect specific resources within the A/P region, (e.g., water quality and recreational aesthetics). These activities, and the subsequent alterations within the system, are most realized when the changes in environmental factors affect other human activities, (i.e., conflicts among competing human uses). Finding realistic, workable methods to mediate conflicts between human uses of the estuaries is one of the challenges now facing North Carolina's citizens (NC NRCD 1987).

The successful management of the A/P estuarine system depends upon the understanding of how human activities affect the natural resource system. Indeed, one of the stated purposes of the A/P Study is to expand relevant knowledge about the impact of human uses upon the physical, biological and social systems of the Albemarle-Pamlico ecosystems (NC NRCD 1987).

Since human activities have been shown to have a profound effect on the A/P system, natural resource managers must consider how human activities have changed and will continue to change within the estuarine system. These activities can be as straightforward as land conversion, population increases, or an increase in livestock production. Some changes are both economic and social in nature. These include modifications in legislation, economic structure, and educational programs. An analysis of these trends, both past and future, is an important step in the formulation of a management plan for the A/P Estuarine System. The purpose of this chapter is to examine the "status and trends" of human activities that directly, and in some cases indirectly, affect the environmental quality of the A/P system.

The activities associated with the Albemarle-Pamlico estuarine system are classified into two broad components. The first is the direct use of estuarine resources. Direct use can involve extractive and non-extractive resource activities supported by the A/P system. An example of an extractive activity is the recreational and commercial fishing industry. The fishing industry is dependent upon the continued health and productivity of the fisheries supported by the estuaries; therefore, harvesting fish stocks can affect the future yield available from those fish populations. Non-extractive activities include other forms of recreation and tourism which are supported by the estuarine systems. The quality of these activities often depends upon the quality of the estuary, but they are described as non-extractive because they do not directly affect the quality of the resource.

Both extractive and non-extractive activities depend on the estuaries and the associated resources they support. Recreational swimming and boating certainly could take place in other areas -- freshwater or other coastal locations -- but they would very likely be different experiences. Consequently, both are dependent upon the character of the Albemarle-Pamlico estuarine system.

Other activities such as agriculture or timber production, while not necessarily dependent upon the A/P estuarine system, certainly have the potential to effect both the extractive and non-extractive activities discussed above. These activities can be classified as indirect uses of the estuary. Indirect uses correspond to economic and social activities that occur within the coastal counties bordering the sounds as well as the inland counties which comprise the estuarine drainage area. In many cases these activities could take place anywhere. An important research task that cannot be addressed with existing

information would be to model the reasons these activities occur in specific locations. In some cases, the answers involve combinations of locational advantages, the use of unique resources such as phosphate ore, or simply the servicing of local populations. These factors often explain, in a retrospective fashion, why certain activities have taken place at particular geographic locations; however, this is certainly not the case for all the sectors involved.

Developing a trends analysis of the direct and indirect uses of the Albemarle-Pamlico estuarine system is important for two reasons. Trend analysis provides resource managers and policy-makers information for appraising what is likely to happen to estuarine activities in the absence of policy intervention. Of course, this first use should be recognized as an indicator of future patterns rather than a prediction. Any examination of past patterns of activity is simply a history of events. It reflects what happened during the conditions of the past period. Prediction requires that we understand why those conditions fostered the observed pattern; nonetheless, in most cases, trends analysis can be used as indicators of future patterns for short time horizons. Dramatic changes in human activities and subsequent changes in socio-economic activities take time. Therefore, one can expect a certain amount of persistence in a well-established trend. If the historical record does not display a clear pattern of change, projections of anything but status quo conditions is much more difficult.

The second potential use of a trends analysis is anticipating how current or future policies may affect the direct and indirect activities using (or affecting) the A/P system. Here the insight provided by past trends is more problematic, precisely because the policy actions imply changes and the analysis is intended to evaluate how they will modify the evolution of these economic and social activities. At best, such information is suggestive. Here we clearly have a need for analyses that focus on the factors that motivated the patterns of activities. This point will be addressed in the final section.

A third component of the discussion of trends will be some consideration of the interconnections between direct and indirect uses of the estuarine resource. Policy-makers at virtually every level of government recognize that certain economic activities have a propagation or developmental effect. That is, the location of a large manufacturing complex or the introduction of an important tourism-based activity has a spill-over effect generating a wide range of other complementary economic activities. This arises because of the interconnections required to maintain the level of activity in each sector. Clearly, the interconnections will vary depending upon the sectors involved. In these cases, increases in the direct uses, extractive and non-extractive, will give rise to increased activity in other sectors; and they in turn will require a more modest increase in yet new sectors. This "multiplier effect" explains why using simple trends to anticipate the nature and composition of future economic or social activities can be difficult.

Thus, this trends analysis is intended to provide information which may increase understanding of likely patterns of use in the future. Indeed, an important message flows from the analysis of the data: that patterns of activities can be highly variable and change from one time interval to the next. This reinforces the need for a clear understanding of the interconnections between economic and social activities and the motivations for changes in their levels and geographic locations.

Equally important, government policy at both the local and state level influences the patterns and types of economic activities taking place in any region. These policies can range from local taxes and zoning ordinances to state mandated land use controls such as those in the North Carolina Coastal Area Management Act of 1974 (CAMA) which requires comprehensive regional resource management for the state's 20 coastal counties. Other factors affecting social and economic activities include the availability of roads, low-cost electric power, skilled labor, and other geographically specific resources that can be influenced by policy decisions. Developing a predictive evaluation of what is likely to take place in coastal counties requires substantive research on these activities. No program of research of this type has taken place in North Carolina. The Albemarle-Pamlico Estuarine Study did not initiate or have access to such a program of research. Consequently, what has been developed here is a short-term appraisal based on existing information only.

The analysis that follows is divided into three broad sections. Following this introduction, we discuss the trends in direct activities (including demographic, economic and social activities) influencing the A/P study area. Next we discuss the indirect activities and the interconnections between direct and indirect uses that are likely to influence the economic and social activities currently taking place in the area. Finally, the last section discusses the need for evaluation in developing a more comprehensive analysis of future patterns of economic and social activities in the Albemarle-Pamlico region.

A. 1. Background

The 36 counties which comprise the North Carolina A/P study area represent a diverse mix of land uses, growth patterns and economic development. There are also 16 counties in Virginia that are included in the complete A/P geographic delineation.

Tschetter (1989) classified the North Carolina study area as non-metropolitan. He notes that the only exceptions are Wake County, in the western part of the study area, and Currituck County, which is part of the Norfolk-Virginia Metropolitan Service Area (MSA) (Tschetter 1989). (Note: Tschetter did not include Durham, Orange or Person counties in his study; however, based on his classification, Orange and Durham would also be considered metropolitan). All of the Virginia counties would be classified non-metropolitan except the Norfolk-Virginia Beach area.

Although the geographic area covered by the A/P Study has been defined in previous chapters, our data analysis and discussion will be based on Paul Tschetter's study area characterization. Tschetter divides the North Carolina counties into three groups: coastline, sound, and drainage basin counties. He separates the 14 counties that directly border on the Albemarle and/or Pamlico sounds into two categories. The 4 counties which border the Atlantic Ocean and A/P sounds (Carteret, Currituck, Dare and Hyde) are referred to as "coastline" counties. The 10 counties bordering the sounds (Beaufort, Bertie, Camden, Chowan, Craven, Pamlico, Pasquotank, Perquimans, Tyrrell and Washington) are referred to as "sound" counties. Since the remaining counties are included in the drainage basins for the sounds, Tschetter refers to these 22 counties as "drainage basin" counties. These include Durham, Edgecombe, Franklin, Gates, Granville, Greene, Halifax, Hertford, Johnston, Jones, Lenoir, Martin, Nash, Northampton, Orange, Person, Pitt, Vance, Wake, Warren, Wayne, and Wilson. The distinction between coastline, sound, and drainage basin counties has some important value when specific data are presented.

A. 2. Data Analysis

Although there are hundreds of human activities that can have an affect on the A/P system, several specific activities were analyzed in this study because it was believed that they have the potential to cause the greatest environmental impacts on the estuarine systems. Some activities, such as agriculture or mining, have both direct and indirect effects that can be measured or determined sufficiently through historical and/or current data. Others such as public sector activity or social structure are less easily determined, although these activities certainly affect the study area in numerous ways.

Data indicative of current status and historical trends were obtained for the majority of the activities; however, data availability varied depending upon the activity. Projections are included for a few activities such as population growth.

For the majority of the activities, data are presented for the entire North Carolina study area (36 counties). In some instances data are presented for individual counties or for a specific group of

counties, (e.g., coastline counties). State-wide averages are used as a control or for comparison in select analyses.

Although 16 Virginia counties are included in the study area, the majority of the data is presented only for the North Carolina counties. Population data are analyzed for all 52 counties in the A/P estuarine system.

B. POPULATION

Analyzing population data is a simple method for determining an area's growth and for comparing different counties or regions of the state. Growth can translate into both economic and social benefits and has a direct connection to the economic well-being of a locality. Generally, population growth benefits businesses, creates jobs and expands the local tax base (Center for Public Service 1988).

Growth can also have detrimental effects. Population growth can strain natural resources and public facilities. Growth can lead to severe environmental consequences such as degraded water quality from overloaded or improperly operated wastewater treatment systems. Localities undergoing rapid development are likely to face challenges that include not only the expansion of government services such as roads or school systems but also planning for growth so that its effect may be favorable to the community and to the surrounding environment.

Since increasing population is the basis for many of the changes in the individual socio-economic divisions, population data could arguably be assigned to either the direct or indirect categories of activities affecting the estuarine system. To provide the reader with an overview of growth within the A/P study area, a discussion of population follows.

B. 1. Permanent Population

The initial population analysis addresses permanent population fluctuations within the A/P study area. Population data will be presented for the entire study area, both North Carolina and Virginia. To further address population changes, specific counties classified according to Tschetter's categories are analyzed. Permanent population data were obtained from "North Carolina Population Projections: 1988-2010", "Virginia Population Projections 2000", and US Census Bureau, Department of Commerce 1991.

Permanent population for the entire A/P Study area has continued to increase since 1970 and is expected to reach almost 3 million by the year 2000 (Figure V-1). When the population data is shown as a growth rate, or percentage change, further trends are evident. During the 1970s, North Carolina counties within the study area grew at a rate below the state-wide average, but in the 1980s those counties exceeded the state-wide average growth rate of 12.7% by 3.6%. The growth rate for A/P counties in Virginia, indicates that the counties within the study area are growing at a rate much greater than the state-wide growth rate. Growth during the 1970s and 80s exceeded state-wide rates. Population growth is projected to slow but still exceed the state-wide rate during the 1990s (Figure V-1).

From 1970 to 1980, 7 of the North Carolina A/P counties and 2 of the Virginia A/P counties exceeded the state-wide growth rates. The rates of growth varied from slightly above 1 to almost 6 times (in Dare County) the state-wide averages. During the same period, six counties lost population. From 1980 to 1990, 11 of the North Carolina A/P counties exceeded state-wide growth rates and 10 lost population. Of the three fastest growing counties in North Carolina, two are in the A/P study area. From 1990 to 2000, 14 counties are expected to experience growth exceeding that of their respective

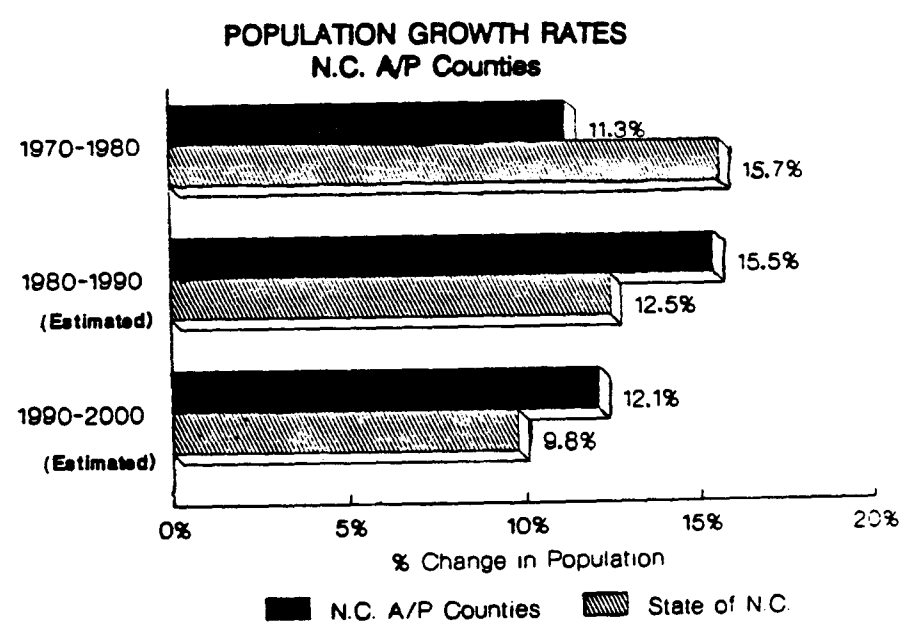
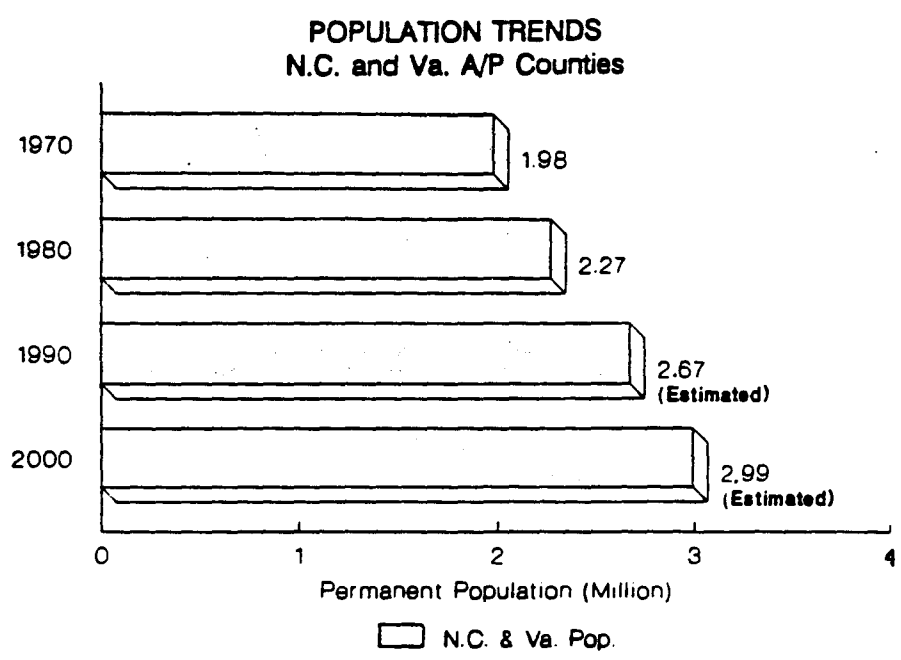


Figure V-1. Population Trends and Growth Rates: NC and VA A/P Counties. From NC OSBM 1988; VA. DPM 1986.

states, and 8 counties are expected to lose population. Twelve of the 14 growth counties are located in North Carolina.

These data indicate that population growth rates vary from county to county as well as regionally. To further illustrate this point, select counties from Tschetter's classification were analyzed. The "coastline" counties of North Carolina are experiencing tremendous growth in permanent populations. Currituck, Dare, and Carteret Counties are among the fastest growing counties in North Carolina. During the 1970s, the growth rate in Dare County exceeded the state-wide rate by almost 6 times, Currituck's exceeded that of the state by almost 4 times, and Carteret's exceeded that of the state by almost 2 times. During the 1980s Dare County was the fastest growing county in the state (70%), growing 5.5 times faster than the state-wide average; Currituck County grew 1.9 times faster than the state average; and Carteret County grew 2.2 times faster than the state average. While these general trends are projected to continue throughout the next decade, growth rates are expected to slow. Hyde County is a coastline county, but it has been losing population during the past decade and is expected to continue to do so throughout the next.

Of the "sound" counties, Beaufort County grew at a rate slightly below that of the state in the 1970s, and significantly below the state in the 1980s and the 1990s. The growth rate of Craven County was below that of the state during the 1970s, but the county surpassed the state's growth rate by 2% in the 1980s. Rapid growth is expected to continue.

There are mixed growth rates for the "drainage basin" counties. Durham and Johnston Counties grew at a rate slightly below that of the state during the 1970s; however, both exceeded the state's growth rate during the 1980s. Wake County grew at twice the state's growth rate during the 1970s, and is now the third fastest growing county in the state (40.5% since 1980). Nash County grew at a rate below the state average in the 1970s, but exceeded the state average in the 1980s. Pitt County grew at double the state's growth rate during the 1970s; its growth rate slowed in the 1980s but continued to exceed the state average. Population growth in Wayne County equalled the state's growth during the 1970s, but it is projected to grow at a rate well below that of the state during the 1980s and lose population during the 1990s.

Finally, two counties in Virginia, selected for analysis, also present a picture of contrasting growth rates. Currently, the City of Virginia Beach is the second fastest growing area in the state. During the 1960s Virginia Beach grew in population 102%; during the 1970s it grew 52% (3.5 times greater than the state-wide growth); during the 1980s it grew 49.9%, more than triple Virginia's growth rate. Southampton County lost population during the 1970s and 1980s and is projected to experience little or no growth during the remainder of this century. Overall, the Virginia portion of the A/P Study area grew 29.4% in the 1980s, with the vast majority of that growth occurring in the eastern and coastal regions.

In summary, the A/P study area is projected to have a population of approximately 3 million by 2000. The growth rate of the North Carolina portion of the A/P study area is expected to slightly exceed state-wide levels until the year 2000. Growth rates tended to be highest in the coastline counties. Craven County was the fastest growing sound county. Among the drainage basin counties, Wake, Durham, Orange and Pitt had the highest growth rates over the 30 year study period. In Virginia, a similar pattern is projected. Virginia Beach, on the coast, is experiencing the greatest increases in population.

A/P counties in North Carolina and Virginia, are experiencing varying levels of population growth. Some of these counties are among the fastest growing counties in their respective states. Dare County and Virginia Beach are experiencing growth rates that are exceeding state-wide levels by 5.5 and 3.0 times, respectively. Numerous counties in the study area, however, are experiencing growth rates well below state levels and many counties are losing permanent residents. The counties which lost population

or are projected to lose population, are predominantly rural, isolated, and heavily dependent upon agriculture (Tschetter, 1989).

B. 2. Recreational Population

Determination of population data for the Albemarle-Pamlico estuarine system area would seem rather straightforward using census data. US Census population data, however, refer only to permanent residents, i.e., people for whom a particular community is their usual place of residence (Tschetter 1989). One of the unique features of the study area is that many locations attract significant temporary populations of tourists. "This temporary population often has a tremendous impact on the demand for housing, food services, health care, water, electricity, waste disposal, police and fire protection, and many other public and private goods and services" (Tschetter 1989). Recreational or seasonal populations, therefore, present serious problems to city and regional managers and must certainly be considered in the development and implementation of management plans for the Albemarle-Pamlico estuarine system area.

In 1989, Paul D. Tschetter completed a study that analyzed the effects of recreational activities on the populations of the North Carolina A/P counties. In that study, Tschetter calculated the total number of persons who were in residence due to recreational activities. Recreational residence was based on occupancy in seasonal units, such as hotels and motels, campgrounds, and marinas. He combined these estimates with published permanent population to obtain the "peak seasonal population"; i.e., the total population if all of the units in the housing infrastructure were occupied. "Such peak populations are approached for specific times during the summer season; e.g., Memorial Day weekend, Fourth of July weekend, and Labor Day weekend" (Tschetter 1989). The data presented in that study are the basis for the following graphical presentations. The 1987 seasonal data are presented for the "coastline" counties as well as for select "sound" counties. The graphs illustrate the total population, (i.e., seasonal population plus permanent population) versus the permanent population (Figure V-2).

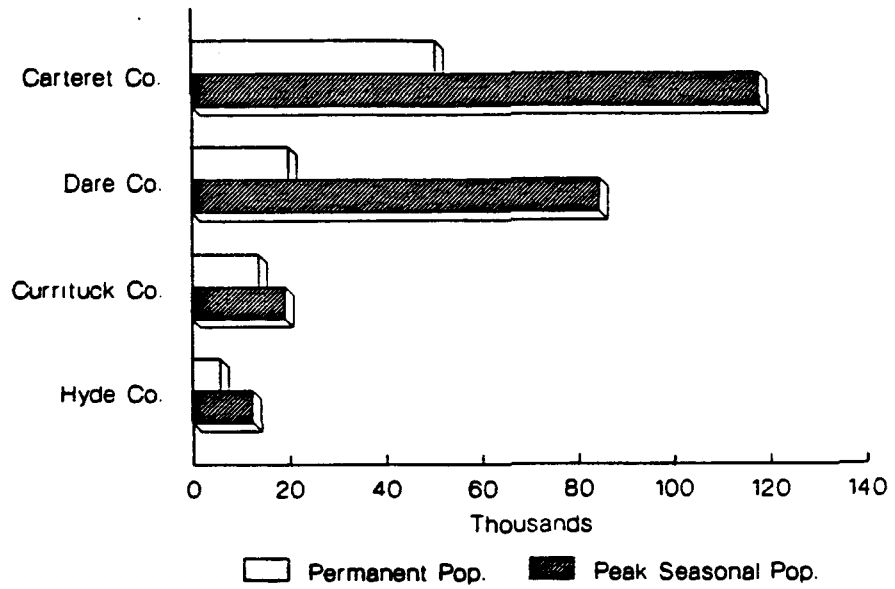
The coastal counties in Virginia and North Carolina experience tremendous population fluctuations due to the influx of recreational residents. The population of Dare County is over 4 times that of the permanent population during the peak seasonal day in 1987. The other coastline counties experienced similar increases. The population of Carteret County increased 2.3 times while the populations of Hyde and Currituck counties increased 2.15 and 1.4 times, respectively. These estimates do not include day visitors, those who visit the area but do not stay overnight. According to a 1985 NC Department of Transportation study conducted in Nags Head, a Dare County beach community, the municipality's population increased over 18 times that of the permanent population during the peak seasonal day (Dare County 1988).

The effects of recreational visitation varies from county to county in the "sound" counties. In Craven County, the fastest growing sound county, the peak seasonal population increase was more than equal to that of the permanent population. Pamlico County experienced an increase of greater than 1.5 times, and Beaufort County's seasonal population was slightly greater than 1.2 times the resident population. Pasquotank County, however, experienced only a slight increase in population during the same period.

Seasonal visitors have only a slight effect on the "drainage basin" counties. Warren County, a county experiencing little permanent population growth, experienced the largest seasonal increase, slightly over 1.3 times that of the resident population. Northampton also experienced a slight increase, but Pitt and Edgecombe Counties realized little, if any, population increase from recreational visitors.

