ALBEMARLE-PAMLICO ESTUARINE SYSTEM

Preliminary Technical Analysis of Status and Trends

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Edited by

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and
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ALBEMARLE-PAMLICO ESTUARINE SYSTEM
Preliminary Analysis of the Status and Trends

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I INTRODUCTION AND BACKGROUND

Written by

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A. THE STUDY

A. 1. Background

During the last decade, the U. S. Environmental Protection Agency has directed its attention to "management conferences" on estuaries of national concern. This concern became necessary in response to public perception 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 1970's to protect them. Chesapeake Bay, Maryland and Virginia, was the first so designated. Later, Narragansett Bay, Rhode Island, Buzzards Bay, Massachusetts, Long Island Sound, New York, Puget Sound, Washington, and San Francisco Bay, 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 perceived trend of degradation. This technical report is a preliminary analysis of status and trends that will serve as the precursor for development of the comprehensive management plan.

Estuarine management is the responsibility of all, but the actual management requires good technical information and a public that understands the system, its problems and issues. Such understanding forms the basis for long-term commitment and development of support for specific management strategies. 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.

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 goals and objectives of the Albemarle-Pamlico Estuarine Study.

A. 2. Purpose of the Study

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 exercise will establish the precursor to the development of a comprehensive management plan for the Albemarle-Pamlico Estuarine System. Technical documents resulting from the analysis of each segment of this study will be summarized in a general interest document suitable for public use.

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. It is intended that a second publication will summarize this more technical version for general interests. Specific objectives, therefore, are:

1. To develop an outline for each of the key issues of Critical Areas (Chapter II), Water Quality (Chapter III), Fisheries Dynamics (Chapter IV) and Human Environment (Chapter V), and 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;

3. To generate a narrative of the status and trends, including an analysis of probable causes, of the four key areas and test the conclusions against technical experts, organizations and leaders of public opinion; and

4. To publish the current information in a technical document that can later be used to develop a final "Status and Trends Report" 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 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 the content of this report is a "preliminary technical analysis" of the status and trends. It will serve as the base from which a concentrated and extensive analysis of status and trends will be developed during the fourth year of the study. Subsequently, a comprehensive management plan will be developed from the status and trends analysis.

A large limitation was the constraint of time compared to the magnitude of the task of analyzing status and trends. Besides, the analysis of status and trends should and will involve the input of all strata 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. With approximately 2,900 square miles of area (Table I-1), the complex is 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).

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 to high
Fisheries		anadromous	marine and fresh
Percent catch of state total		14	78
Percent value of state total		5	73

The estuarine 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 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.

Both sounds are not directly connected to the Atlantic Ocean, but 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 (Figure I-1) extends upstream in tributary basins to the seaward-most impoundment, or if there is no impoundment, to the upstream boundary of the drainage basin, or if the basin extends into Virginia,

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

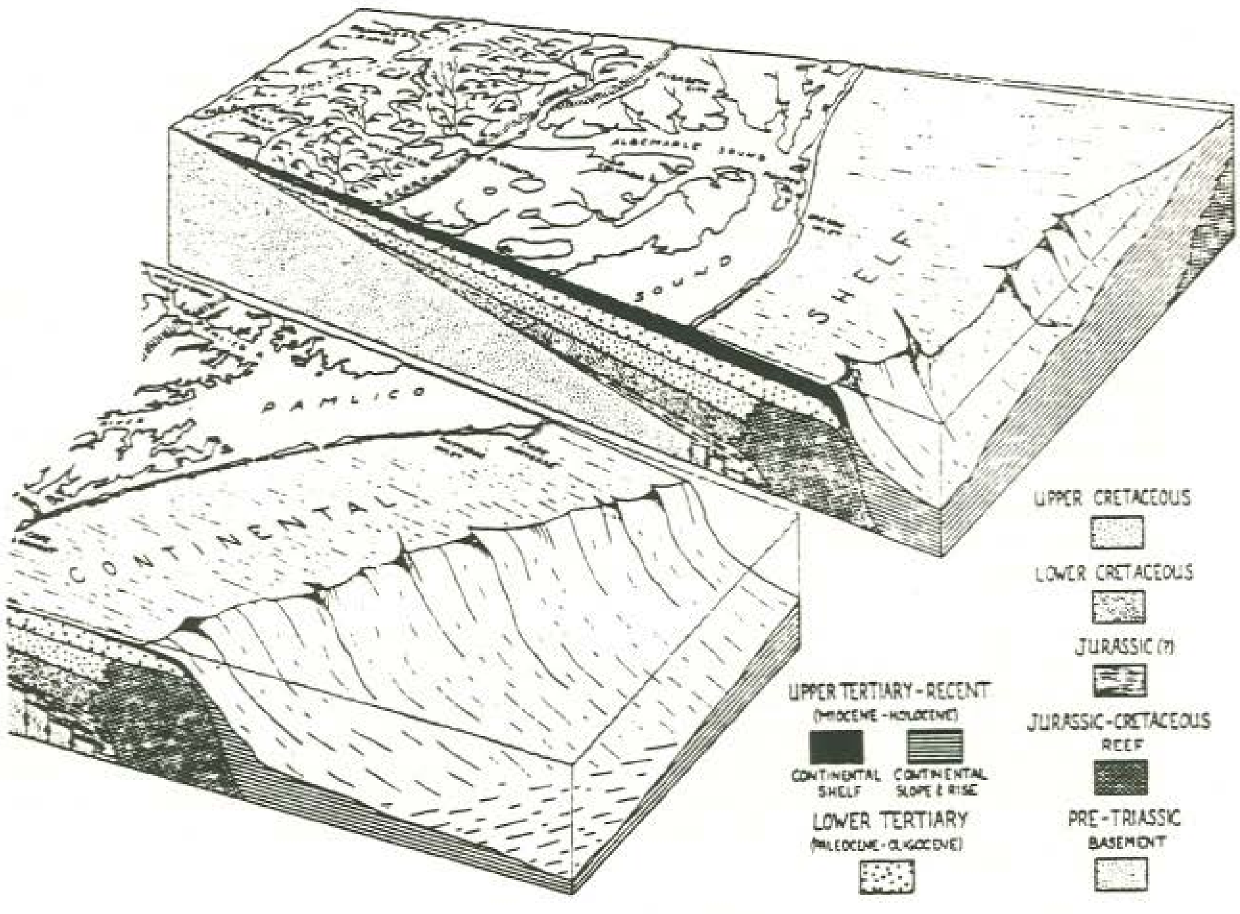

Fig. I-2. Cross-section of the Stratigraphy of Northeastern North Carolina. From Fairbridge 1960.

to the North Carolina-Virginia state line. The seaward limit of the study area is the Atlantic Ocean shoreline.

B. 2. Geological Origin

Sediments and sedimentary rocks of marine origin underlie the entire sound region (Brown et al. 1972). These sediments were deposited on top of the same type of crystalline rocks that occur in the Piedmont and were deposited when the ocean covered portions of the coastal plain. As the coastal system migrated back and forth across the coastal plain-continental shelf during geological times (for at least the last 100 million years) stratified rock layers were laid down. The marine sediments range from 600 m thick at Washington, North Carolina, to 1500 m near Swanquarter, to over 3 km at Cape Hatteras (Figure I-2).

While each in the series of formations has a distinctive textural, mineralogical and fossil composition, and 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. The names and ages of formations in Figure I-2 place the present-day estuary and its sediments in context. 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.

Sediments of interest for the recent Albemarle-Pamlico Estuarine System range from the Upper Miocene to the Pliocene. The Pliocene sediments deposited during this 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 (Hartness 1977). Most of these units are not fossiliferous or, if they have been, the fossils are often partly or completely leached out by the acid groundwater moving through the surface aquifers. The Miocene sediments, on the other hand, do contain several fossil layers and provide the sediments from which the phosphate mining industry along the Pamlico River is derived. 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 m under the outer portions of the Albemarle-Pamlico Estuarine System.

Recent sediments were formed during the Ice Ages of the Pleistocene, when the retreating and melting ice sheets brought about worldwide fluctuations in sea level. When the last major glacial ice advance reached its maximum about 17,000 to 18,000 years ago, the shelf edge was about 40 km east of Cape Hatteras. The land surface sloped gently seaward and was dissected by rivers and associate 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 product 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 (BP) 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.

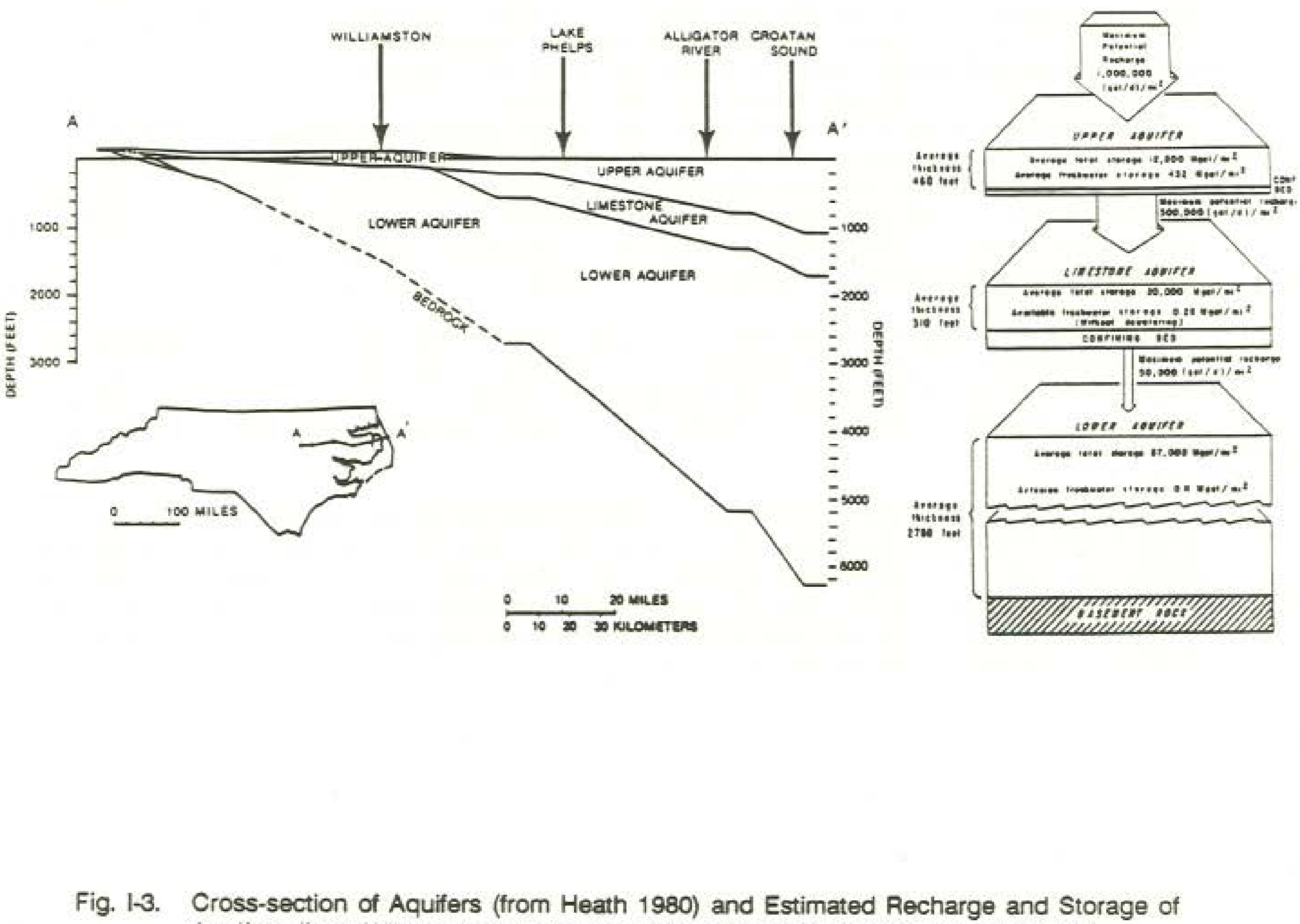

Fig. I-3. Cross-section of Aquifers (from Heath 1980) and Estimated Recharge and Storage of Aquifers (from Wilder et al. 1978) underlying the North Carolina Coastal Plain.

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 m elevations and represents an old barrier island shoreline formed by the sea during a previous Pleistocene interglacial 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 m elevations at the base of the scarp eastward to 0.3 to 0.6 m elevations 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 generally receives between 47 and 56 inches (120 and 142 cm) of rain per year, which varies greatly from place to place and over time (Wilder et al. 1978). Dry years average about 35 inches (89 cm) and in wet years may reach 78 inches (200 cm). Seasonal distribution is relatively uniform, with the highest precipitation occurring in association with thunderstorms in the summer and the lowest occurring during fall and, secondarily, spring. Temperature is moderate, with January averaging between 6 and 8 C° (43 and 46 F°) and the low seldom falling below -12 C° (10 F°). Summers are hot and humid, with the average daytime temperature often above 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 in the winter and localized thunderstorms, hurricanes and tornadoes creating major impacts 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). Distribution of land use indicates small urban areas and a generally rural setting. Land use in the area is changing but largely from forested to agricultural uses, not into large urban areas.

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 likely to be contaminated by land use activities–the water table lies very close to the surface in much of the low-lying areas around the sounds.