In summary, peak seasonal visitors have a great effect on populations in some A/P counties; however, the effect varies from region to region. As one would expect, the counties that border the ocean and

"Coastline Counties"



"Sound Counties"

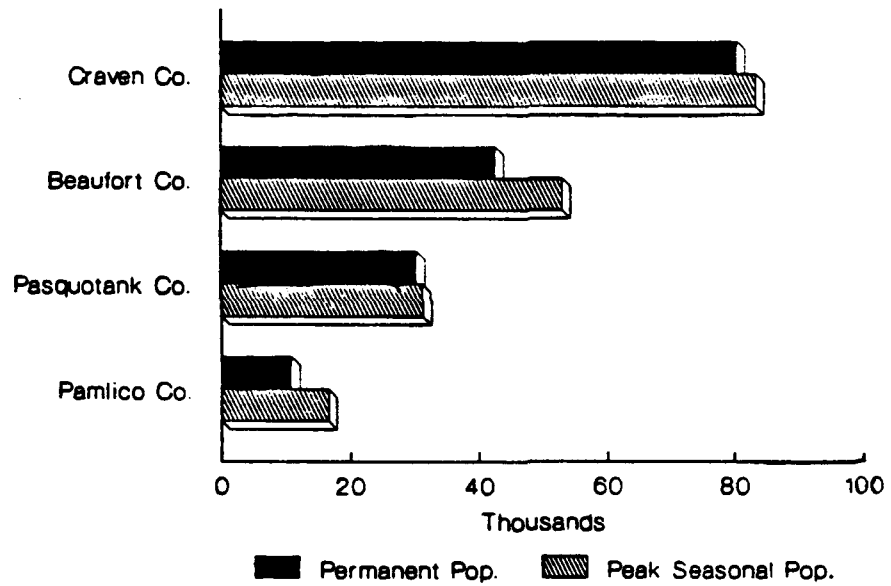


Figure V-2. Peak Seasonal vs. Permanent Population in A/P Counties. From Tschetter 1989.

sounds are experiencing the greatest population fluctuations due to tourism. In many of these counties, public facilities such as wastewater treatment, roads, and water supply systems are being taxed to the limit. The "drainage basin" counties experience little or no effect from seasonal visitors.

C. DIRECT USES OF THE ESTUARINE RESOURCES

It is important to realize that little in the way of actual research has been conducted in terms of analyzing and describing this component from any social science perspective. The few studies that do exist have primarily depended on secondary source material, such as landings and value statistics. This section will depend on these secondary sources of data and provide brief discussions based on a few primary studies done in the area, as well as similar studies in other areas.

C. 1. Commercial Fishing

The commercial fishing sector is marked by a high degree of seasonal variation by species (see Chapter IV). The species important to most fishermen in this study area include blue crab, bay scallops, shrimp, oysters, clams, herring, flounder and other finfish. Because analyses of landings and associated values are discussed in other sections they will be examined only briefly here.

Due to the seasonal nature of species availability, commercial fishermen must often be involved in the harvesting of more than one species. This can involve multiple gears, multiple vessels, or geographical movement. Johnson and Orbach 1989, for example, provide a case study of North Carolina commercial fishermen's adaptation to this seasonality that involves interstate migrations.

Total dockside value of commercial landings for the state, excluding industrial landings (e.g., menhaden), increased from approximately \$24 million to around \$65 million over the 10 year period from 1977 to 1987 (Figure V-3). Although there appears to be an almost three-fold increase in the nominal value of landings over this period, one must be cautious in interpreting this trend. The late 1970s and early 1980s were periods of considerable inflation. Adjusting for this inflation and displaying the value of landings in constant 1967 dollars shows that the value of landings has remained relatively constant or has declined slightly over this period. Most of the increases observed are accounted for by only a few of the counties (i.e., Pamlico, Dare, and Carteret).

Another important aspect of the trends in commercial fishing activities is the number and character of participants. Figure V-4 shows trends in the number of vessel licenses by type between 1977 and 1987. These designations are based on the applicants' own evaluations. Full-time commercial fishermen are defined as those individuals who earn over 50% of their income from commercial fishing, while the part-time designation refers to earnings less than 50%. Pleasure designation is defined as the use of commercial gear without the sale of harvested species. The graph indicates a very slight increase in the number of full-time vessels; though, it is unlikely that this pattern would be judged to be a statistically significant trend. Over the same period, the number of part-time vessels has declined steadily. Pleasure vessel licenses increased dramatically from 1977 to 1982 and dropped sharply in 1983. This is due to a change in the state license fee structure for this designation instituted in 1983. Many pleasure vessel licenses were probably bought by the increasing number of tourists or summer residents frequenting the area. The increase in fees seems to have limited the growth in "recreational" fishing of this type. It should be noted, however, that the self-defining character of these distinctions limits our ability to evaluate these trends.

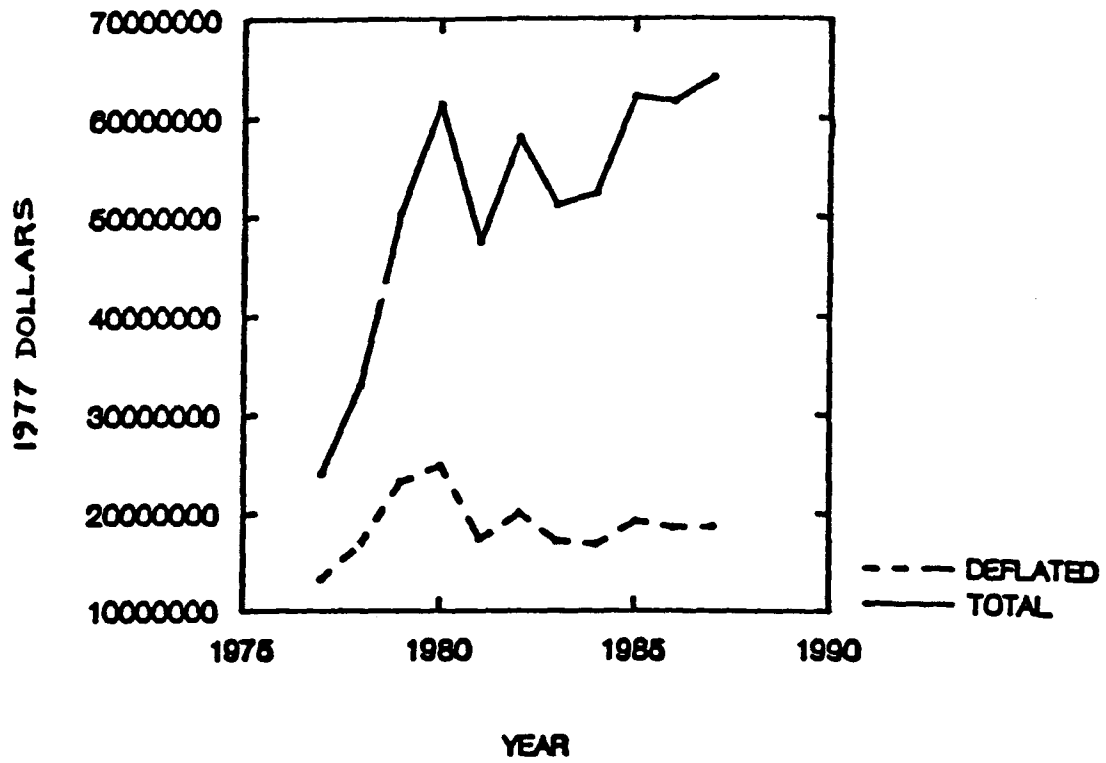


Figure V-3. Total and Deflated (to 1967 Dollars) Annual Dockside Values for NC Commercial Fisheries. From Division of Marine Fisheries Data.

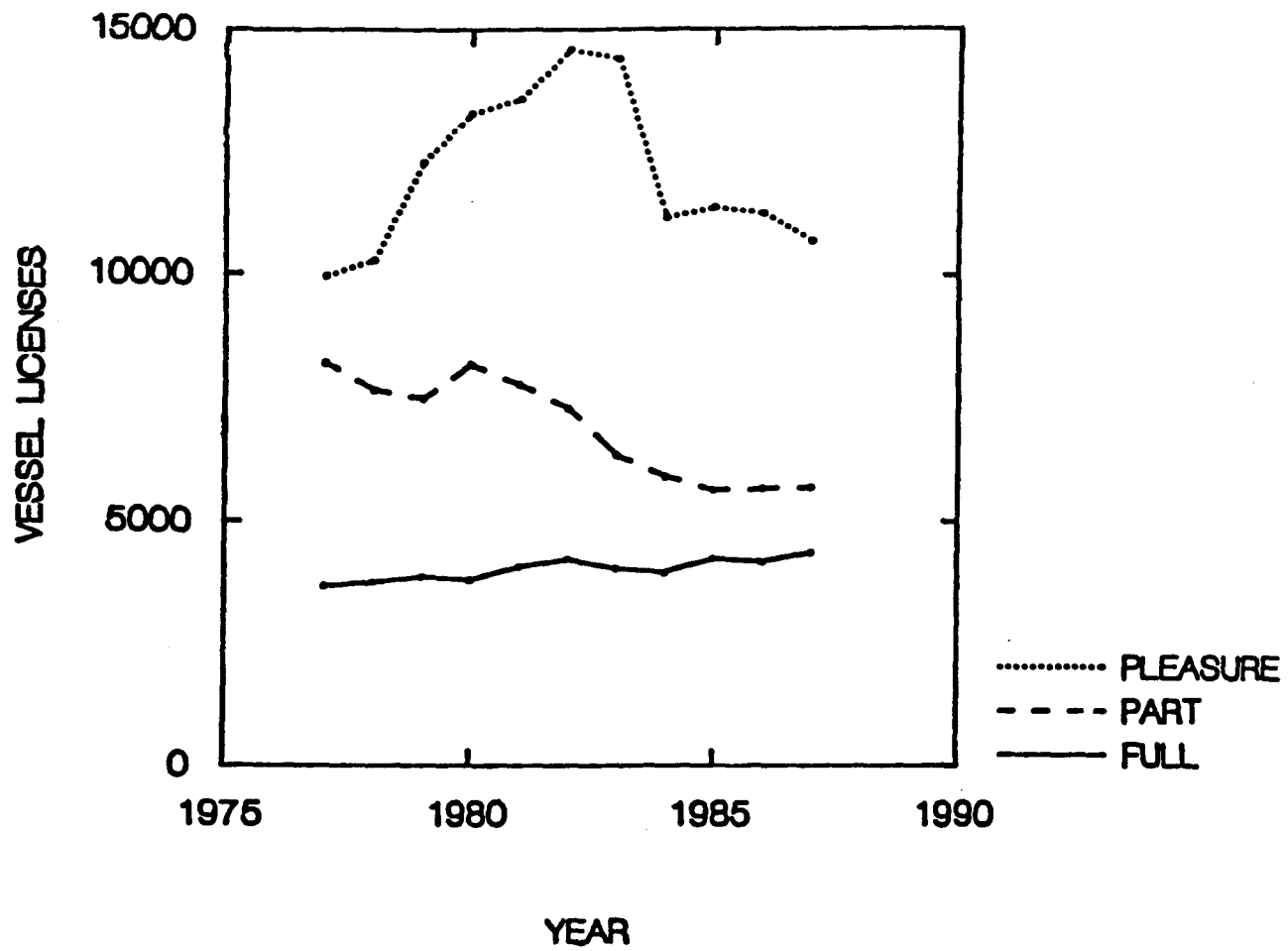


Figure V-4. Total Annual Vessel Licenses in the A/P Counties. From NC Division of Marine Fisheries.

Carteret County has the largest number of fishermen who consider themselves full-time commercial. Similar to the overall trend in commercial licenses, each of three major counties indicates relatively constant participation over the 11-year time period.

In order to develop a crude estimate of the size of the operations, dockside values per full-time vessel for each of the three counties were calculated. Carteret has many small-scale operators, while Pamlico County has fewer large operators. As the next section outlines, this pattern corresponds to the size of processing operations in each of the counties.

C. 2. Seafood Processing

Fishermen are not the only direct users of the estuarine resources who must deal with the seasonal nature of fishing. Processors and processing labor must also contend with such variations. According to 1982 National Marine Fisheries Service statistics, North Carolina had 112 processing plants employing 2,918 seasonal and 1,886 year-round workers. Thus, 60% of the seafood processing labor force was seasonal.

Most of the seafood processing industry in this area consists of small, independently owned and operated fish houses. Griffith (1988) contends that the official employment figures of this labor intensive industry would be higher if one considered the nature of recruitment based on kinship and the lack of good record-keeping. The number of processing firms in each of the counties in the study area for which data is available is shown in Table V-1. Approximately 75% of the 112 processing firms found in North Carolina are found within the study area. By far, the most active counties for processing, outside of the Core Sound/Carteret County area, are Pamlico and Beaufort. The most important species for these firms is blue crab, followed by finfish, oysters, scallops and shrimp. In general, the processing of seafood is labor intensive. According to Griffith (1988), rural counties such as Pamlico are, therefore, important sources of low-wage labor.

TABLE V-1: Number of Processing Firms by Coastal County. From Griffith (1988).

| | Oysters | Scallops | Crab | Shrimp | Fish | Total |
|------------|---------|----------|------|--------|------|-------|
| Carteret | 2 | 10 | 5 | 6 | 8 | 31 |
| Pamlico | 5 | 4 | 11 | 1 | 9 | 29 |
| Beaufort | | | 8 | | 3 | 11 |
| Hyde | 4 | | 3 | | | 7 |
| Bertie | | | 1 | | 1 | 2 |
| Chowan | | | | | 2 | 2 |
| Pasquotank | | | 1 | | 1 | 2 |
| Craven | | | 1 | | | 1 |
| Totals | 11 | 14 | 30 | 7 | 24 | 85 |

Based on an analysis of the North Carolina seafood processing industry, Griffith (1988) provides a three-fold classification of seafood processing, each having different characteristics and implications for policy and management. Based on this classification, firms and workers in the study area outside of Core Sound have predominantly: (1) stability throughout the year, (2) low-dependence on local sources of seafood, (3) typical employer/employee relations, (4) no direct ties between the processing and harvesting sectors, (5) little control over processing, (6) pay based on wages or piece work, (7) low reliability of labor, and (8) a primarily black work force. Such characteristics demonstrate that the bulk of the seafood processing workers in the area outside of Core Sound are heavily reliant on processors and have few employment alternatives. Households to which seafood workers belong must often supplement low wages with transfer payments (Griffith 1988).

The second "category", which incorporates the Carteret County/Core Sound area, is different from the other areas in terms of processing activities for two reasons: (1) this area has the largest number of processors, particularly processors dealing in shrimp and scallops and (2) there tends to be more variance in the form and types of processing labor found here.

Although some of this labor can be characterized in a manner similar to that of Pamlico and Beaufort Counties, particularly in western Carteret County, there are two distinct forms. The dealers in this area can be characterized as having: (1) high-seasonality and dependence on local sources of seafood, (2) familial or community-based worker/employer relations, (3) strong relations between harvesting and processing sectors, (4) more worker control over the processed product, (5) much self-employment or unpaid family participation, and (6) a highly reliable, primarily white, labor force.

Griffith (1988) describes a third category of seafood processors, also found in the Carteret County/Core Sound area that is exemplified by the menhaden processing industry. This form of processing can be characterized as having (1) moderate seasonal dependence, (2) some degree of local dependence on the source of seafood, (3) conventional employer/employee relations, (4) strong ties between harvesting and processing labor, (5) no worker control over the processed products, (6) remuneration based on wages or piece work, and (7) a highly reliable, primarily black labor force. The processors themselves can be characterized as primarily family-owned and operated businesses in which kinship networks play an important role in management, marketing, and labor recruitment. Most of the processing plants are involved in more than one species, with much of the final product being shipped outside the state to such places as Baltimore and New York.

In summary, it is important to note that the seafood processing industry is an important part of the local economies for these coastal counties, particularly as a source of employment for poorer, rural coastal residents. The nature of the economic relations between workers, state and county agencies, and owners are critical determinants of future expansion of the industry under current economic conditions. Whereas workers may welcome alternative forms of employment in the area (i.e., they may have little occupational commitment to seafood processing), the unskilled nature of the labor force seems to imply they will have a dependence on the seafood processing sector for their employment, at least in the near future.

It is also important to anticipate how changes in the quality of the estuary or management policies might affect the levels of harvesting permitted by commercial operators (e.g., plans allocating access to particular fisheries between commercial and recreational fishermen, or limiting seasons, etc.) and impact the seafood processing industry. Firms having less dependency on local sources of seafood for processing naturally will experience more limited impacts. More seasonal operations depending on local sources of seafood can be expected to be dramatically affected. These impacts may be exacerbated for processing operations that are linked directly to harvesting operations through kinship and community ties. Thus, family businesses that involve both harvesting and processing could be more substantially affected by any reductions in harvest levels.

C. 3. Recreational Fishing

Although some recent attempts have been made to estimate and model the demand for recreational fishing in the sounds of North Carolina (Smith and Palmquist 1989), no comprehensive attempt has been made to describe the aggregate value of recreational fishing trips and their associated economic impacts in North Carolina. Moreover, because the Smith-Palmquist analysis is the first such study of demands in this region, there is little basis for evaluating the trends in demands for marine fishing.

The Smith-Palmquist (1989) research primarily focused on estimating the value recreationists would place on improving the quality of marine fishing. Their research focused on boat fishermen and measured quality in terms of an average catch rate (i.e., fish caught per unit of fishing effort) as a proxy measure of fish stocks. They applied a modified version of the travel cost recreational demand model for areas within the Albemarle-Pamlico estuarine system based on the fishermen's launch sites. These sites were treated as distinct recreation sites, and the demands for them were estimated using a 1981-82 survey of sport fishermen sponsored by the NC Sea Grant Program (see Johnson et al. 1986 for a description of these data and the survey procedures). Consumer surplus is the difference between what an individual would be willing to pay for a good or service and what he or she actually pays (directly or indirectly). It is the conventional economic measure of the value or benefit consumers derive in excess of what they actually pay, explicitly or implicitly, for a good or service. Smith and Palmquist (1989) developed estimates for the consumer surplus per fishing trip and for the increase in value per trip that would be generated by a 25% improvement in the catch rate (Table V-2).

TABLE V-2: Benefit Estimates for Sport-Fishing Trips in the Albemarle-Pamlico Sounds. From Smith and Palmquist (1989).

| Demand Model | <u>Consumer Surplus Per Trip</u> | | <u>Increment to Consumer Surplus Per Trip 25% Increase in Catch Rate</u> | |
|------------------|----------------------------------|-----------|--|-----------|
| | (1982 \$) | (1967 \$) | (1982 \$) | (1967 \$) |
| Outer Banks Site | \$163 | \$56 | \$24 | \$8 |
| Pamlico Site | \$103 | \$36 | \$9 | \$3 |

Estimates are rounded to the nearest dollar.

Smith and Palmquist (1989) use the estimates of the value of quality improvements to construct a benefit-quality elasticity estimate, i.e., the percentage increase in the benefits derived from a fishing trip to the Albemarle-Pamlico region in response to a percentage increase in quality. Their estimates imply a range of .40 to .60 for this elasticity, depending on the model and assumptions used. This would imply that a 10% increase in quality would yield a 4 to 6% increase in the benefits per trip.

While this work offers one component of the information necessary to gauge the economic effects of non-extractive uses of the sounds, it is incomplete. It focuses on one type of fishermen, neglects, other types of recreation supported by the estuary, and considers only a single time period. These findings offer no insight into trends, fail to consider the gains or losses non-users experience from knowledge of improvements or deteriorations in the quality or character of the estuary, and provide no insight into the indirect impacts of these activities on other sectors.

Some of these shortcomings can be partially remedied with information recently available in the "1985 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation" from the US Fish and Wildlife Service. This survey indicates that annual participation in saltwater fishing has been growing at a statistically significant rate of over 3% nationally since 1965 (the first year their survey results are reported). Saltwater fishing is clearly an important recreational activity in North Carolina. Table V-3 highlights some of the results of the 1985 North Carolina saltwater fishing survey. Nearly 800,000 people are estimated to have participated in the activity in 1985; over 60% of those were state residents.

TABLE V-3. Saltwater Fishing in North Carolina in 1985. From US Fish and Wildlife Service.

| Fishing Trips, Days of Fishing, Fishermen, Mode of Fishing | Residents | Nonresidents |
|---|-----------|--------------|
| <u>Total</u> | | |
| Fishermen | 503.9 | 294.2 |
| Trips | 3973.2 | 738.6 |
| Days of Fishing | 5401.8 | 1568.0 |
| Average One Way Distance Per Trip (Miles) | 82.5 | 163.0 |
| <u>Type of Water Used (Fishermen)</u> | | |
| Deep Sea (more than 3 miles off shore) | 86.3 | 42.0 |
| Off Shore (.2 to 3 miles off shore) | 52.8 | 41.7 |
| Surf and Shore (less than .2 miles off shore) | 344.7 | 207.3 |
| Sounds and Bays | 151.7 | 68.6 |
| Tidal Rivers and Streams | 39.3 | --- |
| <u>Mode of Fishing (Fishermen)</u> | | |
| Party or Charter Boat | 33.2 | 46.2 |
| Private or Rental Boat | 147.1 | 65.4 |
| Surf or Shore | 293.5 | 174.0 |
| Bridge, Pier, or Jetty | 287.1 | 95.7 |

Except where indicated, these statistics are in thousands of individuals.

Another indirect source of information is boat ownership. Based on an analysis of boat registration in North Carolina, Johnson and Perdue (1986) found 196,269 boats registered in 1984. 45,926 were registered in the coastal counties and a large number (e.g., 12,249 in Wake County) are registered in inland counties near the study area, indicating that great numbers of boats have access to the sounds and their tributaries. It is difficult to determine any trends in registration over the last two decades due to changing registration requirements in that same period. Nevertheless, in the 14-year period from 1970 to 1984, boat registration in the state grew 167%; boat registration within the 22 coastal counties grew 155%. The bulk of this growth occurred inland or in southeastern counties. It is difficult to know how many of these boats are used in recreational fishing, particularly in the area of Carteret County. Based on the estimates of marina operators, Johnson and Perdue (1986) found that an average of 59.1% of the boats in coastal North Carolina marinas were used in recreational fishing. In addition, 22% of the marina operators estimated that all the boats in their marinas were used almost exclusively for recreational fishing.

Using the same data that Smith and Palmquist (1989) employed in their analysis of the demand for sport-fishing, Johnson et al. (1986) reported that most of the recreational boat fishermen interviewed between 1981 and 1982 were not residents of the site county. 28.4% of the boat fishermen interviewed were from the "sound" counties and 52.1% were residents of counties within a three-county radius of the sound, (e.g. "drainage basin" counties). Thus, less than 20% of the fishermen would be estimated to have come from outside this area. By contrast, 45.2% of all bank or fixed structure fishermen came from "sound" counties and 68.7% came from "drainage basin" counties.

In summary, saltwater fishing is an important recreational activity in the study area. An economic model by Smith and Palmquist (1989) indicated that as the quality of fishing increases (improved catches) fishermen are willing to pay more for recreational activities. Boat registration has increased substantially during the 1970s and 1980s. While most of this growth has occurred in the inland counties, many of these boats have access to the study area. The majority of the boats owned in the state are used in some way for recreational fishing. A large percentage of the recreational fishermen are residents of the "drainage basin" counties.