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

County	Total Acres	Water	Urban Etc.	Crop Land	Forest (total)	Wet-lands
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 into 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), Pamlico (Tar) River (5,400 cfs) and the Neuse River (6,100 cfs) for a major portion of the average annual inflow of 31,700 cfs (Giese et al. 1979). Freshwater input is not evenly distributed throughout the year, with the highest runoff during the late winter and early spring, and the lowest 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, such that winds blowing downstream may often drive most of the water from the embayment (Overton et al. 1988). Because of the shallowness, long fetch of the waterbodies 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 (about 17,000 cfs) is larger relative to the sound's volume (about 5.3 million acre-feet) than the 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 volume" for water in Albemarle Sound than in Pamlico Sound (Table I-1). Combined with the almost total isolation of Albemarle Sound from the ocean, the short time for inflow to replace volume 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	Precipi-tation	Evapo-ration	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	Precipi-tation	Evapo-ration	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

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.

<u>B. 5. a. Overview</u> 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. The economic importance of groundwater is high 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 in economic growth in the eastern area of the state, particularly in parts of northeast North Carolina and the Outer Banks.

The amount of precipitation that recharges the groundwater system averages about 20% of the annual precipitation (Winner and Simmons 1977), which ranges from about 44 to 56 inches (112 to 120 cm) in the Coastal Plain. 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 (N. C. Department of Human Resources 1984). Treatment of ground water 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-4). In locations where ground water is pumped near naturally-occurring saltwater, the saltwater may move upward and spread laterally toward pumped wells resulting in increased dissolved solids concentrations in parts of the aquifer.

Other naturally-occurring conditions which may render untreated ground water unsuitable for drinking water 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 leachate from landfills, seepage from waste lagoons, seepage from underground storage tanks and accidental spills of chemical materials; as well as from pumping near naturally-occurring saltwater. 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.

<u>B. 5. b. Principal Aquifers in the Albemarle-Pamlico Region</u> Four of the five major aquifers in North Carolina used for water supply are in the unconsolidated to partly consolidated sedimentary deposits of the Coastal Plain (Figure I-3). 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 Figure I-4 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 in two parts of the Albemarle-Pamlico basin--on the Outer Banks and on the mainland north of Pamlico Sound (Figure I-4). 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.

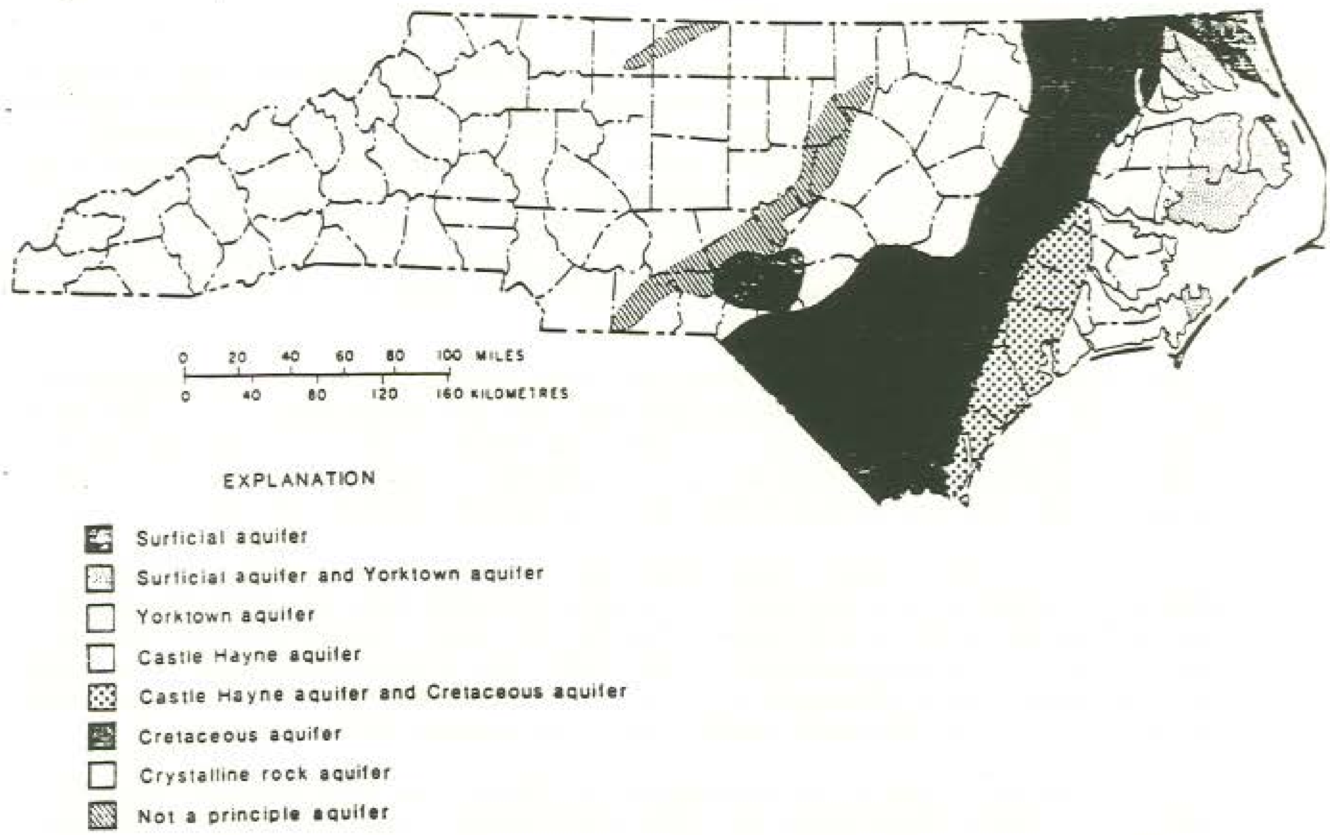

Fig. I-4. Principal Aquifers of North Carolina. From Coble et al. 1985.

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

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 of naturally-occurring conditions, the concentration of dissolved solids in water pumped from this area can exceed the 500 mg/l national secondary drinking-water standard (U. S. Environmental Protection Agency 1986).

On the mainland, the surficial aquifer is between 50 and 200 feet thick, and the aquifer 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, which renders 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 (U. S. 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 at depths of between 50 and 150 ft below land surface in the northern part of the Coastal Plain (Figure I-4). The Yorktown commonly yields 15-90 gpm to individual wells, although yields may occasionally exceed 500. Near Elizabeth City, the Yorktown 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 and 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 U.S. Environmental Protection Agency (1985) proposed a health advisory guidance level maximum of 20 mg/l for sodium in 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-4). In some locations where aquifers above and below the Castle Hayne contain saltwater, the Castle Hayne can yield freshwater. 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 possible.