C. 4. Marinas

As the number of boats increase in an area there is a corresponding increase in the number of marinas (any facility which can service and accommodate one or more boats) that support boating activities (gas pumping, repair work, sewage removal, etc.). There have been two recent studies involving marinas, one by Tschetter (1989) and one by the NC Division of Coastal Management (DCM) (1991). Taken together, these reports present a comprehensive overview of marina activities and they are the basis of the following analysis.

There was a significant increase in marina activity during the period 1970 to 1987. "Marinas existed in 9 of the 36 A/P counties in 1970 and in 11 counties by 1980. There were 32 marinas in 1970, 62 marinas in 1980, and 91 marinas in 1987" (Tschetter 1989). The number of marinas has increased by 184% since 1970 however, the development of marinas has been limited to counties which directly border the Albemarle or Pamlico Sounds (Tschetter 1989).

Between 1980 and 1987 DCM granted permits for the construction of 50 new marinas within the A/P study region. Forty-seven of the 50 permits were in five counties: Carteret (23), Craven (7), Pamlico (7), Beaufort (6), and Dare (4) (DCM 1991). Between 1980 and 1987 there was a 36.6% increase in the actual number of boat slips within the A/P region. An examination of the 1987 marina data indicate that over 51% of the marinas were located in just two counties, Carteret and Beaufort (Figure V-5). These two counties plus Dare, Pamlico and Craven Counties account for over 80% of the marinas in the A/P study area. According to Tschetter, this is because all of these counties border Albemarle or

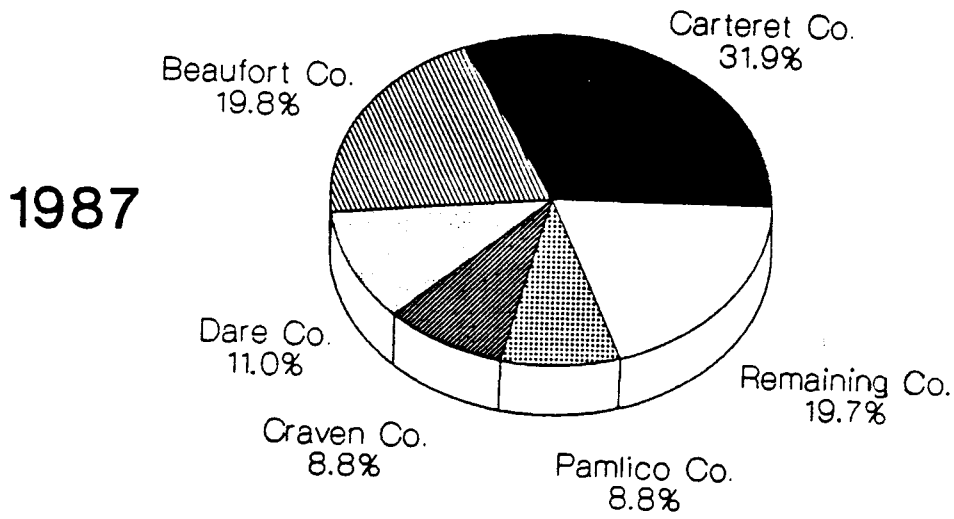


Figure V-5. Distribution by County (1987) of Marinas in the A/P Study Area. From Tschetter (1989).

Pamlico Sound and are on the Atlantic Intracoastal Waterway (Tschetter 1989). Marinas are an important source of jobs and revenues for the counties bordering the sounds. A study by Johnson and Perdue (1986) indicated that in 1985 total revenues from marinas were estimated to be \$23,427,000, of which \$3,950,000 was the result of tourist or non-resident activities. The same study noted that among marina operators interviewed in 1985, 42.8% had added employees in the years from 1982 to 1985, accounting for a growth of between 10 and 30% of the full-time equivalents as of 1985 (Johnson and Perdue 1986).

There is a strong link between marinas and the recreational fishing industry. In 1985, \$13,750,000 of the total marina revenues were attributed to recreational fishing activities. On average, boats engaged in recreational fishing accounted for 59.1% of the boats found in marinas. Commercial boats (e.g., commercial fishing and charter/headboats) accounted for 7.9% of the boats found in the surveyed marinas. Over half the marinas surveyed estimated that over 60% of their business was attributable to recreational fishing (Johnson and Perdue 1986).

In summary, the number of marinas found in the A/P study area is increasing; however, the majority of the marinas are found in 5 counties. As the recreational boat industry continues to grow in popularity, marina construction will likely increase to meet increased demand. Marinas provide substantial revenues for many of the counties that border the sounds. Recreational fishing activities are an important component of the marina industry.

A study of marinas conducted by the NC Division of Environmental Management (DEM) (1990) entitled "North Carolina Coastal Marinas: Water Quality Assessment" did not suggest any widespread water quality degradation due to marina operation. In 1988 DEM estimated that 1.089 acres of estuarine waters in the A/P region were impaired by marinas (NC DEM 1989), an area that represents

only roughly 1% of the impaired estuarine waters. Marina activities can, however, have substantial impacts on local water and sediment quality, particularly in small rivers or embayments (Nichols et al. 1990). Riggs (In Press), in a study of the organic-rich muds of the Neuse River Estuary, found significant enrichment of many trace elements and heavy metals in the sediments around coastal marinas. The nearly automatic closure of shellfish beds in the immediate vicinity of marinas indicates that problems of fecal coliform contamination from marinas are common. Marinas can also spark controversy over issues of access to and ownership of public trust bottomland area.

C. 5. Travel and Tourism

Already one of the larger industries in North Carolina, tourism is likely to grow within the next few years to become the largest, surpassing textiles, furniture, and tobacco. In this analysis, tourism is considered a direct use of the estuarine system, although it is a non-extractive activity. As noted previously in the population section, travel-related activities can cause an area's population to increase many times that of the permanent population. Seasonal populations can create economic havoc with businesses, and pose significant problems for the small local governments found throughout the A/P Study area. The tremendous influx of seasonal residents represents a severe strain on the carrying capacity of the sound and coastal areas. The seasonal populations, however, represent a much needed boost for the economies of this region. This point is addressed in the following discussion.

More than 227,000 North Carolinians, or 10% of privately employed workers in North Carolina are employed in businesses that serve tourists. Other areas of the economy, retail trade for example, also owe a portion of their earnings to travel-related expenditures. Estimates indicate that each travel dollar yields another 79 cents of spending as it moves through the economy of the state. If one includes secondary economic impacts, travel related jobs support another 112,000 jobs state-wide (Armingeon 1989). Much of the growth in the tourism industry is occurring in the A/P study area. Dare County, the state's leader in the tourism industry, generated \$18,607 in travel revenues for each permanent resident in 1986. When that figure is compared to the state's average, \$805 per resident, it is easy to realize the economic impact that tourism is having on the coastal area (Armingeon 1989).

The first analysis of this section will focus on the A/P counties' share of the total travel and tourism expenditures from 1971 to 1987. The next analysis will examine the impact of travel and tourism on the economies of select A/P counties. The Division of Travel and Tourism, in the North Carolina Department of Commerce, compiles and publishes an annual travel study. Those reports provided the data for this discussion. In order to adjust for inflation, revenues were adjusted to 1984 dollars (1984=100) using the Consumer Price Index (CPI).

Tourism provides substantial revenues to the A/P counties. In 1982, revenues exceeded \$1.1 billion (32.4% of the state total) in the 36 A/P counties (Figure V-6) and in 1987 revenues exceeded \$1.8 billion (32.3% of the state total) (Figure V-6). The financial impacts from tourism, however, vary from county to county. Dare and Currituck Counties, both "coastline" counties, present a contrasting picture. The revenues of Dare County have increased steadily since 1971, reaching \$347 million in 1987. Travel revenues in Currituck County have fluctuated and are well below those of neighboring Dare County.

Tourism revenues in the "sound" counties are well below those of Dare County. Beaufort County experienced decreasing revenues during the study period, although the county's 1987 total was double that of Currituck County. Revenues in Pamlico County were well below those of other counties, although they appear to be increasing. If the recreational boating industry continues to increase, tourism revenues in the "sound" counties should also increase.

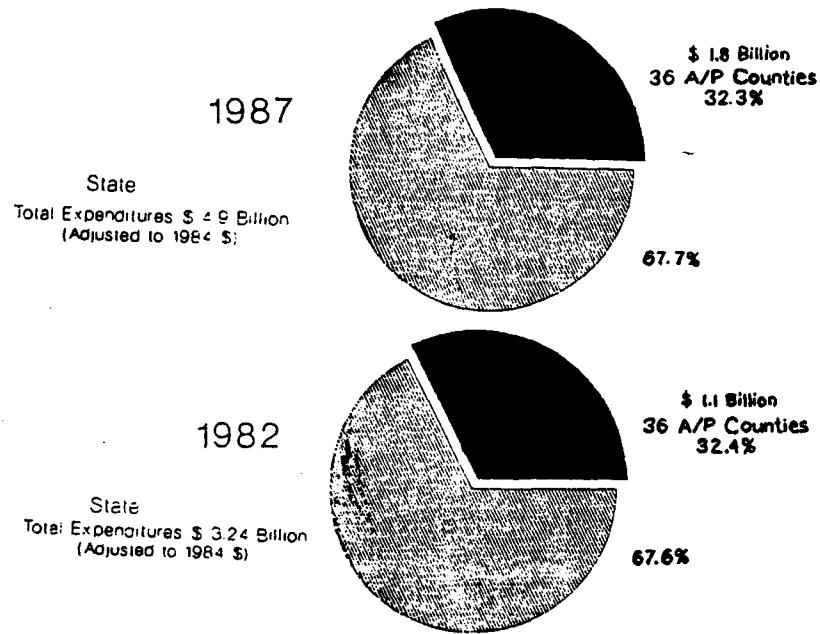


Figure V-6. Travel and Tourism Expenditures in NC A/P counties, 1982 vs. 1987. From NC Travel and Tourism (1983, 1988).

One would expect the tourism revenues in "drainage basin" counties to be well below those of the traditional recreational areas such as Dare and Currituck Counties. This analysis, however, does not support that assumption. Annual travel revenues in Wake County have risen steadily to \$450 million in 1987. Although these revenues do not represent the substantial per capita share as some of the smaller counties, these revenues are important to the local economy. Lenoir County, located midway between the central region of the state and the coast, has also experienced rising travel revenues.

In summary, the travel and tourism industry is an important industry in the A/P study area. In 1987, the share of these revenues in the A/P counties was over 30% of the state's total, representing a \$1.8 billion economic boost to the area. The share of the tourism expenditures vary from county to county, however, it appears that this industry will continue to increase and provide much needed revenues for some of the smaller, rural counties.

D. INDIRECT USES OF THE ESTUARINE RESOURCES

The term "indirect use" does not imply that these human activities cannot seriously affect the environmental quality of the region. To the contrary, many of the indirect uses, while not dependent upon the sounds, have a greater potential for effecting the A/P system than the aforementioned direct uses. One reason is that the magnitude of indirect activities around the sounds is far greater than that of the direct uses.

Measuring the trends in indirect economic and social activities taking place in the study area is a difficult task. As noted at the outset, no systematic programs of research have been in place or are underway to assemble, maintain and analyze these data. Consequently, these efforts have been limited to what could be prepared using readily available data from published sources. An analysis of the trends will consist of two components.

The first component regards the measurement of the real level of economic activities in each of the sectors selected for discussion. For this analysis two types of measures were developed. The first of these is based on annual payroll expenditures reported by standard industrial classification codes by county. The most aggregative one-digit codes were deflated and used to develop a measure of real labor input for many of the indirect activities. Because these sectors are highly aggregated, they will include within them the commercial fishing, seafood processing, marinas, and expenditures on recreation-related equipment, supplies, and services that were discussed as part of the separate consideration of activities directly dependent on the estuary.

In principle, it would be impossible to disaggregate and treat each activity separately by refining the sectoral definitions from one level of one-digit standard industrial classification to the more detailed definitions associated with a higher digit (and therefore finer) classification of industries. This task was beyond the scope of the present exercise. Moreover, the overlap does not markedly detract from our objectives.

The second component regards physical measures of trends in certain activities because many of the indirect uses of the estuarine system, such as agriculture and forestry, are especially difficult to interpret based solely on real payroll trend analysis. These measures are based on historical trends of the indirect activities that surround and/or involve the study area. This analysis is more generalized and deals with factors other than dollar-based economic trends. For example, within the agricultural sector factors such as harvested cropland acreage, livestock production, and fertilizer tonnages are examined. In the forestry sector, woodland acreage and pine plantation acreage are discussed. These general trends, when combined with the economic analysis, presents an accurate picture of human activities that affect the A/P system. These analyses are not all inclusive, nor are they intended to infer a "cause and effect" relationship. Rather they are simply tools to be used by managers in implementing future management schemes for the area.

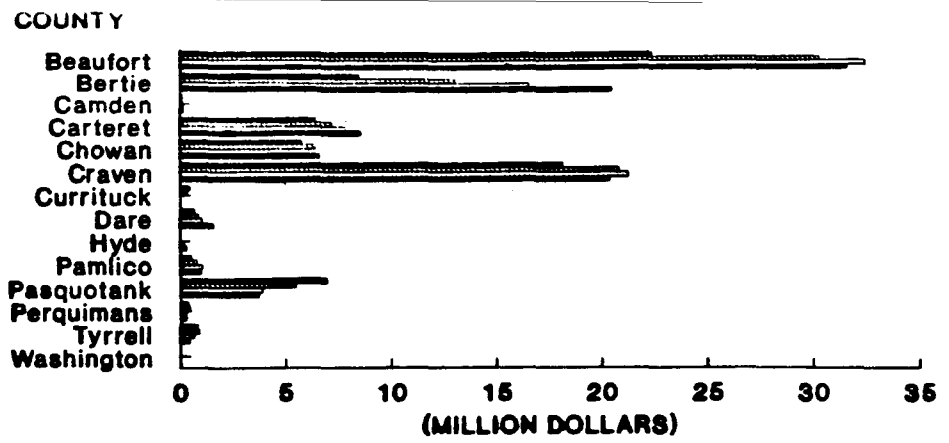
One final note regarding these data. One of the most important factors influencing any activity within the A/P region is rapid population growth. The trends presented here are sensitive to the population base from which the growth takes place. In other words, as population increases many of these trends would mirror this expansion.

D. 1. Real Payroll Trends of Indirect Uses

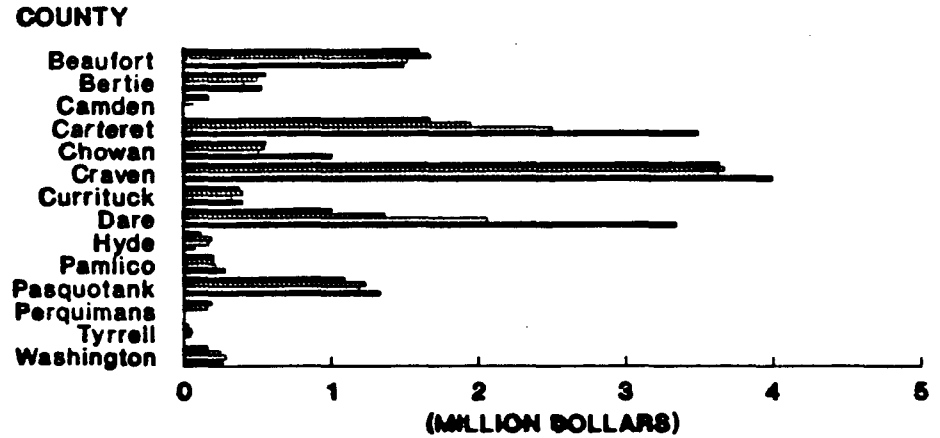
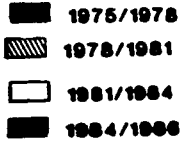
The most readily available and comparable measure of economic activity at the county level is the level of payroll expenditures by sector for each county. These data are available in current dollar terms and reflect (on an annual basis) the expenditures for employment of personnel in each sector. Because inflation will affect the level of wage rates and in turn the dollar expenditures for labor inputs, it is important to adjust these figures for the movement in wage rates over time. This provides an estimate of the level of real activity as reflected by the payroll expenditures in each sector in constant dollar terms.

We developed a specific index of wage movements in North Carolina using the average weekly earnings in the fourth quarter of each year and evaluated payroll expenditures from 1975 to 1986 by sector and county. The statistics reported in Figures V-7 and V-8 are deflated to 1967 dollars based on this index. The definition of the sectors is given in Table V-4. The sources for the information used in

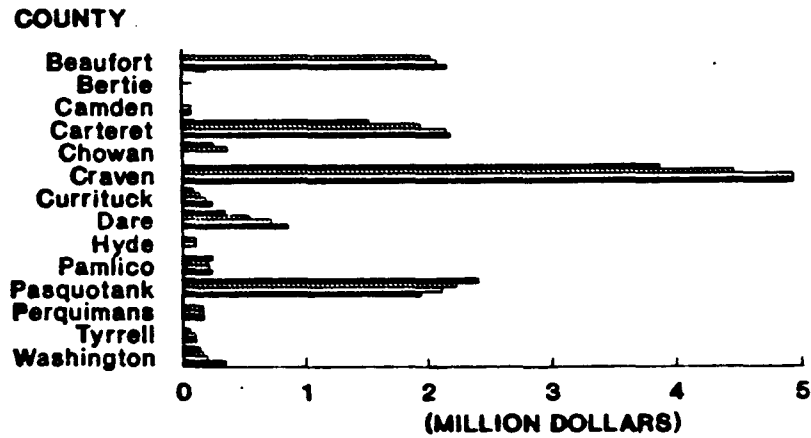
Manufacturing



Construction



Transportation



Wholesale

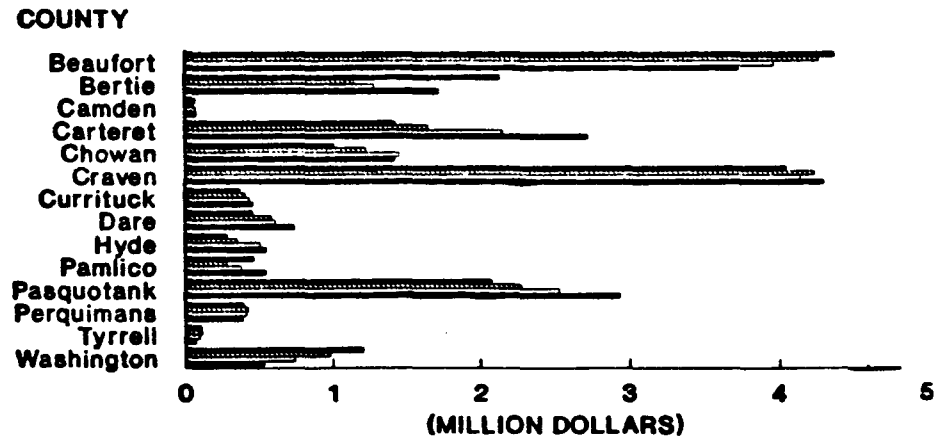
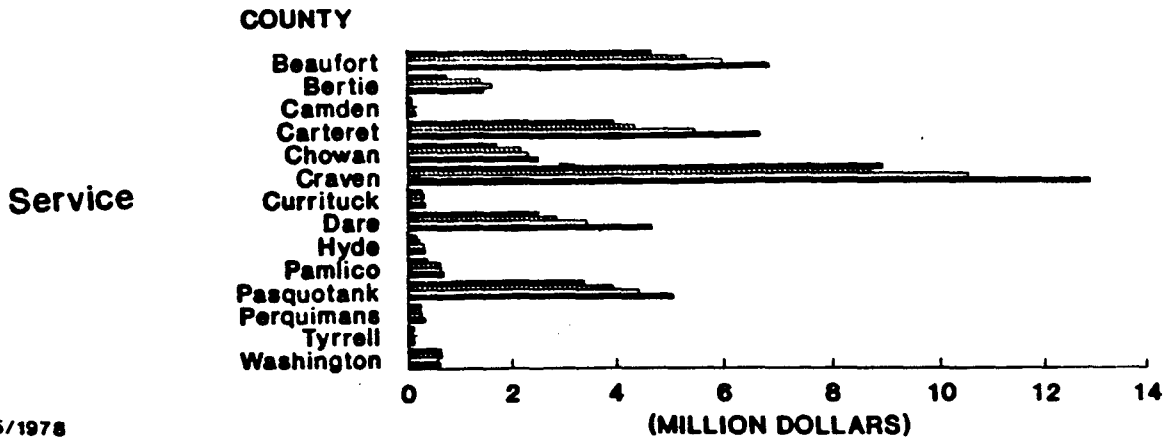
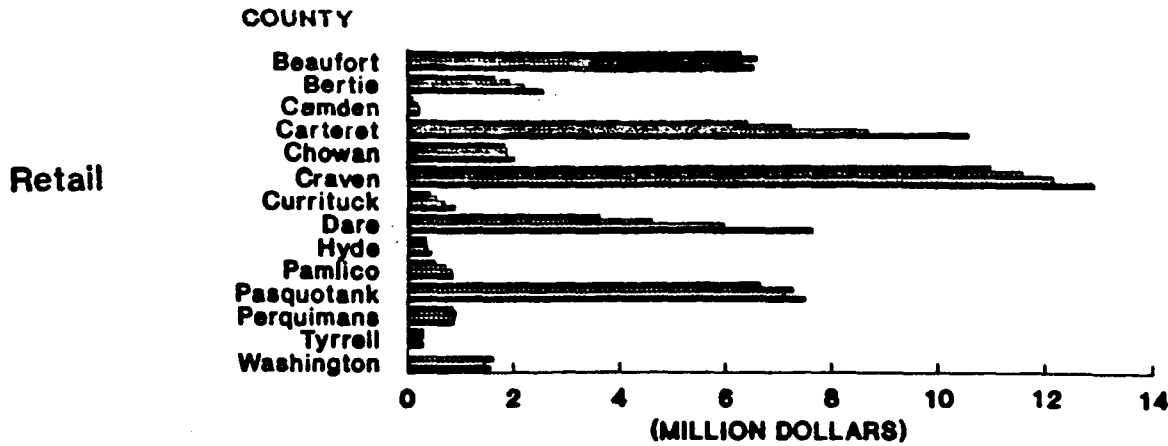


Figure V-7. Average Value of Real Payroll for Manufacturing, Construction, Transportation, and Wholesale Sectors of the Economy in A/P Counties.



■ 1975/1978
 ▨ 1978/1981
 □ 1981/1984
 ■ 1984/1986

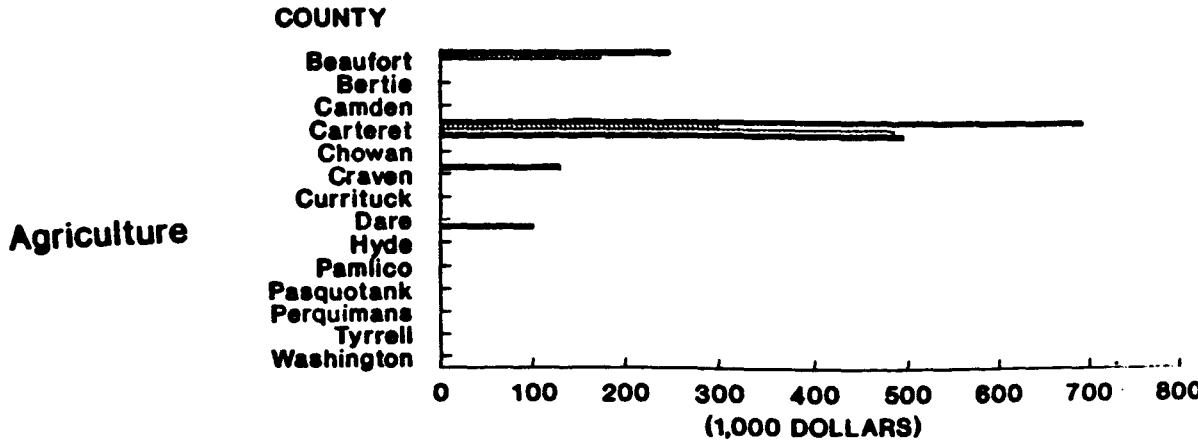
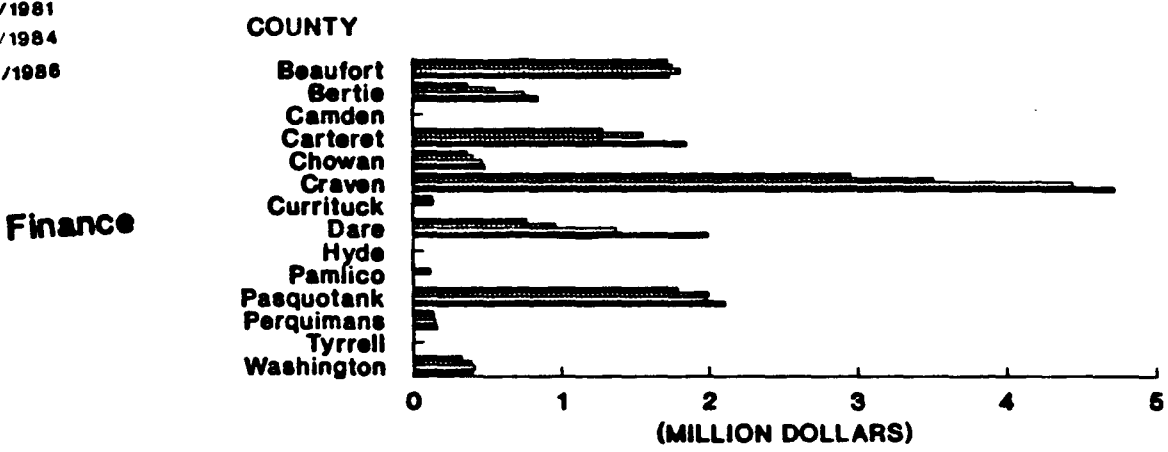


Figure V-8. Average Value of Real Payroll for Retail, Service, Finance and Agriculture Sectors of the Economy in A/P Counties.

TABLE V-4. Definition of Sectors. Office of Management and Budget (1972)

| Sector | Description |
|---------------|---|
| Agriculture | This division includes establishments primarily engaged in agricultural production, forestry, commercial fishing, hunting and trapping, and related services. |
| Construction | This division includes establishments (or kind-of-activity units) primarily engaged in construction. The term "construction" includes new work, additions, alternations, and repairs. Construction activities are generally administered or managed from a relatively fixed place of business, but the actual construction work is performed at one or more different sites which may be dispersed geographically. If a company has more than one relatively fixed place of business from which it undertakes or manages construction activities and for which separate data on the number of employees, payroll, receipts, and other establishment-type records re maintained, each such place of business is considered a separate construction establishment. Each legal entity is considered a separate establishment, even where two or more legal entities carry out construction activities from the same place of business. |
| Manufacturing | This division includes establishments engaged in the mechanical or chemical transformation of materials or substances into new products. These establishments are usually described as plants, factories, or mills, and characteristically use power driven machines and materials handling equipment. Establishments engaged in assembling component parts of manufactured products are also considered manufacturing if the new product is neither a structure nor other fixed improvement. Also included is the blending of materials such as lubricating oils, plastics, resins, or liquors. |
| Transport | This division includes establishments providing to the general public or to other business enterprises passenger and freight transportation, communication services, electricity, gas, steam, water or sanitary services, and the US Postal Service. |
| Wholesale | This division includes establishments or places of business primarily engaged in selling merchandise to retailers; to industrial, commercial, institutional, farm, or professional business users; or to other wholesalers; or acting as agents or brokers in buying merchandise for or selling merchandise to such persons or companies. |
| Retail | This division includes establishments engaged in selling merchandise for personal or household consumption, and rendering services incidental to the sale of the goods. In general, retail establishments are classified by kind of business according to the principal lines of commodities sold (grocers, hardware, etc.), or the usual trade designation (drug store, cigar store, etc.). Some of the important characteristics of retail trade establishments are that: they are usually a places of business and are engaged in activities to attract the general public to buy; they buy or receive and sell merchandise; they may process their products, but such processing is incidental or subordinate to selling; they are considered as retailers; and they sell to customers for personal or household use. Not all of these characteristics need be present, and some are modified by trade practice. |

TABLE V-4. Definition of Sectors (continued)

| | |
|---------|--|
| Finance | This division includes establishments operating primarily in the fields of finance, insurance, and real estate. Finance includes banks and trust companies, credit agencies other than banks, holding (but not predominantly operating) companies, other investment companies, brokers and dealers in securities and commodity contracts, and security and commodity exchanges. Insurance covers carriers of all types of insurance, and insurance agents and brokers. Real estate includes owners, lessors, lessees, buyers, sellers, agents, and developers of real estate. |
| Service | This division includes establishments primarily engaged in providing a wide variety of services for individuals, business and government establishments, and other organizations. Hotels and other lodging places; establishments providing personal, business, repair, and amusement services; health, legal, engineering, and other professional services, educational institutions, membership organizations, and other miscellaneous services are included. Establishments which provide specialized services closely allied to agriculture, mining, transportation, etc., are classified in their respective divisions. |

developing these comparisons is given in the Data Source Bibliography. The values for the wage index to adjust for wage inflation are given in Table V-5. In examining Figures V-7 and V-8, it is important to note the scale on the horizontal axis describing the real level of activity. It switches depending upon the magnitude of the activity between millions of dollars and thousands of dollars.

The most important sector in terms of level of activity in the coastal areas is the manufacturing sector, with the results given in Figure V-7. The most important counties with manufacturing sector activities are Beaufort, Craven, and Bertie. Beaufort County has experienced uneven but progressive growth in the size of real payroll expenditures to over \$30 million (in 1967 dollars) by 1984-86. This represented a slight decline over the 1981-84 period, but was still substantially above levels realized in earlier periods. Craven County demonstrated initial growth between 1975-78 and 1978-81 and relatively stable activity thereafter. Bertie County experienced a more consistent growth rate rising from about \$8 million (in constant dollars terms) to just over \$20 million by the end of this period, making it comparable to the level realized in Craven by 1978-81. The levels of manufacturing activity in the other counties are substantially below those for Beaufort, Craven and Bertie. Carteret, Chowan and Pasquotank Counties experienced much more modest levels of activity, with Carteret and Chowan between \$5 and \$10 million and Pasquotank declining from over \$5 million to about \$3 million (in constant dollar terms) at the end of this period.

Table V-5. Values of Wage Deflator for North Carolina (Base - 1967)

| Year | Wage Deflator (1967 - 1.000) |
|------|---------------------------------|
| 1975 | 1.701 |
| 1978 | 2.074 |
| 1981 | 2.704 |
| 1984 | 3.124 |
| 1986 | 3.438 |

Source of Wage Index: Table C (Average Weekly Earnings per Insured Worker by Quarter and Industry Division) in "Employment and Wages in North Carolina," Fourth Quarter, Labor Market Information Division, Employment Security Commission of North Carolina

The second sector to be considered is the construction sector, which is presented in Figure V-7. Here we find the most dramatic growth rates in the counties experiencing substantial population growth. Carteret and Dare Counties each have over \$3 million in real payroll expenditures by the close of the time period for our analysis. Both represent consistent patterns of growth from 1975 to 1976, with somewhat faster initial growth in Dare County. Of course, Craven County has had the highest level of construction activity, but has experienced little growth in real terms. At the close of the period, there was an increase of \$4 million in real terms. Beaufort County has a fairly steady level of activity around \$1.5 million in real terms, with a slight decline from peak experience in the 1978-81 period. Pasquotank County experienced some slight growth, but the level of real payroll in this sector never exceeded \$1.5 million over the full period of our evaluation. Some growth was experienced toward the end of the

period in Chowan County. In the remaining counties, the value of real payrolls in construction activity is much more limited.

Growth of the payroll in the transportation sector (Figure V-7) is also concentrated. Craven County experienced considerable growth in the transport sector until 1981-84, realizing nearly \$5 million in real payroll, but remaining at that level until the close of the period. Beaufort County has had a relatively steady level of activity as measured by real payroll. Pasquotank County experienced substantial decline from nearly \$2.4 million (in real dollar terms) to under \$2 million by the close of the study period. The data indicate modest increases in the level of real payroll in Dare County following the population growth in that county.

The wholesale sector tracks the level of manufacturing activity which was found to be concentrated in Beaufort and Craven Counties (Figure V-7). However, the level of this activity is steadily declining in Beaufort County from a high exceeding \$4 million (in real dollar terms) in 1975 to below \$2.8 million by the close of our study period. Craven County experienced some growth over the full period, with a slight downturn in 1981-84 and a subsequent recovery to a record level of nearly \$4.5 million at the end of the study period. Carteret, Chowan, and Pasquotank Counties experienced some growth over the period, with Carteret and Pasquotank rising to nearly \$3 million (in real dollar terms) in a steady pattern beginning in 1975. Chowan County increased at a slower pace, with nearly \$1.5 million of real payroll activity in the wholesale sector.

The retail sector (Figure V-8) also tracks population growth and the level of manufacturing activity. This correspondence with population growth is an example of the interdependency mentioned earlier. Of the four counties experiencing the greatest levels of activity by the close of the period, three had either the largest growth in population or high levels of manufacturing activity. Craven County is once again the county with the highest level of activity and displays a consistent growth rate over the period. Carteret County experienced a fast rate of growth from just over \$6 million in real terms in 1975, to nearly \$11 million in 1986. While the levels of activity are not as high in Dare County, the rate of growth appears to correspond to the growth in population, with the closing level of real activity approaching \$8 million. In contrast, while the activity of the manufacturing sector has been largely stable since 1981 in Beaufort County, the retail sector is equally stable. Similarly in Pasquotank County, while construction activity and the transport sector have remained stable or slightly declining, the retail sector has also approximately stable. Other counties have experienced much lower levels of activity. Only Bertie County experienced modest growth over the study period, growth that appears to correspond to the growth of the manufacturing sector.

The service and finance sectors are other cases where we would expect to find activities in support of either population growth or growing levels in the other sectors, and that is exactly what we find on a county-by-county basis. Those experiencing the most dramatic growth in the other sectors, in population, or both, have correspondingly large growth in the service and finance sectors (Figure V-8). The leader for the service sector is Craven County with Beaufort and Carteret Counties distant seconds, and Dare and Pasquotank experiencing steady growth from lower levels. The record is more uneven in the other counties, with Chowan and Bertie experiencing more modest levels of activity in the service sector. For Craven County the level of real activity was nearly double that of Carteret and Beaufort Counties by the end of the study period.

Craven is once again the leader for the finance sector (Figure V-8) with over \$4 million in real payroll by the end of the period. Pasquotank has the second highest level of activity, with nearly comparable levels in Beaufort, Dare and Carteret Counties by the end of the period. Indeed, the record is approximately steady in Beaufort County and somewhat uneven in Carteret County.

The last sector to be considered is agriculture (Figure V-8). Note that only corn, wheat, and soybeans are considered in this analysis and that only those counties exhibiting statistically significant patterns of

growth are recorded. Here the real payroll data suggest a rather small level of economic activity in agriculture for the "coastline" and "sound" counties. Only Carteret County has a high level of activity, and this appears to be declining over time from nearly \$700,000 in real payroll activity at the beginning of the period to under \$500,000 by the end of the period. This is only about 1.5% of the activity measured in these terms attributable to the manufacturing sector in Beaufort County. A pattern of decline is also apparent in the case of Beaufort County, with activity recorded for 1975-78 and 1978-81. Following that, there was nothing large enough to be recorded.

In summary, in the "sound" and "coastline" counties that were analyzed, there are highly concentrated patterns of activity in manufacturing. It also appears that the nature of activities taking place in the coastal zone is moving away from agriculture and forestry activities. Retail, service and finance and supporting activities appear to be more diversified. Construction is concentrated in those counties where population growth or the largest growth in a composite of sectors has occurred.

What do these economic patterns imply for the future? Because the pattern is in many cases mixed, it is difficult to formulate clear-cut expectations. Nonetheless, a few judgments do seem possible with these data. The bulk of the growth in economic activity, to the extent that it is taking place, is concentrated in less than five coastal counties. Craven County appears to be the most consistently high in terms of level of activity and usually in the pattern of growth. Population increases and economic activities do go hand-in-hand. Thus to the extent we have better demographic records than economic records, it is reasonable to assume that the counties experiencing rapid population growth will experience increased economic activities.

This economic analysis has singled out coastal zone counties and broad sectors experiencing growth. All of the counties with high levels of activity (in relative terms) and consistent growth patterns are potentially important contributors to the overall estuarine quality. These impacts have the potential to improve the economic growth of the region, however, as is the case of many human activities, these activities can cause environmental degradation of the sounds.

D. 2. Physical Measures of Indirect Uses

D. 2. a. Agriculture. Agriculture is the largest industry in the 28 counties of the central and northern coastal plain of North Carolina. It accounts for over 40% of North Carolina's gross farm receipts, contains 45% of the state's cropland, 50% of the state's hogs, and 40% of the state's chickens (NC NRCD 1987). Although the environmental impacts of agriculture on the sounds are not well understood, concerns about water quality problems associated with cropland runoff and animal waste do exist. Row cropping is a principal source of sediment as well as nutrients and pesticides in the A/P study area. Studies have shown that there is a statistically significant relationship between the amount of manure generated in a watershed and the mean concentration of nutrients in nearby streams (Humenik and Foreman 1984, Nichols et al. 1990)

There is an important qualification to the use of real payroll as a measure of trends taking place in the agricultural sector. The nature of production activities in this sector, as well as its evolution over time, indicates that measures of labor inputs used may be declining as outputs are increasing. Ideally, one would like to evaluate the trends in output measures for all sectors -- but detailed time series information was not available at the county level. For many sectors, such as agriculture, supplementary information is available to aid in further trend analysis. The North Carolina Department of Agriculture publishes annual reports for most of the agricultural activities within the state, and these reports provided the data for the following discussion.

Harvested cropland for the 36 North Carolina A/P counties rose steadily through the 1970s and peaked in 1980 (Figure V-9). Since that time, acreage in production has fallen. This decline is probably

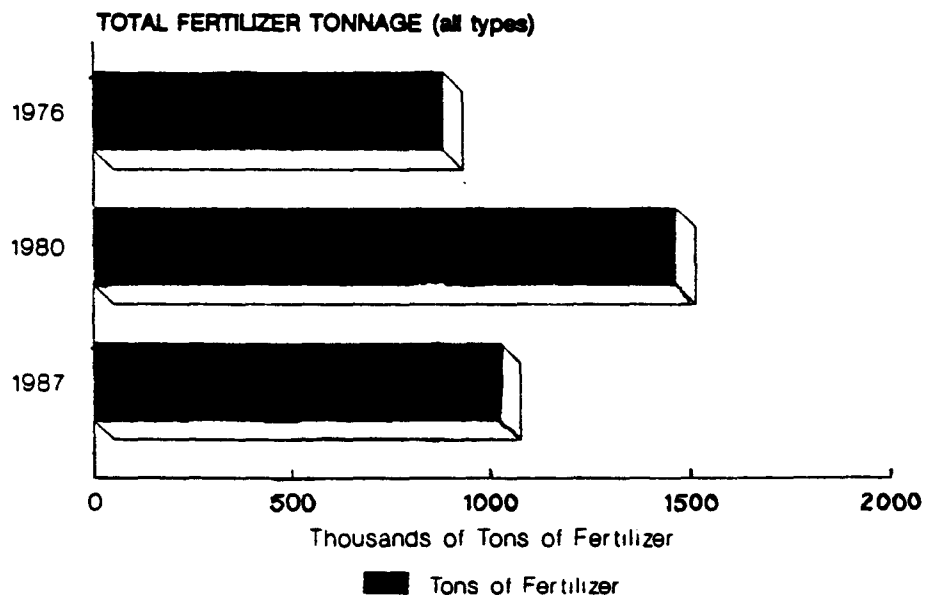
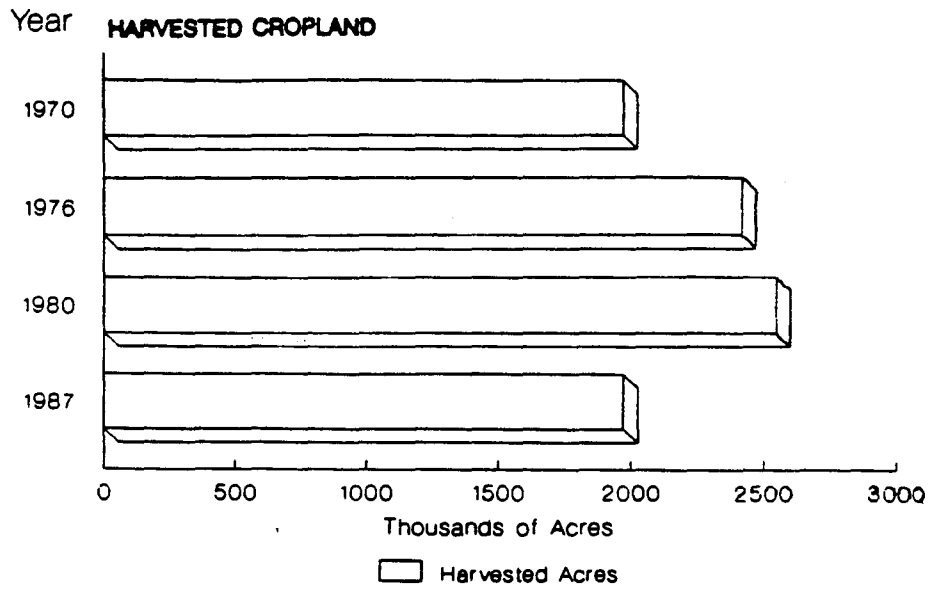


Figure V-9. Acres of Harvested Cropland and Total Fertilizer Tonnage Shipped to the 36 A/P Counties. From NC Department of Agriculture.

an indication of world-wide agricultural trends rather than state-wide trends. A more detailed analysis seems to support this conclusion. From 1970 to 1987, the A/P counties' share was about 50% of the total NC acreage in production. Despite declining acreage, the region's share of the state-wide total of harvested cropland has remained steady for the past 17 years. To further define agricultural acreage trends, three major crops--corn, wheat, and soybeans--were considered.

Wheat appears to be the only crop with consistent growth in acreage between 1975 and 1986 in the coastal counties. Corn and soybeans, in general, exhibited no growth or modest levels of growth in the amount of acreage dedicated to their production (NC DOA, Nichols et al. 1990)

Of course, in interpreting these data it is important to recognize that acres planted will be responsive to economic policy and market conditions. A recent federal policy initiative, the Conservation Reserve Program, might have an important influence on these planting decisions. The program involves targeting land designated as highly erodible for reserve contracts under the program. The contracts involve removing the land from production for ten years. If a farmer accepts the contract, trees or groundcover must be planted at a 50% cost-sharing rate. Land eligible for the program is categorized into pools; each pool has associated with it varying qualifications for the program. Periodically the US Soil Conservation Service reports the number of farms and acres offered and accepted into the program. The number of acres reserved under this program from July 1986 through March 1989 was investigated. A review of the records indicates that the program has had minimal impact on the counties adjoining the Albemarle-Pamlico estuaries. Less than one tenth of one percent of the total acreage accepted into the program in each of eight reporting periods can be associated with the coastal counties. Consequently, the level of the amount of acreage planted by crop does not appear to have been impacted by the Conservation Reserve Program.

One of the major concerns about agricultural nonpoint source pollution of the sounds involves the loading of freshwater with nutrients, particularly nitrogen and phosphorus (NC NRCD 1987). Much of this nitrogen and phosphorus originates from agricultural fertilizer. In 1976 the A/P counties' share of North Carolina's fertilizer consumption was approximately 48%. By 1987, that figure had risen to almost 60% even though harvested cropland decreased by nearly 20%. Beaufort County, directly bordering on Pamlico Sound received the largest share of fertilizer even though it ranked 74th in acres of total cropland (NC DOA). An analysis of fertilizer tonnage shipped to the study area is presented (Figure V-9).

The amount of fertilizer shipped does not necessarily represent the actual amount of fertilizer used during the year, however, according to the NC Department of Agriculture little fertilizer is carried over from one season to the next. As one would suspect, the tonnage pattern closely resembles the harvested cropland acreage graph. The fertilizer tonnage peaked in 1980, at over 1.5 million tons shipped to the region. This amount declined to slightly over 1 million tons in 1987.

Livestock production is another important industry throughout the A/P study area. A recent report by the North Carolina Division of Environmental Management noted that raising of farm animals near the coast is in direct conflict with maintaining habitat for the estuarine biota (NC Division of Environmental Management 1989). This analysis addresses the trends in hog, cattle, and chicken production. These data were obtained from the annual agricultural reports published by the NC Department of Agriculture.