Water from the Castle Hayne is generally hard (121 to 180 mg/l as 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. In contrast, 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 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 from the Castle Hayne aquifer to decrease artesian pressure and de-water overlying phosphate ore beds at a phosphate mine in Beaufort County. Over 60 million gpd are withdrawn from the aquifer near Aurora, 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 mine, a water level decline of over 80 feet has been observed since 1965 (Coble et al. 1985).

The **Cretaceous** aquifer (Figure I-4) is the most widely used aquifer in the Coastal Plain, with much of the withdrawals coming from the central and southern parts of the province. The aquifer occurs at depths of 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 must uses. Water from some parts of the aquifer may, however, contain fluoride concentrations in excess of 4 mg/l, which is the maximum allowable concentration under national drinking water standards (U.S. Environmental Protection Agency 1986). Hence, 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-4).

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

At the state line, water levels have declined abut 45 feet since 1966 and are estimated to have declined as much as 100 feet since the early 1940's when the extensive withdrawals began.

B. 5. c. Groundwater Management The N. C. 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 nondischarge permit program, which is 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, 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 a non-domestic well 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, and is designated by the N. C. 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 N. C. Division of Health Services (DHR). DHR is responsible for monitoring solid and hazardous waste disposal sites. DHR is also 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 coming 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 natives fiercely proud and defensive of their territory, bad weather, and conflicts over presumed rights. While the details and characters have changed, people in the four centuries since 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 1600's. 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 acreages 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 shore of Pamlico Sound in 1704. The sounds served as important highways for the transport of goods in colonial North Carolina. 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 in the total context of settlement history. The Albemarle-Pamlico

Estuarine System has dominated eastern North Carolina 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 conditions that cause definitive environmental problems are not well understood.

C. 1. a. Declines in Fisheries Productivity Major declines in commercial fisheries have occurred in the Albemarle-Pamlico region since the 1970's. 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 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. A large percentage of menhaden sampled in the Pamlico River estuary during the past five years were affected, as well as other commercially important species (such as flounder and weakfish) 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. A red sore disease reached epidemic proportions in some commercial species in Albemarle Sound during the 1970's, but the causes for the outbreaks and the potential for re-occurrence remain ambiguous.

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

C. 1. c. Anoxia-Related Fish Kills Fish kills reported from the Pamlico River estuary have significantly increased in recent years. Variability in interannual 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 are seemingly related to oxygen depletion (probably because of eutrophication, increased organic oxygen demand and stratification), but the causal mechanisms are poorly understood. Regardless of the lack of specific documentation, fishermen complain that the intensity and extent of anoxic waters have recently increased.

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 1940's. 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 1970's 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. The causes for this observed decline have not been elucidated. 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 conditions and algae blooms, and management for minimizing their occurrence is slowly evolving. However, scientists have not yet integrated all the information needed to explain how, when and why blooms occur.

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 areas and modified reproductive, migratory and feeding patterns for a wide variety of aquatic and terrestrial organisms. The relative value of such habitat is poorly known and restoration or mitigation potential for impacted areas has yet to be evaluated. Implementation of new programs like "Swampbuster" should reverse the trend in declining acreages of wetlands.

C. 1. h. Shellfish Closures Closure of shellfish waters due to pathogenic microbial contamination in North Carolina has remained relatively constant over the past few years. About 320,000 acres of estuarine waters in the state are closed to shellfishing on temporary or permanent basis (of this acreage, about 50,000 are thought to be productive shellfish areas). Often, after heavy rainfall, additional acreage is closed for several days to several weeks. Albemarle Sound is not a contributor of commercial shellfish, but Pamlico Sound has oysters, clams and bay scallops in several areas. Most of the closure is outside the study area, but Core and Bogue Sounds are affected in a major way. New techniques to more accurately measure contamination and potential human impact are needed so that management can more effectively allocate shellfish resources. Relationships between contamination and land-use characteristics are poorly understood.

C. 1. i. Toxicant Effects Very little is known about the effects of toxicants on estuarine organisms and/or the distribution of toxic substances in the Albemarle-Pamlico Estuarine System. Specific locations have been identified where toxicant problems are thought to 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 few known "hot spots" have been identified to date. A preliminary survey of toxic contaminants in the 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 to be disposed of 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 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 a large portion of the state's swine, chicken, corn, soybean, tobacco, potato, wheat and peanut crops.

In the lower areas east of the Suffolk Scarp, crops are dominated by corn, wheat and soybeans. Farming activities are highly mechanized, and each individual operation is much larger than the statewide average. Soils require extensive drainage for most agricultural operations; consequently, large acreages are drained into networks of canals eventually reaching an estuary.

Concerns about agricultural impacts include (1) nutrient loading of freshwater, particularly from animal wastes and fertilizers applied to the 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 serves as a probable cause depends upon many factors, including the weather, specific crops grown and the application of Best Management Practices (BMP's). BMP's recommended for the Coastal Plain control soil erosion, sediment delivery, animal waste disposal, fertilizer runoff and drainage water management, and have all been demonstrated to reduce the impact of agriculture on water quality.

Agriculture acreage is expected to remain relatively constant in the region during the foreseeable future. Relative mixes of crops and agriculture activities will vary interannually depending upon economics and environmental conditions. Animal (particularly hogs and chickens) production is expected to continue to increase at a rate similar to that of recent years. But, the use of Best Management Practices should reduce the potential for nonpoint pollution, particularly with the impetus given BMP implementation by the N. C. Agriculture Cost Share Program in all counties of the area. 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 area produces raw materials for a diverse forest products industry. The forests also function as wildlife habitat, recreational areas, and as a filter and surge control mechanism for fresh waters entering the sounds.

Analysis of recent U. S. Forest Service woodland inventories and information from the N. C. 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, with private-owned acres declining and corporate-owned acres increasing.

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 application during the establishment of pine plantations have 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 have 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 at the ocean end of the region and around the extensive shorelines of the sounds. Commercial uses, varying 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 sounds and rivers further inland. Activities seem to be 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. There are several, isolated large manufacturing and mining operations in proximity 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, chemical manufacturing and boat building/repair 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 U. S. 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 oil spills, petroleum by-products and wastes from vessels. Maintenance dredging generates intermittent impacts from turbidities 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 the several such areas around and in the sounds. Broader and more significant impacts may be the use conflicts with commercial fishing, recreation 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 the disposal of wastes generated by domestic, industrial and defense facilities, and by other human activities on the watershed. Point source contributions come from identifiable facilities through discharges, which are regulated by the North Carolina Division of Environmental Management. A very large proportion of the inputs are non-point in origin, which comes 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 effect from anthropogenic augmentation of nutrient fluxes. Other effects, such as the occurrence of ulcerative sores in fish and major shifts in distribution and abundance patterns of estuarine organisms, have resulted from waste loadings, but the causative relationships are extremely unclear.