Swine production accounts for the largest proportion of animal feeding operations in the A/P region; these operations often have the most serious water quality impacts (Nichols et al. 1990). Historical hog production trends for the A/P study area indicate that the pattern is similar to that shown in harvested cropland (Figure V-10). Hog production peaked in 1980 and declined in 1987. When these data are analyzed as a share of the state's total hog production, however, a different trend is evident. In 1974, the A/P counties' share of the state's hog production was 22%. In 1980, that share almost doubled to 43%. By 1987, hog production rose to over a 50% share of the state's total figure. By 1990, NC Department

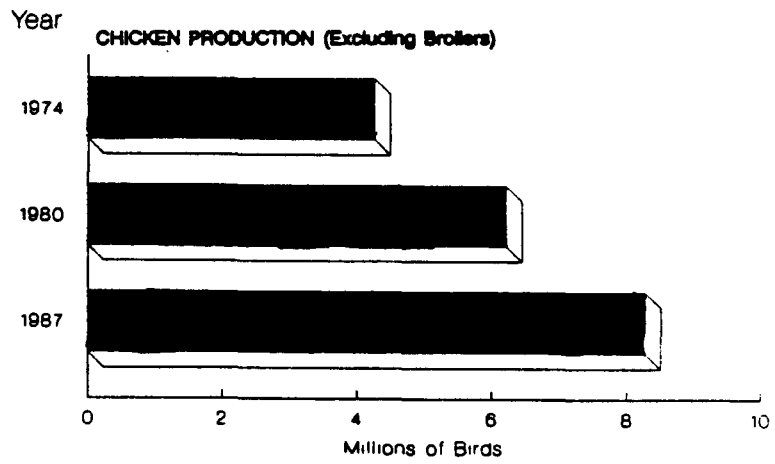
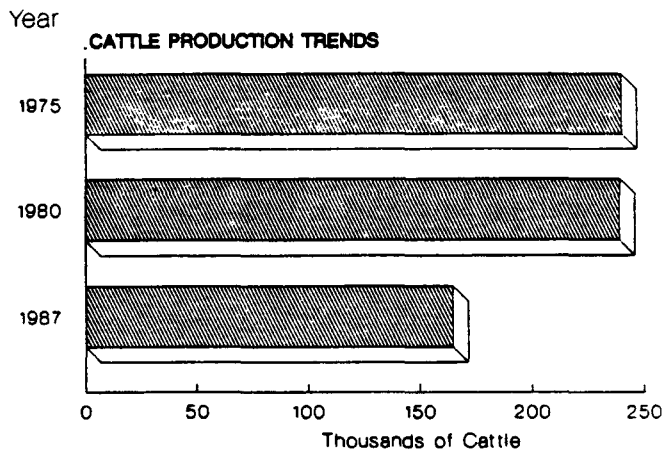
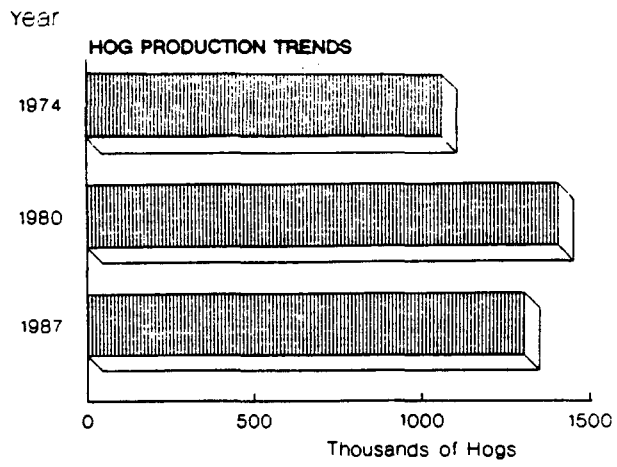


Figure V-10. Production Trends of Hogs, Cattle, and Chickens (Excluding Broilers) in the 36 A/P Counties. From NC Department of Agriculture.

of Agriculture suggested that there were 2000 producers in NC DEM Region 5 (two-thirds of the North Carolina portion of the A/P study area).

Cattle production remained constant from 1975 to 1980, but declined 45% from 1980 to 1987 (Figure V-10). As in the case of harvested cropland, this decline mirrors a nation-wide decline in cattle production. Cattle production is also shown as a percentage of the state-wide total. During 1975, the A/P counties' cattle production was 21.4% of the state's total. That share remained constant through 1980 (22.1%), but had declined to 17.3% by 1987.

Chicken production is an important industry in this region of the state. Chicken production (excluding broilers) has risen steadily in the study area since 1974. In 1974 the A/P counties produced 23% of the state's chickens. In 1980 they were producing 32% of the state's chickens. There was a 33% increase in production from 1980 to 1987 (Figure V-10), and by 1987, the A/P counties were producing nearly 40% of the state's chickens.

In summary, the amount of harvested cropland within the study area has declined since 1980. Fertilizer use within the 36 A/P counties is increasing despite the decrease in cropland acreage. In Beaufort County, 1987 fertilizer tonnage rates exceed all other counties in the study area. Hog production is declining slightly; 1987 production represented over half of the state's total. During the study period, cattle production fluctuated. Chicken production has increased steadily throughout the 1970s and 1980s, and in 1987, almost 40% of the chickens produced in North Carolina were produced in the A/P study area.

D. 2. b. Forestry. The current use of the forestland in the A/P Study area is as a base for the production of raw material for the diverse forest products industry. These forests also serve as extensive wildlife habitat. The Southeastern Forest Experiment Station of the US Forest Service maintains an extensive inventory of the woodlands in North Carolina. These data were used for the majority of this trends analysis. Additional data were obtained from the book, "Who Owns North Carolina?" (Institute for Southern Studies 1986).

In 1984, 31.6% of the woodlands in the state were located in the A/P Study area. In general, however, the amount of forested land in the study area is decreasing. This decrease was also evident in the payroll analyses of the forest industry. Correlative output levels could not be obtained, and the pattern implied by data from the period 1973-1984 is unclear. Most of the calculated rates of change in the outputs of softwood and hardwood, however, indicated declining outputs in coastal counties.

Pine plantation acreage was also analyzed. To date, pine plantations in North Carolina have contributed only minor amounts to the supply of timber in the state. That trend, however, is changing. The US Forest Service expects plantations to provide an increasing share of softwood timber supplies in the coming years (USFS 1986). From 1973 to 1984, there was almost a 79% increase in the amount of pine plantation acreage. According to the "Source Document" for the A/P Study, the establishment of pine plantations has the potential for causing degraded water quality. It is a common practice for the forest industry to apply phosphorus during the establishment of a plantation on poorly drained sites. Post establishment application of nitrogen is less widely practiced and the degree of disturbance involving plantation establishment has decreased, but the use of pesticides in pine plantations is still wide-spread (NC NRCD 1987). In summary, in the mid-1980s one third of the state's woodland acreage was located in the A/P counties; however, woodland acreage is decreasing. On the other hand, the amount of pine plantation acreage increased substantially from 1973 to 1984.

D. 2. c. Mining. As of April 1989, there were 252 permitted mines in the A/P Study area (NC DEHNR Division of Land Resources, Land Quality Section). The type of mine operation varies; however, the majority are sand and gravel mines or crushed stone mines. Because of the nature of the permitting process, a mine may be permitted but may not be in operation at this time. Because of the

limitations of this study, no attempt was made to determine how many of these mines are operating nor how many of them might be discharging into a water body. There are, however, some mining operations that are permitted to discharge into the sounds, and they are briefly discussed below.

Mining of phosphate rock and production of phosphate chemicals is presently limited to Texasgulf Inc.'s operations in Beaufort County. The rate of mining is approximately 150 to 200 acres per year. During the course of the mining process, 50 to 60 million gallons/day of freshwater are pumped into the Pamlico Sound. The 1988 nutrient budget for the Tar-Pamlico River system indicated that over 50% of the total phosphorus budget came from the Texasgulf operation (DEM 1989). A new permit issued by the NC Division of Environmental Management should reduce Texasgulf's loading by 90% by 1992 through a recycling process.

There are three peat mines permitted for operation in the A/P region. In 1987, the total acreage permitted was over 3,700 acres, all of which drains into the Pamlico River (N.C. NRCD 1987). There is the potential for tens of thousands of acres of peat mining, however, because the current peat demand is low, there is only limited active mining at this time.

Mining for sand and gravel (construction materials) consists mainly of sand pits scattered throughout the area. Construction materials mines account for over 90% of the mines in the study area. This type of mine is typically shallow (10 to 20 feet deep). The area devoted to construction materials mining varies according to the market and transportation costs. There are no specific data showing trends in this activity.

D. 2. d. Department of Defense. Department of Defense (DOD) activities have a profound affect upon the Albemarle-Pamlico estuarine system (NC NRCD 1987). Defense activities are diverse and include the construction, use and maintenance of the Atlantic Intracoastal Waterway, Cherry Point Marine Air Station, and numerous and dispersed bombing ranges and target areas. A systematic assessment of DOD activities is, as with some of the other sectors, beyond the capacity of this analysis. There are, however, some data available from North Carolina Department of Environment, Health, and Natural Resources (NC DEHNR) that will be used to indicate the amount of defense activity that occurs within the A/P Study area.

Because of national security restrictions, it is difficult to determine the precise acreage covered by DOD activities. In 1987, the Department of Natural Resources and Community Development (NRCD) estimated that DOD facilities encompassed over 96,000 acres within the study area. On much of this land, civilian use is severely restricted or prohibited (Figure V-11). Currently, extensive areas of the sounds are restricted to military aircraft and boat traffic; only narrow corridors remain for public use. With the Marine Corps' proposed expansion in the Croatan National Forest, this restricted-use acreage could increase.

In terms of persons employed and revenues, the DOD is the one of the largest industries in the A/P area, and if the proposed expansions are realized those figures will surely increase. The number of federal military employees in the A/P Study area declined slightly from 30,000 in 1970 to almost 28,000 in 1987. According to the published military economic impacts in North Carolina, Craven and Wayne Counties received more DOD economic benefits than any other A/P county. In fiscal year 1986, the DOD estimated that Wayne County received \$210,077,221 in revenues from DOD activities. During the same period, Craven County's share of the DOD expenditures was \$476,835,136.

DOD is a major contributor of point source contamination to the A/P estuarine waters. Cherry Point Marine Base, for example, has contributed large quantities of heavy metals to the waters and sediments of Slocum Creek and the Neuse River from its industrial plating, metal cleaning, engine stripping, and sewage discharge practices. Non-compliance with NC water quality standards was found to be common (Riggs In Press).

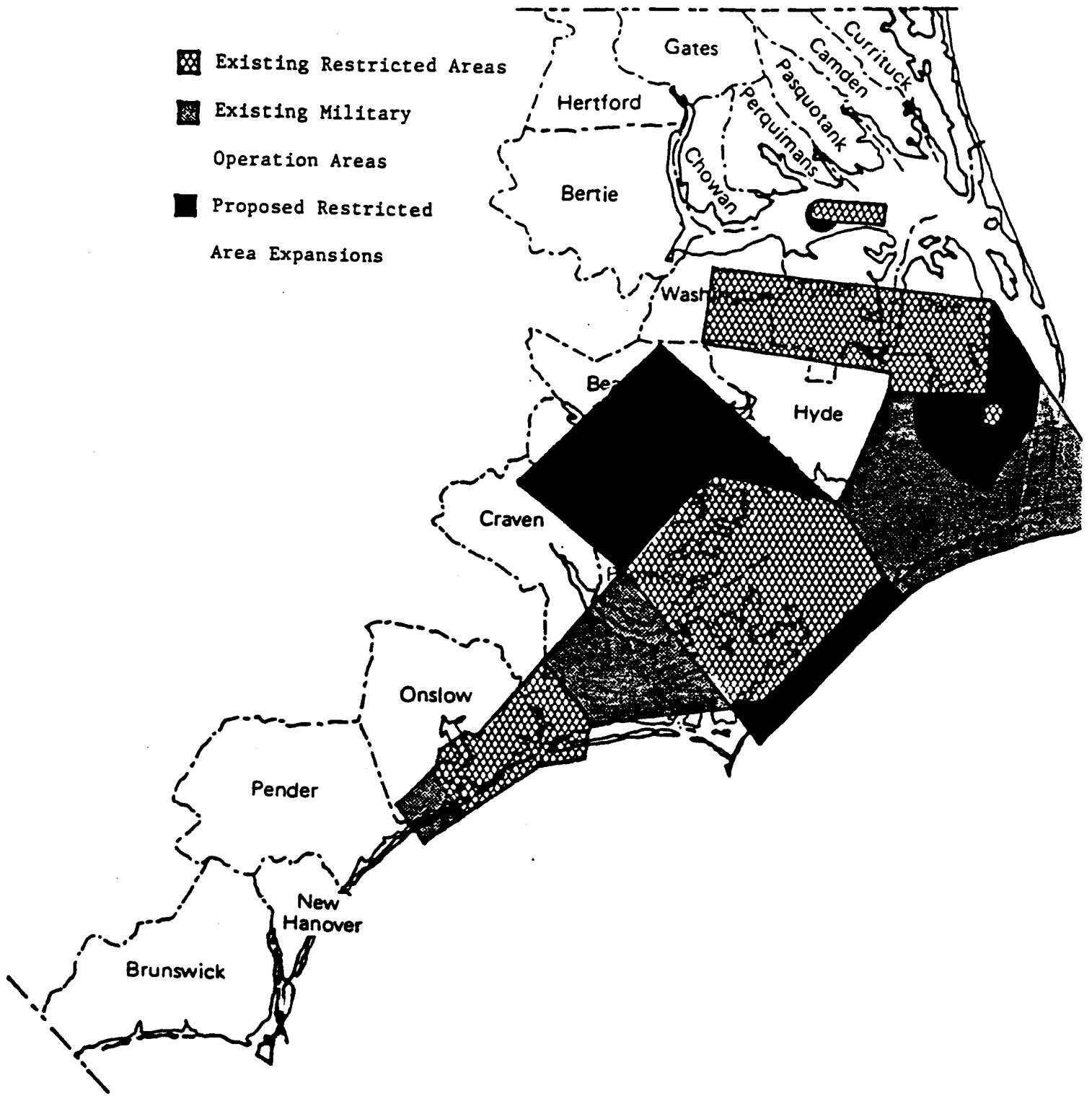


Figure V-11. Existing and Proposed Military Restricted Operation Areas in Eastern North Carolina.

In summary, the DOD is one of the largest single landowners in the A/P region. Although the exact acreage is unknown, it is estimated that DOD activities utilize close to 100,000 acres. The DOD has employed well over 25,000 persons in the A/P area since the 1970s. The DOD has a substantial economic impact in the 36 county study area; however, while localized effects are known, the indirect effects of the DOD's activities on the estuarine systems are not fully understood.

D. 2. e. Waste Disposal. A major use of the Albemarle-Pamlico estuarine system and its tributaries is for the disposal of waste generated by domestic facilities, industrial facilities, and other human activities on the surrounding land. For the purposes of this discussion, "waste" will refer to any material which enters waters of the State of North Carolina through human actions (NC NRCD 1987). Waste disposal within the A/P Study area is a complex topic and cannot be adequately addressed in this limited analysis. The reader is reminded that waste can enter the system through point sources such as pipes or through nonpoint sources such as roadways, agricultural areas, or construction sites. There is little data documenting sources or amounts of nonpoint source runoff, however, there are some data that can be presented to show trends in waste disposal.

The discharge of waste by domestic and industrial facilities is regulated in North Carolina by the Division of Environmental Management (DEM) under the National Pollution Discharge Elimination System (NPDES) permit program. The reconstruction of temporal trends in waste disposal in the A/P region is difficult because NPDES permit information contains both active and inactive permits. ("Inactive" refers to permitted facilities that are not actually discharging waste). Nearly half of all permits represent small domestic dischargers such as schools, prisons, and private residences. The vast majority of the waste volume, however, is discharged by municipal wastewater treatment plants and industries. Figure V-12 shows the approximate location of the NPDES permits in the North Carolina portion of the study area.

NPDES temporal data for the 36 North Carolina counties were obtained from the NC DEM data files. Based on these data, it is evident that NPDES permitting has increased steadily since 1973. Much of this activity has taken place since 1980. From 1980 to 1987 the number of NPDES permits increased nearly 2.5 times to 600 dischargers permitted to release up to 368 million gallons per day. It should be noted that approximately one-half of the permits issued during the 1980s are now "inactive". Actual discharges were roughly 65% of the permitted total. Wastewater discharges from permitted activities can have a substantial impact on the receiving water bodies. In the Tar-Pamlico River in 1988, 14.9% of the nitrogen budget and 25.2% of the phosphorus budget originated from wastewater treatment plants.

Due to the changing character of land uses, it is difficult to determine trends for nonpoint source waste disposal. A 1982 DEM study indicated that over 75% of the nitrogen and phosphorus loads in the Chowan River originated with nonpoint source discharges. The levels of nutrients contained in nonpoint sources can be estimated from information such as cropland acreage, crop type, and management practices, however, this type of estimate is well beyond the scope of this analysis.

In summary, whereas waste disposal throughout the A/P area is extensive, the true impacts of these practices is unknown. The number of NPDES permits issued in the region has increased dramatically since the early 1970s, but approximately 50% of the permits are presently inactive. Because nonpoint pollution is dependent to a large extent on land uses, it is difficult to determine trends for this type of waste disposal.

D. 2. f. Automobile/Transportation. Since World War II, the number of cars in this country has grown dramatically. Today, many households have two or three cars. Fueled by relatively cheap gasoline and a subsidized road network, human activity has spread out in the low density pattern that is often labeled "sprawl" (Chesapeake Executive Council 1989). Due to shifting development patterns and economic need, owning and operating a car has changed from a luxury to a necessity. In a largely rural area such as the A/P region, employment opportunities are limited. In 1984, over 56% of the persons

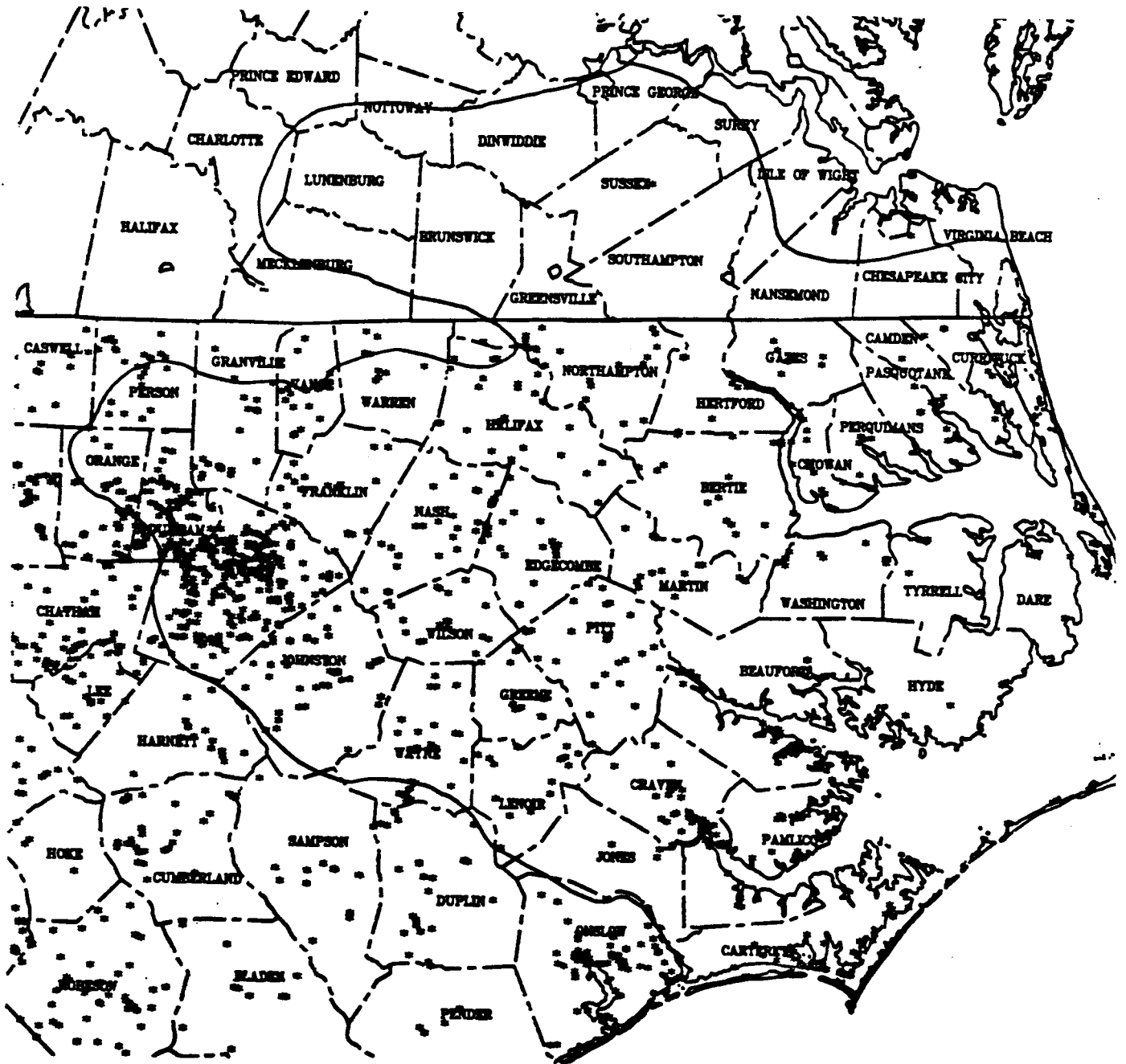


Figure V-12. NPDES Discharge Locations in the North Carolina portion of the A/P Study Area, 1989. From NC Land Resources Information Service.

residing in the Albemarle area found employment outside of the region (Albemarle Regional Planning Commission 1987). Much of the commuting to jobs outside the local area is dependent upon automobile travel. As with many of the human activities previously described, there are environmental impacts associated with this dependence on automobiles.

In communities of low density, such as those found throughout the A/P region, a single automobile can produce 147 pounds of carbon monoxide, 18 pounds of hydrocarbons, and over 17 pounds of nitrous oxides (Chesapeake Executive Council 1989). In a 1989 report, the DEM estimated that 18.6% of the nitrogen budget in the Tar-Pamlico River originated from atmospheric deposition. The same study estimated that 5.5% of the phosphorus in the basin also came from atmospheric deposition. Some of these atmospheric contaminants originate from automobile emissions. The environmental impacts of automobiles are not only due to airborne pollutants; runoff from paved surfaces such as highways and parking lots contain heavy metals, hydrocarbons, and sediments. These too, have the potential to degrade the water quality of the sounds.

In 1984, there were 22,430 miles of primary and secondary roads in the A/P study area. This figure was approximately 30% of the state's total. To determine automobile ownership patterns in the region, the change in the number of vehicles registered was compared to the change in population growth. The results of this comparison are shown in Figure V-13. In the decade from 1970 to 1980, the population in the region increased by slightly more than 11% while vehicle registration (cars and trucks) increased 56.8 percent. From 1980 to 1988 the population increase was estimated at 10.3 percent, however, the increase in vehicle registration was over 6 times that figure, or 65 percent. It seems that multi-vehicle ownership is quite common throughout the A/P study area. In many families both parents work at jobs great distances from the home, necessitating more than one vehicle.

As noted earlier, the coastal zone is experiencing growth that exceeds much of the remainder of the state. The increasing populations are taxing many public facilities including water supplies and wastewater treatment facilities. This growth is also affecting the road system in the region. In order to determine how growth is affecting the highway network, the North Carolina Department of Transportation (NC DOT) selected 11 sites along major highways leading from the central portion of the state to the coast. Most of the sites were located near a municipality and ranged from the northern to the southern boundary of the study area. Traffic counts (average 24 hour day-all vehicles) are maintained by the NC DOT. During the period from 1975 to 1983, average traffic counts increased at the majority of the study sites. These increases ranged from 117% at the bridge over Currituck Sound to only 8% at US 13/64 near Williamston. Only two sites experienced decreases in traffic counts. For the period from 1983 to 1985, all 11 sites experienced an increase in traffic, ranging from 3% near New Bern to 87% at the Roanoke Sound Bridge. The greatest increases were observed at sights on or near the coast.

As noted in the permanent versus seasonal population discussion, seasonal population may far exceed permanent populations. This fact is supported by comparing seasonal traffic counts to the 24 hour average day counts. At the Bonner Bridge on the Outer Banks, the 1988 July Fourth traffic count exceeded the daily average by 2.5 times (9,760 vs. 4,000). Anyone who has visited Nags Head or Atlantic Beach during the summer months can attest to the effects of recreational travel on the coastal road system.

In summary, in much of the rural A/P study area, employment opportunities are dispersed. For many people in these areas automobile travel is a necessity. The rate of vehicle registration far exceeds population increases implying that multi-car households are likely to be increasing. Automobiles and roadways have the potential to impact the sounds' water quality. Many of the major highways leading to the coast are experiencing increased traffic counts; however, it is difficult to separate the effects of increasing permanent population from that of the travel and tourism industry.

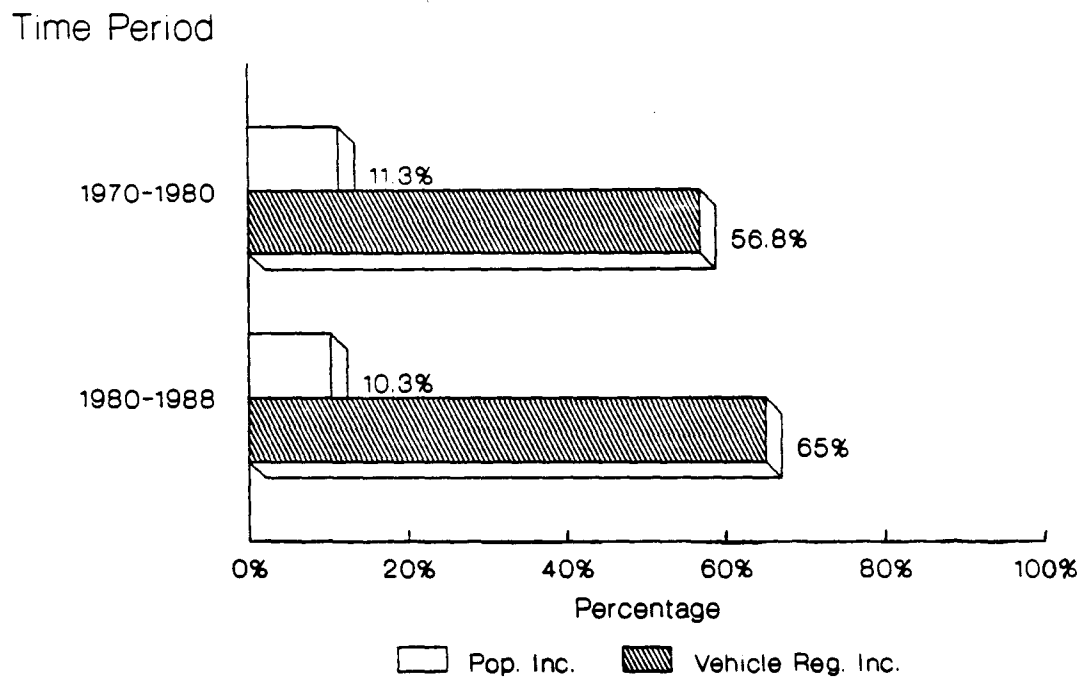


Figure V-13. Population Change vs. Vehicle Registration in the 36 North Carolina A/P counties. From NC Department of Transportation.

E. PUBLIC SECTOR ACTIVITY

Previous discussion addressed both direct and indirect uses of the Albemarle-Pamlico estuarine system. There are, however, sectors of activity that affect the study area that are not classified in either of these two categories. For the purpose of this discussion, these interactions will be addressed as public sector activities. Public sector activities include legislation and the educational system. In the case of legislation, or "governmental intervention", the potential for affecting change within the A/P region is great; so, too, within the education system. The values and beliefs taught in the school framework have the potential to affect a large proportion of the population now and in the future. A more informed public can take an active role in the maintenance and management of the A/P estuarine system.

As mentioned throughout this analysis, very little research has taken place regarding the socio-economic forces that affect the study area and only a small portion of that research has dealt with public sector activities. Unlike woodland acreage, vehicle registrations, or fish landings, there is little historical data regarding the effects of legislative or educational programs. Rather than addressing trends based on insufficient data, this section will deal with legislation and educational processes currently in place throughout the region.

E. 1. Legislative Programs

There are three levels of government that affect the Albemarle-Pamlico region: 1) federal government, 2) state government and 3) local government. Each level represents a separate jurisdiction, yet each interacts with the others regularly (Appendix V-1). It is beyond the scope of this study to discuss each of these levels of government in detail, however, a brief discussion of each follows.

As of December 1986, there were at least 81 federal programs affecting activities within the A/P region. Federal laws cover a variety of activities from water quality to soil conservation, and from endangered species to hazardous waste storage. Although some laws are more inclusive than others, each has the potential to alter many of the previously discussed land and water uses. Finch and Brower (1987) used a simple classification system to divide them according to their potential impact on the various activities taking place. Forty-eight federal laws and regulations are described as having a "major" impact on human activities, 8 are classified as having a "minor" impact on the region, and 25 legislative programs are classified as having a "marginal" or "extremely minor" impact on the area (Appendix V-1).

As in the case of the federal laws, state laws govern a variety of activities ranging from wastewater treatment plants to bicycle paths. Some of the state laws, such as the Coastal Area Management Act (CAMA), are very selective and only apply to the counties that border the ocean or sounds. As of December 1986, there were at least 109 North Carolina regulatory programs affecting human activities in the study region. Forty-two are classified as having a major impact on the sounds, 6 are considered to have a minor impact on the A/P study area, and 61 are judged to have only a marginal impact on the direct or indirect uses of the area's resources.

Local government ordinances, like federal and state regulations, cover a wide range of human activities. Land-based development controls are one method whereby local governments can affect water quality. There is some limited data available on this type of program. In 1987 the Division of Community Assistance, within NC Department of Environment, Health and Natural Resources, conducted an inventory of local land development controls within the Albemarle-Pamlico study area. The study collected data for 33 counties; these data are the basis for this brief description. In 1987, only slightly more than one-half of the counties had zoning ordinances in place. Seventy-nine percent of the 33 counties had subdivision ordinances in effect and 79% of the A/P counties had land use plans in effect.

In summary, there are over 200 state and federal laws that regulate human activities within the A/P study region. These laws govern countless activities involved with both land and water use. There is little data that addresses how these regulations effect the use of the sound. The majority of the local governments within the study area have adopted the necessary planning and management tools to control land use activities (i.e., zoning ordinances, subdivision regulations, and land use plans), the first step in effectively managing their resource base.

E. 2. Education and Public Awareness

North Carolina citizens have many opportunities to learn about the status and health of coastal waters and estuaries. Increased recreational use, development around the estuaries and on the barrier islands, and greater impact on the estuaries from their watersheds are major forces of change. Education agents include mass media, public schools, universities, state agencies, and private initiatives.

Many statewide and regional newspaper and television stations devote sections to pressing environmental issues. Reports on fish kills, declining fisheries, algal blooms, and poor water quality are frequently in the media. These features increase public awareness and help to educate citizens about estuarine issues. Mass media are an increasingly important educational resource.

Within the past ten years, new programs have been developed that focus specifically on coastal water resources. Educational funding from the Albemarle-Pamlico estuarine study has provided additional projects targeted at youth and adult audiences.

E. 2. a. Education Curriculum Materials. "North Carolina Coastal Plain: A Geologic and Environmental Perspective" -- An eight-part video accompanied by scripts and a student activity guide was developed by the NC Department of Public Instruction, East Carolina University, and Texasgulf, Inc. It is correlated to the eighth grade Standard Course of Study in social studies and science and is applicable in grades 4-12. A 1987 one-day summer workshop introduced this material to teachers in the northeast education region. The original materials were in a filmstrip/cassette format and were distributed to 543 northeast schools and to the eight statewide regional education centers. The new video format is now available through UNC Sea Grant at a cost of \$30.

"Project Estuary" -- A multidisciplinary curriculum guide appropriate for grades 5-10 that includes a variety of activities and information materials designed to fit into the existing science curriculum, this project was developed by the NC National Estuarine Research Reserve System, written by Gail Jones and published by the NC Division of Coastal Management.

"Project MOST Environmental Curriculum, Pitt County Schools" -- Project Model Outdoor Science Teaching (MOST) is an outdoor education program designed to complement on-going K-6 science instruction. The project encourages the use of local natural resources as alternatives to distant, often expensive, field trips. Using swamps as off-campus visitation sites, Project MOST promotes the philosophy of making outdoor education "a part of" rather than "apart from" the overall learning experience. More than 5,000 students are served by the project each year. Project MOST was developed by the Pitt County Schools and funded, as part of a nation-wide effort to improve science education, by the Association of Science-Technology Centers in Washington, D.C. Actual funding was made available through the Science Teacher Education at Museums (STEAM) program sponsored by the General Electric Foundation. Pitt County Schools and the East Carolina University Science/Math Education Center provided matching funds to be used in teacher training under Project MOST.

"Project Wild/Aquatic WILD" -- Another educational packet and more training for teachers occurs under Project Wild/Aquatic Wild. In this program, education activity guides have been developed for

teachers of kindergarten through high school age students. The most recent instructional material titled "Project WILD Aquatic Education Activity Guide" provides opportunities to explore and understand the aquatic habitats. The aquatic environment includes freshwater rivers, lakes, ponds, and streams and saltwater marshes, estuaries, and oceans. The material in Aquatic WILD is designed to assist learners of any age in developing awareness, knowledge, skills, and commitment to result in informed decisions, responsible behavior, and constructive actions concerning wildlife and the aquatic environment upon which all life depends. Project WILD was initiated under the sponsorship of the Western Association of Fish and Wildlife Agencies and the Western Regional Environmental Education Council. In North Carolina its sponsor is the NC Wildlife Resources Commission. Educational guides are provided to those teachers who participate in training workshops on the material. Representatives of the NC Wildlife Commission, the NC Department of Public Instruction and others have conducted workshops to train teachers in the use of these and other estuarine and wetland materials.

"Project Learning Tree" -- Project Learning Tree (PLT) is an award-winning environmental education program designed for teachers and other educators working with students in kindergarten through grade 12. PLT is a source of interdisciplinary instructional activities and provides workshops and in-service programs for teachers and youth group leaders. PLT was developed through a joint effort of the American Forest Foundation (AFF) and the Western Regional Environmental Education Council (WREEC). The materials are written by classroom teachers and other educators, resource agency personnel, representatives of private conservation groups and forest company representatives. WREEC also developed Project WILD, an environmental education program emphasizing wildlife. PLT, which has a significant water resources component, is growing in popularity among teachers in North Carolina. For example, in 1988 there were 33 teacher workshops in which 876 teachers were trained to use the PLT guides and resource materials for classrooms. In this state, PLT is sponsored and coordinated by the North Carolina Agricultural Extension Service and the North Carolina Forestry Association.

E. 2. b. Examples of Sponsored Teacher Workshops. "Elizabeth City State University Teacher Training Workshops" -- With the support of A/P Study, Elizabeth City State University conducted a series of three teacher workshops in 1989 on aquatic environmental management. These workshops stressed the integration of aquatic management into classroom environment, the development of class projects, and the development of lesson plans.

"Water Quality Training Institute for Teachers" -- In 1989, a two-week workshop was conducted at the University of North Carolina at Chapel Hill to give middle, junior high, and high school public school teachers an opportunity to learn about the state's major water quality issues. Topics included the impact of wastewater treatment plants, agricultural runoff, industrial discharges, and development on the state's rivers and estuaries. The institute was conducted by the Environmental Resource Project of UNC-CH's Institute for Environmental Studies and the UNC-CH Department of Environmental Sciences and Engineering with support from the NC Center for Math-Science Education. Teachers were paid a \$35-per-day stipend and received two graduate credits from UNC-CH.

E. 2. c. Environmental Group Initiatives. Educational materials from the Department of Public Instruction have been shared with representatives of the Pamlico-Tar River Association, who in turn conduct lessons in the schools. Teachers have been recruited to have their classes involved in Citizens Monitoring. Teachers are informed that environmental groups are an educational resource.

E. 2. d. State Agency Support. Representatives of appropriate state agencies have been invited to teacher workshops in order to apprise teachers of the educational services available and of the involvement of state agencies in conservation. Some examples are the Soil Conservation Service, the Agricultural Extension Service, the Division of Coastal Management, the NC Department of Environment, Health, and Natural Resources, and the NC Wildlife Resources Commission.

E. 2. e. NC Agricultural Extension Service. The North Carolina Agricultural Extension Service (NCAES) has an educational program committed to improving water quality. Extension is already helping protect water quality by teaching farmers and other land users to deal properly with pesticides, animal wastes, sediment, commercial fertilizers and freshwater drainage. Extension promotes BMPs to keep these contaminants out of water bodies, including the Albemarle-Pamlico estuarine system. The NCAES has an established network of offices and agents in every county in the project area. County Extension agents have connections with local communities that can serve to further the goals of the A/P Study.

The Albemarle-Pamlico Estuarine Study is supporting a project in which NCAES will conduct a series of four leadership development workshops and develop a handbook on water quality impacts of nonpoint source pollution. This project will promote public understanding of and support for the Albemarle-Pamlico Estuarine Study through increased awareness and involvement of local leaders, professional agricultural workers, and concerned citizens. These workshops are expected to improve two-way communication between the citizen advisory committees and local leaders.

The Agricultural Extension Service 4-H and Youth Development Program has educational curricula for youths which address coastal environmental problems. These curricula include:

- * "Aquatic Wild" -- a K-12 curriculum designed in lesson-plan format and delivered in all modes
- * "Marine Science Camp" -- a week-long curriculum designed for teenagers
- * "River's Edge" -- a curriculum developed for fifth grade and delivered in the school enrichment or special interest mode
- * "Soil and Water in North Carolina" -- a curriculum designed for 10-year-olds, teaches the basics of soil and water quality
- * "Plastics" -- lessons designed for 9 to 12-year-olds, focus on the perils of plastic in an aquatic environment
- * "4-H Seafood Project" -- designed for the 4-H members in a community or project club. 4-H delivers its program in a variety of ways including community/project clubs, special interest groups, school enrichment and camping.

E. 2. f. UNC Water Resources Research Institute. The Water Resources Research Institute (WRI) is a unit of the University of North Carolina with offices located at North Carolina State University in Raleigh. The mission of the Institute is to identify the state's water-related research needs, support research by qualified scientists, train graduate students, and provide for technology transfer. WRI has supported 35 research projects on estuarine and coastal water problems of North Carolina and has published and made available to the public reports on these projects. Some of WRI's published reports are on problems associated with fish diseases, aquatic plants, sediments and nutrients, nutrient and algae relationships for both the Pamlico Estuary and the Chowan River, water management and water quality associated with intensive agricultural operations, wetland buffers to improve water quality, and detention basins for stormwater management. WRI also conducts workshops on coastal water issues and publishes a newsletter as part of its technology transfer and education efforts.

E. 2. g. UNC Sea Grant College. The UNC Sea Grant College, administered by the University of North Carolina system, operates in three capacities: research, education, and communications. Results of research funded by Sea Grant are published in reports and scientific journals. The main points are often included in Coastwatch, a free newsletter sent to 18,000 readers. Education workshops initiated or

supported by Sea Grant agents and specialists provide techniques and information on applying the results of the research in industry, agriculture, and fisheries. These include concepts such as models for predicting movement of nutrients from soils to estuarine waters and the role of sediments in removing nutrients.

Sea Grant assisted the NC Coastal Federation in producing The Citizen's Guide to Coastal Water Resource Management (out of print). This guide provided information for public involvement in management policies.

A Sea Grant education specialist has assisted in teacher in-service programs providing techniques and information concerning watersheds, plastics in the marine environment, and ecological activities. A set of marine education curriculum materials is available for teachers and 4-H staff. It includes the following publications: Coastal Geology, Seawater, Coastal Ecology, and Coastal Beginnings and Connections. A primary curriculum guide, Coastal Capers, is available for grades K-3. Other publications on seashells and marsh and dune plants support field trip activities.

"The Big Sweep" is a multi-agency, public and private program which is in its third year. Begun as "Beach Sweep" initiated by UNC Sea Grant, the Division of Coastal Management and the Division of Parks and Recreation, it focuses on litter as a visible symbol of habitat degradation and public responsibility, and on citizens' ability to take corrective action. This program won state and national awards in "Keep America Beautiful" for 1987 and 1988. In 1989, the project expanded to include estuarine shores, reservoirs, rivers and state parks. The NC Wildlife Resources Commission, 4-H, WRAL-TV, and private companies are part of the expansion strategy for a statewide aquatic program. The goal is to increase public awareness and institute a sustained, multi-age education program.

E. 2. h. North Carolina Aquariums. The North Carolina Aquariums provide educational opportunities for the public in an effort to create a better understanding and appreciation for the diverse natural resources of coastal North Carolina. The aquariums are located on Roanoke Island, at Pine Knoll Shores and at Fort Fisher. They are administered by the Office of Marine Affairs in the North Carolina Department of Administration. The facilities are open seven days a week, all year, and are staffed by professional educators, exhibitors, and aquarists.

The Aquariums offer a wide variety of educational activities highlighted by living displays of North Carolina's marine life. Exhibits on coastal ecology, outdoor field experiences, seafood workshops, films and other events are all designed to increase public awareness of and appreciation for the fragile coastal environment. Each year, over 50,000 students from around the state and region participate in educational programs, such as offshore trawling excursions, beach and salt marsh studies, workshops, films and other "hands-on" activities. In 1988, the Aquariums were visited by nearly 1.5 million people, making them the most visited state facilities.

The North Carolina Aquarium on Roanoke Island was a 1988 winner of the Today's Aquarist Conservation Award for its exhibit "Secrets of the Salt Marsh." The 1,500-square-foot exhibit is designed to educate the public about the value of North Carolina's marshes and estuaries. The exhibit features an estuarine touch tank, video system, interpretative graphics, an interactive computer center, a 1,100-gallon aquarium and a discovery room equipped with projection microscopes and computers. This aquarium, made possible with a grant from the A/P Study and private support, provides an ideal setting for conducting educational programs aimed at increasing the public awareness of one of the nation's largest estuarine systems.

E. 2. i. National Estuarine Research Reserves. The four estuarine reserves in North Carolina--Currituck Banks, Rachel Carson, Masonboro Island and Zeke's Island--serve as natural, outdoor laboratories where scientists, students, and the public learn about coastal ecosystems. Established by the state of North Carolina in 1982 with matching funds from the National Oceanic and Atmospheric

maritime forests, and estuarine waters at the four sites. The Reserve is part of the National Estuarine Reserve Research Systems created by Congress to ensure the preservation of vital coastal systems for research and study. In North Carolina the program is administered by the Division of Coastal Management. Education and research are the primary objectives of the National Estuarine Reserve Research System. Educational programs, guided tours, and workshops are offered at most reserves.

A useful educational publication available to the public is "A Field Guide to Exploring the North Carolina National Estuarine Research Reserve", published by the Division of Coastal Management. A fifteen-minute video entitled "It's a Beautiful Day: A Visit to the North Carolina National Estuarine Research Reserve" is also available. This video, designed for middle school students, will be available through the Regional Education Centers of the Department of Public Instruction.

E. 2. j. A/P Education Projects. The Albemarle-Pamlico Estuarine Study has supported a number of projects which are designed to increase public awareness and aid in disseminating relevant knowledge about the estuaries to the general public. These initiatives play an important role in helping to inform and/or educate the public.

Public involvement projects which have a significant educational component include the following:

- * Development of a citizen estuarine monitoring network;
- * A state-of-the-estuaries booklet;
- * Public service announcements (PSAs) on the radio and television;
- * A media tour;
- * Workshops on management issues and a management guidebook;
- * A video-tape and slide show;
- * A program newsletter;
- * Public meetings;
- * A Guide to the Estuaries booklet;
- * "Journey of the Striped Bass" aquarium exhibit;
- * Community education outreach;
- * A 1990 educational calendar; and
- * Teacher environmental education programs.

E. 2. k. Department of Community Colleges. The North Carolina System of Community Colleges is made up of 58 community and technical colleges, 25 of which are in the A/P Study area. Colleges in the system offer a host of programs to meet the needs of individuals, businesses, and industries. These programs range from one quarter to two years in length. Single courses are also offered to update job skills and for personal enrichment. The primary emphasis of every college is on-job training, and most programs are in vocational and technical areas.

A few community colleges and technical institutes, mostly outside the A/P Study area, have programs in commercial fishing, environmental science technology, fish and wildlife management technology, marine maintenance, marine technology and soil and water conservation technology. Some colleges have individual courses in which the marine environment and biology are explored. For example, the College of the Albemarle offers relevant specialized credit courses such as "Introduction to the Marine Environment" and "Current Issues in Biology and Principles of Ecology". These courses include topics on pollution, marine resources, productivity, nutrient cycles, and other environmental factors.

There has been no systematic review of the community colleges outreach and extension activities relating to coastal water quality and estuarine protection. In such programs a variety of topics could be addressed depending on the expressed needs of adults in the community.

E. 2. i. The North Carolina Coastal Federation. The North Carolina Coastal Federation is a non-profit, tax exempt organization dedicated to involving citizens in decisions about managing coastal resources. Its aim is to share technical information and resources to better represent present and long-term economic, social and environmental interests of coastal North Carolina. The Federation has been involved in the following educational activities:

- * Organization of the kick-off meeting for the Albemarle-Pamlico Estuarine Study which was attended by nearly 600 people;
- * Planning and implementation of a three-day press tour for the Albemarle-Pamlico Estuarine Study;
- * Writing and distributing 2,000 copies of A Citizens Guide to Coastal Water Resource Management;
- * Organizing and conducting four two-day workshops in the Albemarle-Pamlico study area to discuss citizen participation in coastal water resource management;
- * Publishing a quarterly newspaper (Coastal Review) about coastal management issues;
- * Alerting citizens about up-coming public hearings concerning coastal management issues and activities;
- * Organizing the annual meeting for the Albemarle-Pamlico Estuarine Study; and;
- * Developing a series of workshops to examine alternatives for managing estuaries.

E. 2. m. Pamlico-Tar River Foundation, Inc. The Pamlico-Tar River Foundation (PTRF) is a non-profit research and public education foundation concerned with the environmental quality of the Pamlico-Tar River, its tributaries, and surrounding land. The Foundation seeks to protect the water resources through education, advocacy, monitoring, research, and recreation.

The PTRF has a number of educational programs directed toward informing the public about the need to protect the natural resource. Among its programs are the following:

- * A citizens water quality monitoring program involving adults in monitoring at 65 sampling stations. Trained citizens test for pH, temperature, salinity, turbidity, dissolved oxygen, nitrogen and phosphorus;
- * A community education outreach project consisting of an inventory of existing educational materials (booklets, maps, posters, etc.) to assist with educating the public regarding estuaries and their

management. Presentations on these materials are made to school children, youth groups and citizens' organizations;

- * Development of "A Guide to the Estuaries." The educational publication is designed to be an avenue for dissemination of information about the estuarine system and the work of the A/P Study; and
- * Development of an educational calendar to convey information about estuaries, the ecology and the A/P Study.

E. 2. n. Albemarle Environmental Association. The Albemarle Environmental Association (AEA) is an organization concerned with a number of environmental topics including water quality. Its membership includes individuals and groups such as civic associations and Extension Homemakers clubs. The Association publishes newsletters for its members and local libraries. It also holds public meetings on environmental issues and sponsors outings to sites of environmental interest.