C. 2. g. Commercial Fisheries Commercial fishing is as old as colonial North Carolina and serves as a traditional coastal industry. The Albemarle-Pamlico Estuarine System is the ecological basis for most of our fishery. Its diversity and setting result in a complex of habitats supporting 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, 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 habitat intervention 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. Therefore, a large proportion of boating activities support the recreational fishing effort. Boating also results from commercial fishing, sailing, skiing and other recreational activities. In 1986, over 49,000 boats were registered in the 25 counties in the study area, which was about 23% of the 218,000 boats registered in North Carolina (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 economic and growing forces in the Albemarle-Pamlico area. Development of second homes and facilities to support this growing industry 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, diving ducks and sea ducks utilize the estuary system. A variety of other wildlife also utilize the diverse habitat available in the area. Several threatened and endangered species are found around the sounds. Potential human impacts come from increasing hunting activities and development of private waterfowl impoundments.

The U. S. 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 prime examples of habitats, and provision of opportunities for wildlife-oriented education, interpretation and recreation. Managing wildlife refuges to provide maximum habitat and species is difficult, and some off-site impacts can occur.

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II CRITICAL AREAS

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A. INTRODUCTION

The natural resources of the Albemarle-Pamlico 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, 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 Albemarle-Pamlico 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 area section ends with a short summary of existing regulatory mechanisms which govern the critical area's use and management.

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 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.

Scientific names used in the text are based on Radford (1968) for plants and the American Ornithologists Union (1983) for birds.

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 that 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 areas, bottom coverage, and hydraulic regimes (Thayer et al. 1984b; Fonseca and Fisher 1986).

Accompanying these functional attributes of SAV systems are interactions between 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 and reduces both turbulence and scouring of the sediment (Fonseca and Fisher 1986). These processes significantly influence the ways 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 most frequently implicated in the temperate marine species. However, the subject of nutrient sources and availability, as well as the general nutritional requirements of SAV, is open to more research.

Light availability appears to be the primary factor limiting both depth 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 impact the distribution of SAV.

B. 2. Status and Trends of Information

The majority of research on the temperate seagrasses, particularly *Zostera marina* (eelgrass), has been conducted in only a few locations: the Beaufort, North Carolina, area by the 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 West Coast. Much of the information gathered on this species is applicable to the other marine species common to the area, such as *Halodule wrightii* (Cuban shoalgrass), and to the halotolerant species *Ruppia maritima* (widgeongrass), at least in generic terms. Likewise, the functional characteristics attributed to marine SAV are probably applicable to the brackish/fresh water complex of species. Information needs also apply across the board, but there is a need for comparative research among habitats rather than on a single habitat type if relative habitat values are to be established.

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 both temporally and spatially (Summerson and Peterson 1984; Thayer et al. 1984b). Larval and juvenile fish and shellfish including *Cynoscion regalis* (gray trout), *Sciaenops ocellatus* (red drum), *Cynoscion nebulosus* (spotted seatrout), *Mugil cephalus* (mullet), *Leiostomus xanthurus* (spot), *Lagodon rhomboides* (pinfish), *Orthopristis chrysoptera* (pigfish), *Mycteroperca microlepis* (gag grouper), *Haemulon plumieri* (white grunt), *Bairdiella chrysoura* (silver perch), *Paralichthys dentatus* (summer flounder), *P. lethostigma* (southern flounder), *Penaeus aztecus* (brown shrimp), *P. duorarum* (pink shrimp), *Callinectes sapidus* (blue crabs), *Mercenaria mercenaria* (hard shell clams), and *Argopecten irradians concentricus* (bay scallops) utilize the SAV beds as nursery areas. These meadows also are frequented by adult spot, spotted seatrout, summer and southern flounder, pink and brown shrimp, hard shell clams, and blue crabs, and are the sole nursery grounds for North Carolina bay scallops. 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 swan, geese, and ducks feed directly on the grass itself. *Chelonia mydas* (green sea turtles) 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 the 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. 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. The literature on the sound has been reviewed by Davis and Carey (1981) and Davis and Brinson (1983). For this reason it is difficult to point up whether there are major losses or gains in abundance and distribution in the A/P Study area.

Studies have sporadically documented the status of SAV in the Currituck Sound since 1909. After a review of unpublished literature, Sincock (1966) implied the presence of lush SAV in the sound from the mid-1800's to around 1918, at which time deterioration began. This condition 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. By 1967

Eurasian watermilfoil (*Myriophyllum spicatum*) had become a pest species in the sound, but it has caused few problems since about 1978. Transects that had been sampled earlier by Kearson (1976) in 1973 were rerun in 1978 (Davis and Carey 1981). Eurasian watermilfoil biomass in the sound was about one-half that of 1973, and decreased by 1988 (Davis and Brinson 1989). The decrease in Eurasian watermilfoil biomass observed in 1978 was attributed to unusual weather conditions which contributed to water turbidity and turbulence. Widgeongrass gradually increased 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. Little River also had high areal coverage and biomass of SAV, with Eurasian watermilfoil and perhaps *Potomogeton foliosus* (leafy pondweed) often in abundance. In contrast to the Perquimans and Little Rivers, the Pasquotank River was essentially barren in 1988. 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 only significant rooted aquatic macrophyte biomass in the Chowan River in 1973-1974 was *Nuphar luteum* (yellow waterlily or spatterdock) and *Justicia americana* (water willow) (Twilley et al. 1985).

In the mid-1970's and before, SAV was common in the upper half of the Pamlico River estuary (Davis and Brinson 1976, 1989). By 1985, however, biomass had been reduced to about 1% of that of the 1970's 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 *Vallisneria americana* (wild celery), previously the most important species in the estuary, probably were negated by 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 species 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 at the same time in July 1989. However, high salinities and a heavy epibiotic load may have impacted 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.

Small and generally healthy beds of wild celery now occur in a short stretch of the narrow southern littoral of the upper reach of the Neuse River estuary during 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 wildcelery is highly restricted by morphologic features of the Neuse River, such as a narrow littoral in the low salinity reach.

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 (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 subtributaries in these systems.

Except for locally dense Eurasian watermilfoil in tributaries of North and South Creeks of the Pamlico River system, *Zannichellia palustris* (horned pondweed) 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. The presence of these species in the littoral of smaller creeks to around the 1-1.2 m depth contour is the rule, especially for the upper and middle reaches. Thus, there tends to be SAV cover on these creeks throughout most of the year.

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 NC Department of Transportation photographs taken in 1981, they estimated a total of 16,901 acres of SAV in their study area. Of the total, 12% was located in western Bogue Sound (from Bogue Inlet to a line running from east of Gales Creek to Rock Point), 13% in Back Sound (east and south of a line from Shackleford 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 the remainder in Core Sound (from Lighthouse Channel to a line between Camp Point and Core Banks).