AEA has assisted in organizing volunteers for monitoring of local bodies of water. This group is currently monitoring water quality at eight sites in Albemarle Sound. AEA has also undertaken, with support from the Albemarle-Pamlico Study, a program of public education. In this effort three groups have been targeted: public officials, high school students and teachers, and members of local civic associations. A half-time educator has been hired to prepare and present programs about water quality and the Albemarle-Pamlico Study.

E. 2. o. WRAL-TV, Channel 5. One of North Carolina's largest television stations has given the sounds and coastal environment top priority with a significant public education program. The station's stated mission was to educate and alert the viewer to the extent of the problem, to sensitize the whole community, and to move the issue to the top of the public agenda, thereby stimulating the preservation of North Carolina's coastal environment.

With "Troubled Waters," a half-hour documentary examining the sources of water pollution in the rivers and sounds of the state, WRAL-TV launched a year-long campaign in the fall of 1988 called "Save Our Sounds," which included the following elements:

- * "Sound Advice" resource book, sent to schools statewide and offered to the public;
- * Poster produced and distributed to elementary schools;
- * "Save Our Sounds", year-long weekly news report;
- * Public Service Announcements and "info-mercials" (educational spots);
- * "Reflections on Our Coastal Environment" symposium, a free lecture, with keynote speaker Walter Cronkite. WRAL-TV hosted two receptions around Mr. Cronkite's speech to raise funds to sponsor the Carolina Coastal Celebration; and
- * "Carolina Coastal Celebration", a two-day education fair/festival with exhibitors, craftspeople, environmental groups, music, and seafood. The event was attended by 10,000 people.
- * "Troubled Waters", a half-hour television documentary which won the National Edward R. Murrow Award in the news series/documentary category.

E. 2. p. Conclusions. In the past 2-3 years there has been increased educational activity for youth and adults on coastal and estuarine issues. Much of this increase can be attributed to the initiatives of individuals in the public school system, state agencies, the media, and environmental groups. The A/P

Study has stimulated part of the education and awareness efforts and has supported a number of projects especially for teacher training and public awareness. The A/P Study has also developed a very active public awareness and public participation program.

While there has been a noticeable increase in educational programs, much of the work is sporadic, heavily dependent upon one-time funding, and much of it is left to voluntary efforts of a few leaders. While many young people and adults are being reached, a majority of citizens need educational information if they are to be active participants in protecting and enhancing the coastal environment.

F. RECOMMENDATIONS

The preceding discussion addresses many of the activities that affect the quality of life within the Albemarle-Pamlico estuarine system. This discussion has been rather anthropocentric, but one should remember that the A/P Sounds are home to many thousands of organisms who coexist within its borders. There are numerous environmental factors that contribute to the health of this unique natural system and maintaining water quality is of the utmost importance. The difficult question for residents and natural resource managers is, what is the best way to accomplish this mandate?

This chapter presents a large amount of data; however, despite this volume, little is known about the many subtle interactions that maintain the estuaries. Rather than an all encompassing view, the reader has been shown a "snapshot" of the activities that have taken place over the past 15 to 20 years. This chapter presents a picture of increasing populations, automobile use, wastewater discharge, and use of fertilizers, etc. In fact, little in the region has decreased except for fish stocks and wetland acreage.

While much discussion has dealt with indicators of growth, there has been little discussion regarding the far reaching effects of this ever increasing human activity. It is hoped that this analysis will lay the foundation for this type of dialogue. Based on the insight gained through the collection and analysis of these data, the following recommendations are presented to those interested in the future of the Albemarle-Pamlico ecosystem:

- * A central database, such as that created by NC Center for Geographic Information and Analysis (CGIA), should be maintained to catalog and analyze all data involving the A/P area. A system such as this would assist many divisions within NC DEHNR, simplify future projects such as this, and prevent duplication of data collection.
- * The Department of Defense activities must be better documented. Furthermore, there is a need for research projects to identify the environmental impacts of DOD activities within the study area. The DOD is one of the major actors in this region, yet little or no useful data is available for much of its land use practices. This completed document should be used to identify future data needs and research projects. Little research appears to involve the socio-economic activities that greatly affect the estuaries.
- * The environmental cost of the ever-increasing travel and tourism industry should be determined. Tourism is one of the major industries in the area; however, little is known about its affects upon these environmentally sensitive coastal and sound systems.
- * Comprehensive and consistent land use plans, similar to those required by CAMA, should be developed and implemented throughout the entire A/P region. Financial aid should be supplied to the smaller, rural counties who are unable to undertake such projects.

- * Waste disposal should be addressed from a regional viewpoint rather than from a county by county level. Waste disposal, both solid and liquid, is potentially one of the most serious environmental problems within the A/P Study area.
- * A clearer direction should be established for the A/P Study and increased efforts at public education should be undertaken. Many people in the region (citizens and environmental managers) are unaware of the Albemarle-Pamlico project or do not fully understand its goals. This was very evident in many of the state agencies interviewed for data requests.

F.1. Research Needs to Adequately Deal with Economic and Social Trends

Following the same structure we used to assemble the information available on economic trends, we have outlined some research needs that should be addressed if we are to adequately evaluate the potential effects of a comprehensive conservation management plan. We must be able to identify the factors influencing direct and indirect uses of the estuary and how those factors and uses might respond to alternative management options.

Develop a model of recreational fishing in the A/P estuarine system. Ideally, we would like to be able to model the demand for recreational fishing in the Albemarle-Pamlico area. Many qualities of the estuary affected by management influence recreational choices. These dimensions are more subtle than simply fish availability. They involve the aesthetic dimensions of the resource and the likelihood of disruption to environmental quality by specific episodes, such as the "red tide" and other forms of coastal pollution not easily predicted in advance. In order for a model to adequately reflect the influence of management policies, it would need to incorporate measures of: (1) how the quality of the estuary affects recreational fishing in the area, (2) local vs. non-local use, and (3) how the decisions to use the estuary are made.

Develop a model of commercial fishing in the A/P estuarine system. Commercial activities are also dependent upon the character of the estuarine resource, and the nature of the response to change can be equally as complex as that of recreational fishing. Clearly they are related to the availability of fish, but they are also affected by regulations, cultural patterns, and market economics. Anticipating future trends in the fisheries and their responses to management policies is critical to successful management of this precious resource.

Develop an economic model of the different productivity sectors. Such an analysis would allow some predictions to be made regarding the scale and location of growth and development and their relation to coastal policy. Development of such a model would involve the determination of the change in output or the change of location as functions of the characteristics of the location in question. Carlton (1979, 1983) and Bartik (1985, 1988) have conducted research on the location of firms or plants according to regional and local characteristics including: (1) access to markets, (2) the price, character, and quality of local labor, (3) the quality and accessibility of the overall infrastructure (e.g., highways and support industries), and (4) policies regulating operations and finances. The Bureau of the Census Longitudinal Establishment Database provides information that could be used to develop these types of models for coastal areas in North Carolina and other regions.

Determine the real costs associated with each production sector and the costs associated with extant and proposed management policies. Calculations of the revenues generated by one activity or another provide only a part of the picture. Environmental, social, cultural, and hidden economic costs are real and, at times, great. Realistic estimates must be developed so that balanced and far-sighted policies can be developed. In this we can begin to balance the implications of alternative uses of the estuary and develop management plans that reflect both the benefits and costs of alternative uses.

F. 2. Recommendations for Public Education

Expand educational programs on coastal water and estuarine issues. Policy makers, educators, mass media representatives, adult citizens, youths, planners, engineers, legislators, and leaders of business and industry must be reached. This will require creative leadership, financial support, and a planned and diverse program. The NC Department of Environment, Health, and Natural Resources should be responsible for sponsoring such a program. Following are some specific recommendations.

1. The program should coordinate closely with the A/P Study.
2. The program should define major categories of information to be presented.
3. The program should identify specific target audiences and strategies for reaching those audiences.
4. The program should identify and work in support of those organizations best suited to assist in the task of public education.
5. The program should provide teacher training workshops.

Other recommendations for education and public awareness include the following:

- * Conduct a study identifying and describing the presentation of estuarine and local environmental science in the A/P region's public schools and determine, if possible, the long-term effects of such education. Such a study could help identify successful strategies for classroom presentation and teacher education.
- * Assess current youth and adult understanding of environmental issues and concepts, so that public education programs can be tailored to their needs.
- * Encourage local school systems and funding agencies to support teachers attending training workshops and to provide study and presentation materials for estuarine-related topics. There is a need for strong leadership within the public school system to create new and expand current programs. Such programs are often heavily dependent upon a few enthusiastic individuals and one-time funding efforts from sources such as the A/P Study.
- * Conduct follow-up studies to determine the effectiveness of teacher workshops, educational materials, and different modes of presentation.
- * Develop cooperatively with professional educators additional information and materials on estuarine related topics
- * Encourage community college officials in the region to become more actively involved with adult education outreach and extension programs dealing with coastal and estuarine issues. The Community Colleges should also be encouraged to provide more standard course offerings related to these issues, such as Marine Operations, Fishing, and Wastewater Disposal.
- * Work with the NC Department of Public Education to develop curricula regarding estuarine systems and aquatic resources for the public school system. Ideally, such programs would be initially introduced in primary schools and expanded upon in the secondary schools as special units or as elective science courses.

G. SUMMARY

The A/P Study region, like other coastal regions, is experiencing rapid growth of permanent and seasonal (recreational) populations. This growth generates employment opportunities and revenues, but also has associated with it real costs. The growth is placing ever-increasing demands on the limited resource base: direct demands for the extraction and utilization of coastal and estuarine resources and indirect demands for continued existence of those resources. Direct uses of the estuarine system include commercial and recreational fishing, marina development and operation, travel, and tourism. Indirect uses of the estuarine system may be supportive of or completely independent of the direct uses. They include the agricultural, construction, manufacturing, transportation, wholesale, retail, finance, and service sectors.

Growth of each of the direct use sectors can be measured in real dollar terms. Measurements of specific industries give indications of the growth of the indirect use sectors. In this report, trends in agriculture, mining, national defense, point source waste disposal, and automobile registration and traffic are described.

State and federal legislative/regulatory programs as well as numerous educational programs supported by state, local, and federal governments and private organizations aim to combat the negative effects of coastal development and foster good stewardship in the citizens of the North Carolina.

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APPENDIX V-I
PROGRAMS THAT AFFECT DEVELOPMENT IN THE A/P REGION
(December 1986)

Federal Legislation

Major Impact

Anadromous Fish Conservation Act
Clean Air Act Amendments (1967, 1970, 1977, and 1990)
Clean Water Act (1977)
Coastal Barrier Resources Act (1982)
Coastal Zone Management Act (1972)
Comprehensive Environmental Response, Compensation, and Liability Act (1980)
Consolidated Farm and Rural Development Act (1965)
Department of Transportation Act (1966)
Disaster Relief Act (1974)
Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)
Federal Environmental Pesticide Control Act (1972)
Federal Land Policy and Management Act (1976)
Federal Water Pollution Control Act Amendments (CWA) (1972)
Fish and Wildlife Act (1956)
Fish and Wildlife Conservation Act (1980)
Fish and Wildlife Coordination Act (1934)
Fishery Conservation and Management Act (1976)
Forest and Rangeland Renewable Resource Planning Act (RPA)
Highway Beautification Act (1965)
Housing and Community Development Act
Land and Water Conservation Fund Act
Marine Mammal Protection Act (1972)
Marine Protection, Research, and Sanctuaries Act (1972)
Migratory Bird Conservation Act
Migratory Bird Treaty Act (1918)
Mineral Leasing Act (1920)
National Environmental Policy Act (NEPA) (1969)
National Flood Insurance Act (1968)
National Forest Service Organic Act (1897)
Ports and Waterways Safety Act (1972)
Resource Conservation and Recovery Act (RCRA) (1976)
Rivers and Harbors Acts (1899, 1917, and 1968)
Rural Development Act (1972)
Safe Drinking Water Act (1974)
Small Business Act
Soil Conservation Act (1935)
Solid Waste Disposal Act
Surface Mining Control And Reclamation Act
Toxic Substances Control Act (TOSCA) (1976)
Water Quality Improvement Act (1970)
Water Resources Planning Act (1965)
Watershed Protection and Flood Prevention Act (WPFPA)

Minor Impact

Airport and Airway Development Act (1970)
Airport and Airway Improvement Act (1982)
Atomic Energy Act (1954)
Commercial Fisheries Research and Development Act (1964)
Energy Reorganization Act (1974)
Energy Supply and Environmental Coordination Act (1974)
Fish Restoration and Management Projects Act (1950)
Wild and Scenic Rivers System

Marginal Impact

Agriculture and Consumer Protection Act
Deep Seabed Hard Mineral Resource Act (1980)
Deepwater Port Act (1974)
Federal Water Power Act (1920)
Food and Agriculture Act (1962)
Hazardous Material Transportation Act
Interstate Land Sales Full Disclosure Act (1969)
National Ocean Pollution Research and Development and
Planning Monitoring Act (1978)
National Wilderness Act (1964)
Natural Gas Act (1938)
Natural Gas Pipeline Safety Act (1968)
Natural Gas Policy Act (1978)
Noise Control Act (1972)
Occupational Safety and Health Act (OSHA) (1970)
Oil Pollution Act (1961)
Outer Continental Shelf Lands Act (1953)
Port and Tanker Act (1978)
Public Health Services Act
Shipping Act (1916)
Submerged Lands Act (1953)
Urban Mass Transportation Act (1964)
Water Bank Act (1970)

State Legislation**Major Impact**

Agricultural Development Act
Air and Water Resources Act
Boating Safety Act
Coastal Area Management Act (1974)
Conservation and Historic Preservation Agreements Act
County Service Districts Act
Dredge and Fill Act
Drinking Water Act
Emergency Management Act
Environmental Policy Act (1971)
Fisherman's Economic Development Program
Forest Development Act
Industrial and Pollution Control Facilities Federal Program
Financing Act

State Legislation (cont.)

Major Impact (cont.)

Industrial and Pollution Control Facilities Financing Act
Metropolitan Sewerage Districts Act
Metropolitan Water Districts Act
Mining Act (1971)
Mosquito Control Districts
Municipal Services Districts Act
Municipal Subdivision Control Act
Municipal Zoning Act
Natural and Scenic River System Act
Nature and Historic Preserve Dedication Act
Oil Pollution and Hazardous Substances Control Act
Pesticide Law (1971)
Regional Sewage Disposal Planning Act (1971)
Regional Water Supply Planning Act (1971)
Sedimentation and Pollution Control Act (1973)
Small Watershed Projects Act
Soil Additives Act
Soil and Water Conservation Districts Act
Solid Waste Management Act (1978)
Special Assessments Act
Stream Sanitation Act
Structural Pest Control Act
Toxic Substances Act (1979)
Water Use Act (1967)
Watershed Improvement Districts Act
Watershed Improvement Programs Act
Well Construction Act (1967)
Wildlife Resources Law

Minor Impact

Condominium Act
Outdoor Advertising Control Act
Tax Increment Financing Act
Trails System Act
Water Safety Act

Marginal Impact

Advertising Control Act
Air and Water Quality Reporting Act
Airport Development Act
Alien Property Act
Annexation Act
Archives and History Act
Atlantic States Marine Fisheries Compact Act
Balanced Growth Policy Act
Bicycle and Bikeway Act (1974)
Building Contract Act
Carrier Act
Cemetery Act
City-County Consolidation Act

State Legislation (cont.)

Marginal Impact (cont.)

Condemnation Act
Connor Act (registration of conveyances)
Corporations Act
Dam Safety Law (1967)
Energy Policy Act
Engineering and Land Surveying Law
Fiscal Information Act for Local Government
Fraudulent Conveyance Act
Gas Conservation Act
Highway Safety Act
Horizontal Property Act
Housing Authorities Law
Housing Corporation Act
Housing Finance Agency Act
Inheritance Tax Act
Land Contracts Registration Act
Land Policy Act
Local Government Budget and Fiscal Control Act
Local Government Fiscal Information Act
Local Government Bond Act
Mine Safety and Health Act
Mining Compact
Municipal Corporations Act
Municipal Finance Act
Municipal Fiscal Control Act
Occupational Safety and Health Act of North Carolina
Oil and Gas Conservation Act
Public Building Contracts Act
Public Transportation Authorities Act
Public Utilities Act
Public Utilities Commission Act
Public Works Act
Quarries and Mines Act
Real Property Acquisitions Policies Act
Right of Way Act
Rural Electrification Act
Sales and Use Tax Act
Sinking Fund Act
S.E. Interstate Forest Fire Protection Compact
S.E. Interstate Low-level Radioactive Waste Management Compact
Southern Growth Policies Agreement Act
Southern State Energy Compact
Supplemental Local Government Sales and Use Tax Act
Transportation Authorities Act
Unmarked Human Burial and Human Skeletal Remains Protection Act
Use Tax Act

VI. SUMMARY

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CHAPTER VI: SUMMARY

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A. THE STUDY

During the last decade, the US Environmental Protection Agency has organized and co-sponsored "management conferences" on estuaries of national concern. These conferences of federal and state environmental regulatory and management agencies were organized to respond to public concern arising from the fact that some of the nation's prominent estuaries are in serious decline in spite of a plethora of laws and regulations enacted in the 1970s to protect them. The Albemarle-Pamlico estuarine system of North Carolina was designated as one of the estuaries of national concern in 1987. A series of activities was initiated that are designed to culminate in 1992 with a comprehensive management plan to more effectively manage the system and to reverse any degradation that has occurred. This report is an analysis of status and trends that will serve as the precursor for development of the comprehensive management plan.

This report contains the best synthesis of the existing information about the Albemarle-Pamlico estuarine system currently available; it includes an assessment of the status and trends of probable causes apparent in the system. This technical study has been summarized in a general interest document suitable for public use. Specific objectives of this status and trends analysis project, therefore, were:

1. To develop an outline for each of four broad areas of concern: Critical Areas (Chapter II), Water Quality (Chapter III), Fisheries (Chapter IV), and Human Environment (Chapter V); and to set up a mechanism for analysis and summarization;
2. To direct the attention of an organized group of the State's top experts in each area toward developing a consensus of the status of each key issue;
3. To generate a narrative of the status and trends, including an analysis of probable causes, of the four key areas and to test the conclusions against technical experts, organizations and leaders of public opinion; and
4. To publish this "Status and Trends Report" and to create a general interest summary for public use.

This exercise was approached through a series of work sessions in which the experts available provided their ideas about the status and trends of issues facing the estuary. Data files available to and utilized by these experts form the basis for the technical analyses. Technical quality was emphasized more than completeness--i.e., it was concluded that it is far better to relate an accurate picture than to include every shred of data that has ever been collected.

It should be emphasized that this is a "living document"; that is, further information and analysis will be added as they become available. A comprehensive management plan will be developed from the status and trends analysis.

B. THE SETTING

The Albemarle-Pamlico (A/P) estuarine system is one of the largest and most important in the United States. With approximately 2,900 square miles of area, the complex is the second largest estuarine system on the East Coast of the United States, exceeded in area by only the Chesapeake Bay. The estuarine system comprises an extensive complex of creeks, rivers, swamps, marshes and open water sounds dominating northeastern North Carolina. Tributaries originating in the Piedmont serve as conduits to a major geographic portion of North Carolina and southeastern Virginia. Albemarle Sound

is the drowned portion of the Roanoke River and its extensive floodplain. Other major, lateral tributaries of Albemarle Sound include the Chowan, Perquimans, Little, Pasquotank and North Rivers on the north; and the Scuppernong and Alligator Rivers on the south. Pamlico Sound is the drowned portion of the Tar and Neuse Rivers and their extensive floodplain. Several small, lateral tributaries drain off the low, flat, swampy coastal area; with the largest one being the Pungo River on the north.

Neither sound is directly connected to the Atlantic Ocean: both are behind extensive barrier islands referred to as the "Outer Banks". Albemarle Sound has three open-water estuaries at its eastern end that are parallel to the ocean and Outer Banks--the freshwater Currituck Sound to the north and brackish Croatan and Roanoke Sounds to the south. Albemarle Sound is connected to the ocean through Croatan and Roanoke Sounds via Pamlico Sound. As a result, Albemarle Sound is strongly influenced by freshwater and only marginally by the ocean. Pamlico Sound is connected to the ocean through several inlets including Oregon, Hatteras, Ocracoke, Drum, Bardon and Beaufort. These tidal connections exert considerable oceanic influence on Pamlico Sound.

Albemarle Sound and Pamlico Sound, as well as Core, Bogue and Currituck Sounds, are the focus of the Albemarle-Pamlico Estuarine Study and, therefore, this report. The study area encompasses the entire drainage basin of Albemarle and Pamlico Sounds, except for the portion of the Roanoke River Basin that lies above Lake Gaston. Roughly one-third of North Carolina and one-sixth of Virginia are, therefore, included. The seaward limit of the study area is the Atlantic Ocean shoreline.

C. RESPONSE TO ENVIRONMENTAL CONCERNS

Definite changes have taken place in the Albemarle-Pamlico estuarine system in recent years -- hence, the designation as an estuary of national concern. Early in the study, the Albemarle-Pamlico Estuarine Study Work Plan identified a series of environmental conditions that concern scientists, management agencies, and the public. There is a general impression that events of concern have become more frequent, and that conditions that cause definitive environmental problems are not well understood. The purpose of this summary is to relate our findings to those concerns previously identified.

C. 1. Declines in Fisheries Production

The fisheries resources of the Albemarle-Pamlico estuarine area are very important to the state and region. Commercial fishing is one of the oldest industries in North Carolina, having its genesis in colonial times. Recreational fishing is a more recent, but rapidly growing component of the coastal economy. Often, both commercial and recreational fishermen seek (or take as by-catch) the same species, thus giving rise to conflicts between these two groups. The increasing demand for fisheries products and recreational pursuits has resulted in potential declines by over-fishing and/or destruction of habitat by certain harvesting techniques. Changes in land use, increases in pollution loadings, and physical perturbations have affected habitats--thereby negatively affecting fisheries' yields. More than 90% of North Carolina's seafood catches are dependent on the vast, shallow sounds and the multitude of embayments and tributaries around the sounds. Habitat types in the Albemarle-Pamlico estuarine system include one of the largest coastal freshwater sounds in the country, major anadromous fish spawning and nursery grounds, large areas of sea grass meadows, vast expanses of adjacent and diverse wetlands, and nursery grounds for most of the economically important species on the East Coast.

The longest fisheries data base is the commercial landings statistics, which extends from 1880 to the present. Commercial landings data are generally used to indicate levels and trends in fisheries primarily because they are the longest consistent record available. Landings data, however, are influenced by many

factors, such as market demands, price, fishing effort, weather, availability of alternate species, regulations, stock abundance, and validity of reporting, which may render them questionable as indicators of fish stocks. In any case, they characterize the various fisheries and provide insight into fishing trends relative to the various factors which influence the statistics. Very little long-term data exists for recreational fisheries catch, but recent commercial landings data indicate severe declines in stocks of several species.

A fisheries management issue needing immediate attention concerns the collection, assimilation and analysis of the fisheries data base to determine the true status and trends of the fishery resource. Commercial landings indicate drastic declines in most of the anadromous fish (Albemarle Sound) during the past 30 years, but the yield of migratory fish (Pamlico Sound) have fluctuated. While there have been declines over certain periods (e.g., the 1980s), it is unclear whether total fisheries resources have, in fact, declined.

North Carolina allows a wide variety of fishing activities with relatively little regulation, compared to other states. As a result, the Albemarle-Pamlico estuarine system is one of the most intensively fished areas on the Atlantic Coast. Large numbers of people fish, both commercially and recreationally, for a wide variety of species and use a large assortment of gear. As expected, this intense utilization results in highly volatile management issues. Arguments over the allocation of species and fish among commercial and recreational interests has intensified in recent years. In addition to commercial and recreational conflicts, user conflicts often occur between different commercial harvesting sectors.

Impacts on fishery habitats, resulting from fishing practices, pollution, and physical alterations have increased. Trawls, clam kicking, and mechanical dredging all disturb the bottom. Nursery areas and critical wetlands habitats have been destroyed and/or altered. The impact of by-catch on subsequent stock levels has been recently questioned. Unfortunately, no quantitative relationships between these "perturbations" and fisheries yields have been developed.

C. 2. Sores and Diseases

Epidemic disease was first reported in the Albemarle-Pamlico estuarine system in the 1970s, when there were massive kills of largemouth bass and white perch and smaller kills of other species in Albemarle Sound. Dying fish frequently had extensive skin lesions, which were referred to as "red sores". During the summer of 1975, as much as 50% of the commercially harvested fish in Albemarle Sound was affected. Levels of the observed bacterial invader, Aeromonas hydrophila, apparently correlate with levels of several water pollution indicators, although no direct correlation to the onset of red sore with any known indicators has been described.

More recently, other types of diseases have been recognized in Currituck Sound and Pamlico Sound (and its tributaries). In the winters of 1981 and 1983, southern flounder from the Pamlico and Pungo Rivers exhibited lesions, which significantly declined when the water warmed in the spring. An epidemic of severe ulceration of largemouth bass was reported for Currituck Sound during the winter and spring of 1986-1987. The most common disease currently affecting fish in the Albemarle-Pamlico estuarine system is ulcerative mycosis, a fungal infection especially affecting Atlantic menhaden. First reported in the Pamlico River in 1984, it has since been reported for the Neuse River, New River, and Albemarle Sound. The disease has also been reported in several species other than menhaden, and it seems that other species are affected when menhaden epidemics are at their peak.

While lesions on finfish have been most intensively studied in the area, problems with shellfish have also recently been documented. In 1987, a shell disease was reported on blue crabs in the Pamlico River. The shell lesions in the Pamlico River blue crabs were reported to be very aggressive, frequently penetrating the carapace and rendering the crab unsalable. The shell lesions were more prevalent on the

south side of the Pamlico River where cadmium and fluoride concentrations in the sediments were relatively high.

Disease problems have also recently (1988) been reported in oysters. Core and Pamlico Sound oysters were infected by MSX and *Dermosystidium*, both of which are fatal. These pathogens have now spread to oysters in other areas. Toxic dinoflagellate blooms in the fall and winter of 1987 resulted in mortalities of bay scallops.

Definitive causal relationships between diseases and sores and environmental factors have not been established, but declining water quality has been implicated. It is evident that finfish and shellfish are exposed to abnormal stresses in certain areas.

C. 3. Anoxia-Related Fish Kills

There are no systematic data regarding fish and benthos kills in North Carolina's estuaries, although most fish kills have been attributed to low concentrations of dissolved oxygen. In most cases, measurements of dissolved oxygen have been made after a kill is reported so that precise determination of circumstances at the time of a kill is difficult. Commissioning of the Pamlico Environmental Response Team (PERT) may help close the time gap between reporting and investigation of fish kills and may, thereby, generate more pertinent information. Comparisons among 23 estuaries in North Carolina, South Carolina, and Georgia, indicate that the Pamlico is not unique nor are there prolonged periods of impact. Lack of long-term data for these systems makes it impossible to determine exactly how much impact cultural eutrophication has had on the dissolved oxygen conditions.

Bottom water dissolved oxygen concentration is controlled primarily by climatic and hydrologic factors in the Pamlico River Estuary, the only area where studies have been conducted. There has been no trend toward lower dissolved oxygen concentrations over the past 17 years of record. Low bottom water dissolved oxygen (hypoxia) does not occur in the estuary when water temperatures are lower than about 20°C. Above 20°C, dissolved oxygen values of less than 1 mg/liter were found in about 20% of the samples from the upper estuary, but in only 4% of the samples from the lower estuary. Salinity stratification prevents mixing of the bottom water with surface water, which prevents aeration of the bottom water, leading to anoxia. Anoxia can become established in a short period of time during summer; and, conversely, can be dissipated very quickly if mixing occurs.

While widespread sediment contamination is not apparent, several "hotspots" of elevated concentrations of heavy metals have been identified within the study area; most are believed to be associated with known point source dischargers. Anoxic and other adverse water quality episodes were probably as common in past decades, as they are today. However, long-term data upon which to base arguments regarding changes and trends in sediment characteristics and subsequent water quality or biological impacts simply are not yet available. The precise relationship between pollutant loading and pollutant concentrations in sediments is unknown since the role of nutrient recycling has not been quantified.

C. 4. Changes in Distribution Patterns of Benthic Organisms

Beds of submerged aquatic vegetation (SAV) occupy the shallow waters immediately behind the barrier islands (seagrass meadows) and some of the tributaries along the mainland side of the Albemarle-Pamlico estuarine system. Distribution of the SAV varies greatly in space and through time. Near the inlets, and in higher salinity water, the SAV is composed largely of eelgrass and Cuban shoalgrass. In waters of somewhat lower salinity, widgeongrass may predominate; and in slightly brackish or fresh water areas, wild celery, Eurasian watermilfoil, or a mixture of pondweeds and related species may occur.

Currituck Sound once contained dense growths of native SAV, which were largely replaced by Eurasian watermilfoil during the 1960s and 1970s. The watermilfoil decreased dramatically during the latter 1970s and was replaced, in turn, by widgeongrass (a native plant). Similarly, SAV was common in the Pamlico River until the mid-1970s, decreased to about 1% of its former concentration by 1985, and has since recovered to some degree. Seagrass meadows near the Outer Banks have remained relatively stable in their coverage during the past 20 years, although mechanical shellfish harvesting and land-use changes have caused local perturbations.

Studies have indicated that SAV is a very important habitat, nursery area, and food source for many important estuarine organisms. The bay scallop, for example, is dependent upon seagrass meadows for its propagation and survival. However, quantitative links between SAV and secondary productivity are generally unknown.

Declines in the SAV in the tributary areas (e.g., Pamlico River and western Albemarle Sound) are thought to be caused by increases in turbidity of the water. Causes of increased turbidity are thought to be water quality related (i.e., increased algal growth in response to nutrient additions and increased suspended solids). Available evidence indicates that the increases in nutrient loading seen during the past have been reversed and that the actual loading rates today are declining. Perhaps this could explain some of the reasons for SAV recovery in recent years.

There is considerable interest in the commercial benthic assemblages (i.e., bay scallops, hard clams, and oysters), but they do not constitute a significant feature of Albemarle Sound. Distribution and abundance patterns of bay scallops are virtually unknown, although they seem to be intimately related to seagrass meadows. Hard clams are limited in their distribution by salinity, with populations almost entirely restricted to eastern Pamlico Sound and Core Sound. Hard clam abundance is strongly affected by harvesting pressures and techniques that harm the bottom habitat, both of which have apparently decreased the abundance of hard clams. Oysters, which require a hard substrate in mid-salinity waters, have recently moved upstream in response to drought conditions. The incidence of MSX and *Dermocystidium* has dramatically increased since 1988, probably as a result of the hot, dry summer of 1988. Consequently, there has been a dramatic decline in oyster populations. Some shellfish areas are closed to harvesting due to the occurrence of pathogens (as indicated by coliform tests). Permanent closures of this type have remained relatively stable, but the number of temporary stormwater-related closures has continued to increase.

Assemblages of benthic animals serve as food for many important finfish and shellfish. In some areas, especially the Pamlico River Estuary, anoxia results in massive die-offs. The benthic population, however, seems to recover during the fall and winter recruitment time when the water does not experience extensive anoxia.

C. 5. Impairment of Nursery Area Function

Nursery areas are those shallow, protected waters where post-larval and juvenile fish and shellfish development occurs. Primary nursery areas are generally located in the upper portions of tributaries and embayments around the sounds and rivers. They are generally bordered by marshes. Primary nurseries are used mostly by organisms which arrive in late winter and spring from ocean spawning grounds and leave by summer. Transport mechanisms are related to wind-induced tides and currents in combination with larval behavior.

Primary nursery areas were first designated in 1977 by North Carolina Marine Fisheries Commission regulations. Designation is based on the occurrence of certain concentrations of specified species. Immediately downstream from primary nursery areas, the secondary nursery areas are larger, deeper waters containing high numbers of mixed sizes of organisms. Most juvenile organisms leave the primary

nursery areas during the summer and occupy the secondary nursery areas until they migrate offshore with declining temperatures in the fall.

Because primary nursery areas are located in the upper reaches of estuaries and are characterized by low salinity, they are very easily affected by activities on adjacent uplands. Variations in freshwater inflow, resulting from land drainage or an increase in the area of impermeable surface, can alter the velocity and magnitude of salinity changes. Sediments from land clearing and development activities can reduce light penetration and suffocate benthic organisms. Nutrients and other pollutants originating from septic tanks or industrial and municipal point sources and non-point sources can increase production of frequently unwanted plankton or decrease other organisms through toxic effects.

Although there are regulations which can be used to reduce such impacts, the degree to which any perturbation is limiting primary nursery area functioning at any particular time is difficult to demonstrate due to the complexity of the estuary and synergism among environmental factors. While there are many pieces of evidence that primary nursery areas are sensitive to environmental alterations and impending threats, no definitive analysis of environmental or fish population trends in the nurseries has been completed. Because of the tremendous importance of the primary nursery areas to the continued propagation of fish and shellfish, protection of these sensitive areas must continue.

C. 6. Eutrophication

Among the vast suite of nutrients essential for primary production, nitrogen and phosphorus have been of most concern as "limiting factors" controlling eutrophication. Accelerated eutrophication is of environmental and economic concern. Frequently, serious water quality degradation in the form of uncontrolled nuisance algal blooms accompanies accelerated eutrophication. To varying degrees, symptoms of eutrophication have affected many tributaries of the Albemarle-Pamlico estuarine system, with fully developed cases being observed in some. In all cases, enhanced sediment and soluble nutrient loadings have been identified, or suspected, as causative agents for some forms of water quality degradation.

Sources of pollution are generally grouped into two categories -- point sources and nonpoint sources. Point sources of pollution enter a stream or estuary at a discrete location (or point), usually a discharge pipe. Point sources are composed of municipal and private wastewater treatment facilities. These facilities must obtain a National Pollutant Discharge Elimination System permit from the NC Division of Environmental Management which limits the amount of pollution that may be discharged to a given water body. Point sources contribute about 15% of the North Carolina nutrient inputs to the Chowan, about 50% to the Neuse, and about 18% of the nitrogen and 7% of the phosphorus (Texasgulf, Inc.) to the Tar-Pamlico. In contrast to point source pollution, nonpoint source pollution is that which enters waters mainly as a result of precipitation and subsequent runoff from land or percolation through the soils--primarily from areas that have been disturbed by man's activities. Nonpoint source pollution is addressed through a combination of regulatory, cost incentive and voluntary programs.

In 1988, the NC Division of Environmental Management conducted a water quality assessment of the Albemarle-Pamlico study area as part of the statewide Nonpoint Source Assessment (NSA) Report to determine impacts from nonpoint sources of pollution. Using information from "monitored" (based on ambient data) and "evaluated" (based on information other than site-specific data, such as complaints or professional judgement) segments, overall water quality ratings were assigned to nearly all stream and estuary segments. Nearly half (49%) of all stream segments in the A/P study area were judged to be "unimpacted" by nonpoint sources of pollution, while nearly 40% were "partially" or "seriously" impacted (11% were not evaluated). In the estuarine portion of the study area, about 93 of the segments were unimpacted by nonpoint sources. It should be noted that "unimpacted" indicates that the segment in question met water quality criteria for the designated use.

Trends in land use and nutrient loading over long periods of time were estimated for two major tributaries of Pamlico Sound. Estimates were made for the Neuse River basin by summing computed estimates of annual point and nonpoint source loadings for each county during the period of 1880 through 1985. Twenty years (1967-1986) of data for the Pamlico River Estuary were synthesized. Both sets of data were subjected to a non-parametric trend testing to analyze for statistical significance and magnitude of trends. No such analysis has been done for the Albemarle Sound system.

Despite the scarcity of open-water nutrient and productivity data, a reasonably diverse and comprehensive data bank has been established for some of the main tributaries; especially the Chowan, Pamlico, and Neuse River estuaries. The main forms of nutrient inputs are nitrates and phosphates (ammonia is more significant as an "internally cycled" nutrient). Nonpoint sources are thought to be the major contributors of both nitrates and phosphates; although point sources become more significant for phosphates than nitrates and during the summer nitrate from point sources becomes relatively more important.

Nitrogen, chiefly as nitrate, loading and cycling is a strong determinant in the regulation and ultimate limitation of primary production as well as bloom development in the freshwater tributaries and diverse estuaries examined to date. Accordingly, nitrogen loading and flux rates, as well as magnitude, timing and location of inputs, are of vital importance in assessing production and eutrophication processes in the estuarine portions of the study area. Phosphorus loading, cycling and utilization by phytoplankton, on the other hand, is quite a different picture. There are, indeed, quite high standing concentrations (in comparison to other highly eutrophic, similar systems in the country) of phosphate in North Carolina coastal waters. Whereas inorganic nitrogen is often rapidly depleted during summer phytoplankton growth periods, phosphate concentrations act in a much more conservative fashion, indicating both excess supplies and a general lack of phosphorus limitation. Furthermore, phosphorus is effectively recycled between sediments and the water column, assuring the maintenance of sufficient supplies of phosphate during periods of maximum phytoplankton demand (exceptions may occur in the Chowan River during bloom periods when high algal biomass leads to concurrent depletion of nitrogen and phosphorus). Phosphorus appears to have limiting effects (i.e., additions provide stimulation of productivity in the presence of nitrogen) during the high runoff spring months when rapid dilution can occur.

Accelerated nutrient loading, particularly over the past 2 to 3 decades, has ushered in some ominous and increasingly common symptoms of eutrophication, which apparently were extremely rare prior to World War II. However, data to verify the trophic state of coastal rivers and estuaries prior to the mid-1960s simply do not exist. Trend analysis for the Neuse River estuary indicates that total phosphorus loadings from all sources increased about 60% during the past century, primarily due to point sources, and total annual nitrogen loading is estimated to have increased about 70% from both point and nonpoint sources. By contrast, total phosphorus levels in the middle of the Pamlico Estuary have doubled since 1967, with smaller increases in both upstream and downstream sections. Nitrogen concentrations are very similar to those of the Neuse. No trend analyses have been performed on other estuaries in the study area. It is recommended that a long-term trend analysis be completed for the Albemarle Sound area. While significant progress has been made in recent years to reduce the nutrient loading to the Albemarle-Pamlico estuarine system, continuing development and population increases threaten to bring the loading rates back to previous levels in a few years.

C. 7. Habitat Loss

The Albemarle-Pamlico estuarine system has vast and diverse acreage of critical habitat that constitutes the foundation of the region's inherent wealth. Some of these are particularly important in sustaining its vitality. Habitats were assessed based on their role (1) in maintaining estuarine

productivity, (2) as indicators of the environmental health of the region, or (3) of uniqueness, sensitivity to disturbance, or relationship to regional development.

Drastic losses and shifts have occurred in the brackish water submerged aquatic vegetation communities. By contrast, the marine submerged aquatic vegetation communities appear relatively stable, at least since the recovery of eelgrass from the "wasting disease" of the 1930s. The number of applications for permits for development activities that could potentially affect the seagrasses is increasing, and mechanical harvesting of clams and bay scallops continues to threaten the stability of the seagrass communities. It has been established that the submerged aquatic vegetation serves as critical habitat for several important animals.

Indirect impacts are more subtle and difficult to assess. These effects center around changes in light availability to the plants by changes in turbidity. Turbidity, which results from upland runoff with suspended solids or nutrients, causes decreases in SAV growth and hardiness. This is the primary cause thought to have affected the decline in SAV in the upper estuarine areas.

Coastal wetlands, consisting of tidal salt marshes, tidal freshwater marshes (or swamps), nontidal brackish marshes, fringe swamp forests and nontidal freshwater marshes, receive attention because of the many biological, geomorphological and hydrological values they provide for society. The Albemarle-Pamlico region has one of the most extensive and diverse assemblages of this type of habitat anywhere. In spite of this preponderance of habitat types, the North Carolina systems have received surprisingly little study. It is not possible to judge whether the rate of loss of these wetlands is increasing because of the lack of accurate information for the past; although, the available observations indicate that North Carolina has lost several thousand acres over the recent years.

Tidal salt marshes, because of the high level of protection afforded them, are not likely to suffer future losses as a result of direct impacts like dredging and filling. In addition, the technology for creating new marsh is very advanced. Rising sea level and inlet instability are the primary threats to tidal salt marshes.

Nontidal brackish marshes seem to be stable now, but we do not know the extent of alteration or how alterations are distributed among geographic areas. Analysis could be very easily done by using aerial photography. In many areas, the marshes have been ditched for mosquito control and impounded for waterfowl management. These wetlands are protected by the same mechanisms used for other wetlands. The influence of rising sea level on these and associated ecosystems should be considered in all projections.

Fringe swamps have been harvested for timber. It is likely that they were the first to be cut during colonial times because water provided access. In many places now, poor stocking may make these forests of more limited timber value, especially where shoreline erosion has exposed gum-maple-bay assemblages of smaller trees. Regulatory mechanisms are in place to protect the fringe swamps, but it is doubtful that they receive the level of surveillance that coastal marshes get.

The lack of consistent, comprehensive studies precludes precise identification of historical acreage of riparian forested wetlands and pocosins in the Albemarle-Pamlico area, but the geographic extent is significant. Forested wetland losses have occurred at a high rate on a national basis in recent years, but this may not be the pattern in the A/P region. Dredge or fill of these important habitats are regulated and mechanisms are in place to use them. However, general permits, jurisdictional disputes and categorical exclusions, particularly for silviculture, have contributed to wetland losses.

Going from navigable waters of the United States upstream and inland, one encounters a continuum from strong federal involvement and generally effective overall regulation to almost exclusive local control and fewer restrictions. Construction on lands beneath navigable waters of the United States,

extending inland to the mean high or low water line in tidal waters or the ordinary high water line in nontidal areas and including contiguous wetlands, is regulated by the US Army Corps of Engineers under provisions of the River and Harbor Act of 1899 (33 USC 401, 403). Dredging in coastal waters also requires a state permit (NCGS 113-22). Upland and inland from this zone, deposition of dredge and fill material in other waters and wetlands without a Corps permit is prohibited by Section 404 of the Clean Water Act (33 USC 1344). Much of the same area is included within Areas of Environmental Concern (AEC's) identified by the Coastal Resources Commission under provisions of North Carolina's Coastal Area Management Act (CAMA) (NCGS 113A-101 et seq.). Development in such areas requires a permit from the NC Division of Coastal Management. Discharge of pollutants into these areas is similarly regulated by a combination of federal and state laws, generally implemented through permits issued by the NC Division of Environmental Management.

A number of activities, which may have profound effect on critical habitat areas, escape the regulatory matrix. Nutrients, pesticides, and other pollutants may enter these areas through diffuse overland flow or other nonpoint sources without regulation, although Section 208 of the Clean Water Act (33 USC 1288) and Section 319 of the Water Quality Act of 1987 (33 USC 319) address this subject. Many interior wetlands are not protected against destruction unless fill is involved, and neither the state or nation has legislation directly addressing the wetland issue.

C. 8. Shellfish Closures

When the results of detailed Sanitary Surveys (bacteriological, hydrological, and shoreline surveys) indicate the potential for human infection, NC Shellfish Sanitation Branch recommends to the DMF that the affected waters be closed to the harvest of clams and oysters. There are roughly 270,000 acres of coastal waters closed to shellfishing on either a permanent or a temporary basis. The area closed has remained relatively constant over the past few years, down from a high of about 670,000 acres in the 1973. Decreases in permanent closures (due primarily to improvements in waste water treatment plants) seem to have been balanced by increases in temporary stormwater-related closures. Most of the closed areas are outside the A/P study area, but Core and Bogue Sounds and several small embayments are affected. In the A/P Study area, approximately 36,000 acres are closed to the harvest of shellfish. Roughly another 15,000 acres in the Study area are subject to temporary closures due to contaminated stormwater runoff, an indication of continued localized water quality degradation.

The source of bacteriological contamination (fecal coliform is used as an indicator organism) is the waste from warm-blooded animals. Bacteria enter coastal waters via treatment plant outfalls, percolation from nearby septic tanks, and runoff from uplands inhabited by humans and certain other animals. Often, after heavy rains, an additional several thousands of acres of shellfish production area may be contaminated and, therefore, closed for a period of time. While there is no indication of major water quality deterioration, this additional acreage of closures, especially in the smaller estuarine waters, indicates continued localized degradation of water quality. Regulations exist to help prevent land activities that would contribute to pathogenic contamination during runoff events.

New techniques to more accurately measure contamination and potential human impact have been developed, but have not yet been implemented at the state and federal levels. Their implementation might enable management to more effectively allocate shellfish resources. Relationships between contamination and land-use characteristics are poorly understood.

C. 9. Toxicant Effects

The first detailed study of the metals and toxicants in the Albemarle-Pamlico estuarine system is underway. The first phase, a study of heavy metal pollutants in the organic-rich muds of Pamlico and

Neuse River estuaries, has been completed. A similar study of the Albemarle Sound will be completed by the end of 1991. The Albemarle-Pamlico estuarine system is not thought to be severely contaminated relative to estuarine systems in more populous areas of the country, but several "hot spots" around known point source dischargers have been identified.

C. 10. Increasing Population and Development

The Albemarle-Pamlico study area has traditionally been rural in its character and is relatively sparsely populated. The diverse and tremendous natural resources, however, are attracting more and more people to the area. Population growth rate is far exceeding the state average, in both the North Carolina and the eastern Virginia segments. Building, services, transportation and sales are also increasing at a very rapid pace. These activities, along with increases in population and activities in the drainage areas, are imposing strains upon the governments, facilities, services and natural resources of the A/P region.

The changes and rates of changes are not evenly distributed in the area. Carteret, Dare and Currituck Counties are among the most rapidly growing counties in the state. Related activities are also rapidly increasing in these counties. Increases in recreational populations, when added to the increasing permanent population, have dramatically affected some areas, especially Dare County. There are instances of water supply limitations, groundwater declines and contamination, problems with waste disposal, and drastic changes in land-use to accommodate additional dwellings.

Indirect uses of the area are increasing faster than direct uses, and seem to have profound impacts in some areas. And, as the population continues to increase, these trends are expected to continue.