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 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 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 with about 12% occurring along the western Core Sound shoreline and 88% along the eastern shore (Figure II-1). SAV was limited to a maximum depth of about 2 meters, probably as a result of light attenuation by turbid water. Widgeongrass was uncommon and 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 habitats unrecorded in the 1981 study and noted a larger 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.

Figure II-2 shows the approximate location of seagrass habitat based on previous reports, aerial overflights, analyses of the 1985 photography, and preliminary analysis of 1988 photography (Ferguson et al. 1989b). The estimated acreage of marine SAV covered by this area is approximately 200,000 acres 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

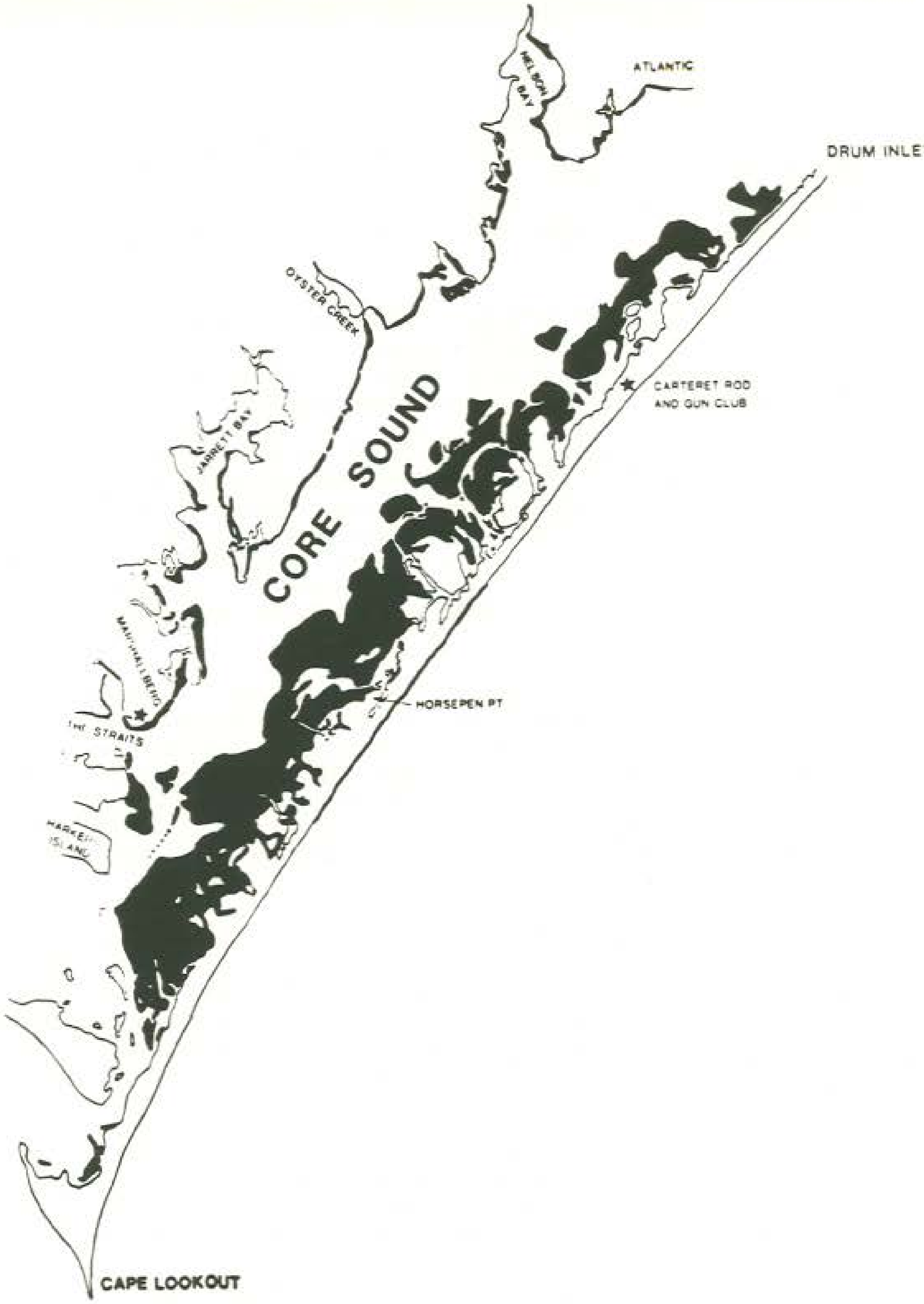

Fig. II-1. Southern Core Sound with location of submerged aquatic vegetation. From Ferguson et al. (1989b).

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, with shoalgrass being somewhat more dominant numerically in both the northern Core Sound area and southeastern Pamlico Sound area. As is the case for southern Core Sound, SAV almost exclusively occurred at depths shallower than 2 meters.

The estimate of 200,000 acres of SAV in North Carolina is similar to the acreage of salt marshes in the state. Further, this estimate ranks North Carolina second only to Florida in extent of marine SAV.

Unlike the drastic losses 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 1930's (see Thayer et al. 1984b for discussion). The drought and increased water clarity during summer 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 on 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. Finally, clam-kicking is a contentious issue within the state of North Carolina, and 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) and Section 404 of the Clean Water Act (1977) and the North Carolina Coastal Area Management Act (CAMA) section 10 requires a permit from the Corps of Engineers for construction in Navigable Waters of the United States. Section 404 prohibits deposition of dredged or fill material in waters of the United States without a Corps permit. 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 (AECs). The Fish and Wildlife Coordination Act gives federal and state resource agencies the authority to review and comment on permits, while the U. S. National Environmental Policy Act requires the development and review of Environmental Impact Statements. In addition, the Magnuson Fisheries and Conservation Act of 1976 established eight regional Fishery Management Councils (FMC). The Councils 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 habitat subcommittees 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.

These federal and state resource agencies and the Fishery Management Councils must be aware of a number of factors as 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.

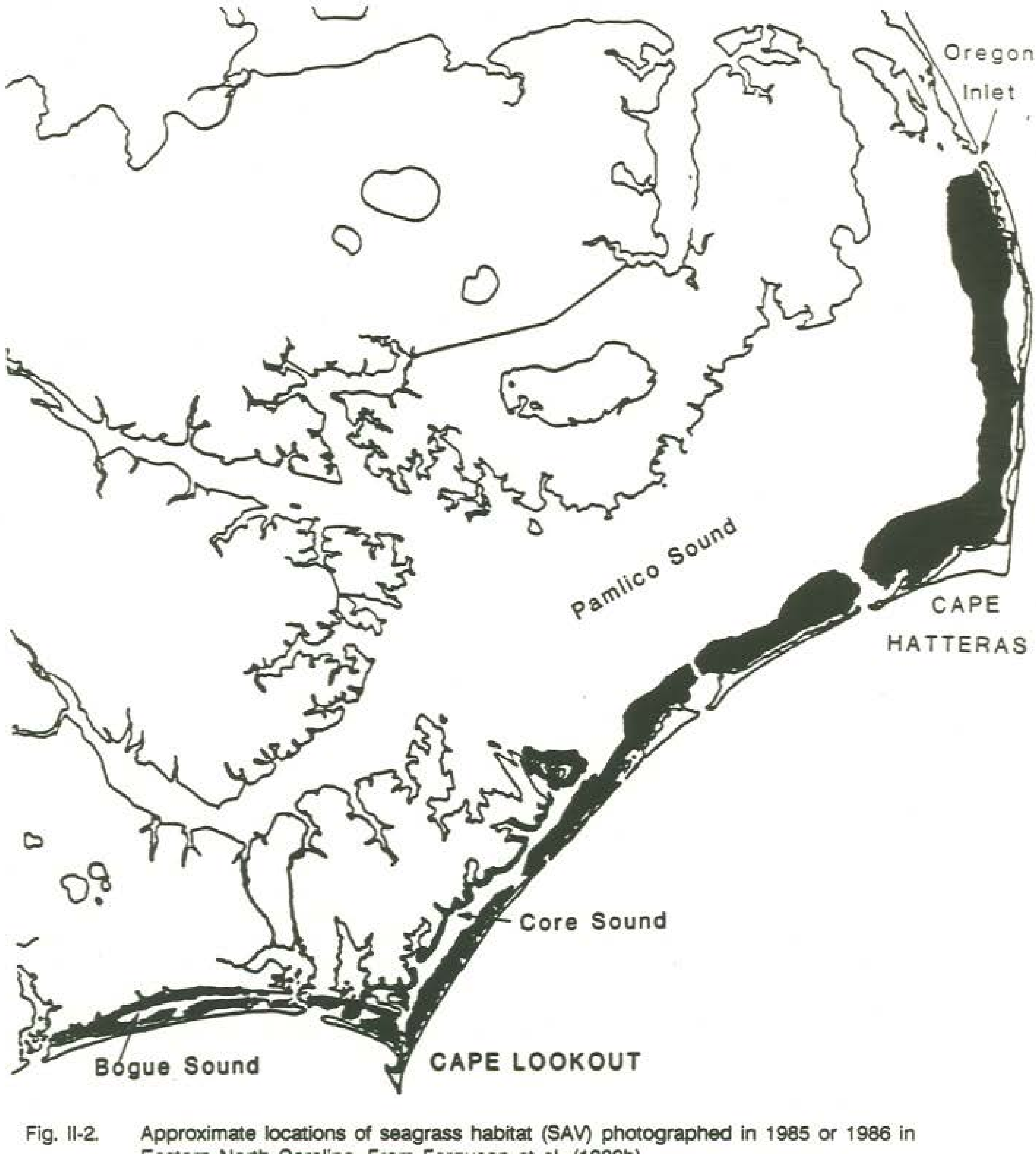

Fig. II-2. Approximate locations of seagrass habitat (SAV) photographed in 1985 or 1986 in Eastern North Carolina. From Ferguson et al. (1989b).

1984b; Davis and Brinson 1989; Fonseca In Press). Degradation of SAV habitat is most easily understood when broken down into categories of direct and indirect causes. In the category of direct causes, dredging and filling are the most obvious. Dredging and filling are easily observed and are regulated through Section 10 and Section 404 permits.

Indirect losses are more subtle and difficult to assess. These losses center around changes in light availability to the SAV by changes in turbidity. Other indirect causes of SAV loss may be ascribed to changing hydrology which may in turn affect salinity levels and flushing. Reduction in flushing can cause an increase in salinity and the ambient temperature of a water body, stressing the plants. Increases in flushing can mean decreased salinity and increased turbidity and near-bottom mechanical stresses which damage or uproot plants.

Increased turbidity is most often recognized as the cause of decreased SAV growth (see Description). Turbidity may result from upland runoff, either as suspended sediments or dissolved nutrients. The introduction of additional nutrients from terrigenous sources often leads to plankton blooms and increased epiphytization of the plants, reducing light to the SAV plants themselves. Groundwater enriched by septic systems also may infiltrate near-shore SAV beds with the same effect (Fred Short, pers. com.).

Conservation of existing SAV habitat is critical to maintenance of the living estuarine resources that depend on these systems. These habitats cannot be readily restored, and 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). As a consequence of this recognition, staff of the National Marine Fisheries Service Beaufort Laboratory have published guidelines for management and restoration of SAV that are being used by NMFS and other agencies.

C. EMERGENT AQUATIC VEGETATION UNDER SEA LEVEL INFLUENCE

C. 1. Introduction

Coastal wetlands nationwide have received a great deal of attention because of the many biologic, geomorphic, and hydrologic values they provide for society (Chapman 1976; Odum et al. 1974). Salt water and daily tidal cycles are normal properties of most coastal wetlands. The extensive coastal wetlands of North Carolina, however, are unique because of the preponderance of brackish to fresh water wetlands which lack tidal influence. Two wetland types, nontidal brackish marshes and nontidal forested wetlands, are dominant in the Albemarle and Pamlico Sound region (Wilson 1962). They have been little studied and are poorly understood ecologically compared to tidal salt marshes (Pomeroy and Wiegert 1981; Teal 1986) and tidal freshwater marshes (Simpson et al. 1983; Odum et al. 1984). This section deals with wetlands that occur east of the Suffolk Scarp and are controlled by sea level.

The hydrologic and geographic setting of Albemarle and Pamlico sounds departs sharply from the remainder of the Atlantic Coast. The presence of the barrier islands restricts the exchange of water with the ocean, resulting in lower salinities and lower amplitude tides than elsewhere (Copeland et al. 1983 and 1984; Giese et al. 1985). Tides and salinity are the two most important controls on vegetation in these sea-level controlled coastal wetlands. Figure II-3 illustrates how these two variables produce one of the four major wetland types under sea level control. The presence or absence of semidiurnal astronomic tides separates wetlands into tidal and nontidal types. Within the nontidal or irregularly flooded category, when salt water is present, woody vegetation and hence swamp forest cannot develop. Halophytic species such as *Juncus roemerianus* (black needlerush) dominate under saline conditions along with an assemblage that may include *Distichlis spicata* (salt grass), *Spartina patens* (salt meadow grass), and *Spartina cynosuroides* (giant cordgrass) (Cooper and Waits 1973). This ecosystem type has widespread occurrence in the Pamlico Sound region. Water level fluctuations driven by wind direction and force are dominant rather than the lunar tide. In the Albemarle Sound area, the normally fresh or oligohaline conditions favor the development of forested wetlands rather than marshes. Well over 100 kilometers of shoreline are occupied by forested wetlands in this region (Table II-1). The ecological characteristics of this wetland type are not well documented in the literature.

Within the tidal category (Figure II-3), tidal freshwater marshes and tidal freshwater swamps may develop, but these communities are virtually absent from the Albemarle-Pamlico region because it lacks significant tidal influence in the low salinity estuarine portions. Tidal freshwater marshes occur in Virginia (Odum et al. 1984; Odum 1988) and south of the A/P Study area in North Carolina (Rozas and Hackney 1984). They will not be discussed further. However, where salt water is present in combination with semidiurnal tides (Figure II-3), as it is in areas in close proximity to the inlets, *Spartina alterniflora* (smooth cordgrass) communities develop. Associated with these regularly flooded tidal marshes is a landward zone that receives most of its flooding from a combination of spring tides, wind-generated floods during storms, and precipitation. These irregularly flooded brackish marshes, or "high marshes," are present wherever tidal salt marshes are found. Their vegetation resembles that of the nontidal brackish marshes (Figure II-3). The principal difference is landscape position. In Pamlico Sound, nontidal brackish marshes border the open waters of the estuary with no intervening zone of *S. alterniflora* as found in tidal marshes. These nontidal marshes comprise most of the marsh total in Table II-2.

A classification as simple as Figure II-3 is not without exceptions, most of which occur in transitional areas between tidal and nontidal regions and between brackish and fresh water conditions. The extent to which diminution of the tidal influence affects species composition has not been well resolved for this region. Parallel changes in salinity make difficult the separation of the two as controls of species composition. Salinity does not exactly correlate with vegetation cover. The low salinity of Currituck Sound, for example, would suggest that more forested wetlands should be present. Extensive areas of nonhalophytic marsh grasses in that region and other freshwater localities in Albemarle Sound may be explained by the environmental history of the site or by disturbance. For example, Currituck Sound was once saltier than present because of the existence of New Currituck Inlet which closed around 1830. More recently, however, influxes of marine waters from northeasterly storms (e.g., the Ash Wednesday storm of 1962) have episodically increased the salinity to above the normal level of one to a few parts per thousand. Present day salinity levels suggest that forested wetlands could develop in these areas (Sincock 1966). The extensive marshes may be simply remnants of more brackish conditions. Also, disturbance by fire would tend to perpetuate marshes rather than forests.

With the exception of these transitional areas, vegetation structure in these geographic regions varies with salinity of the estuaries: wetlands in Albemarle Sound and the Alligator River are mostly forested, while wetlands in the Pamlico Sound are mostly marsh. Where there are marshes, a salinity gradient also occurs from the marsh shoreline to the wetland interior. Hence, marshes transform into shrub and forested wetland communities depending on the steepness of the salinity gradient and the importance of fire in maintaining physiognomy of the vegetation.

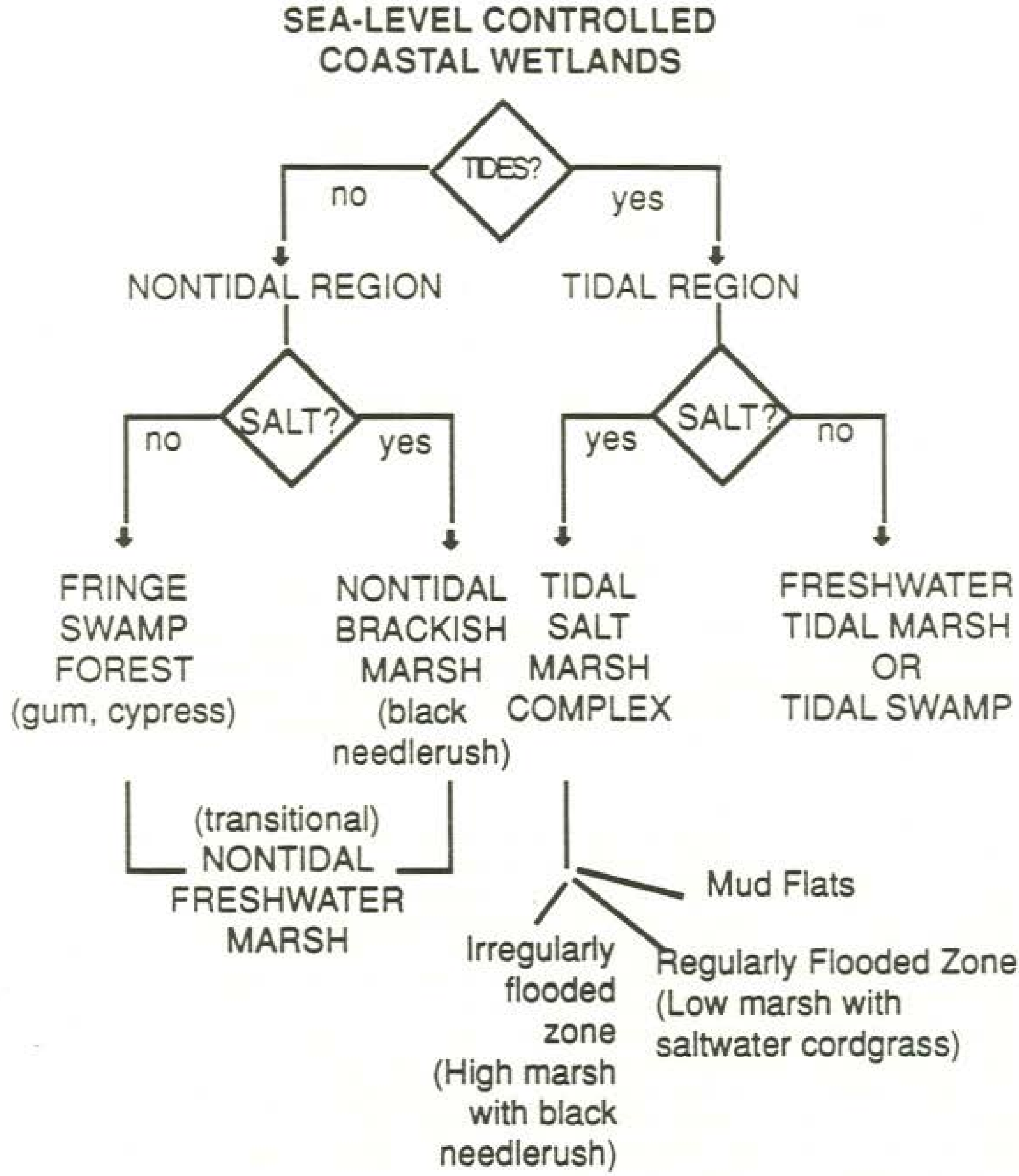

Fig. II-3. Factors controlling the expression of plant community physiognomy and species composition of the four basic coastal wetlands types in North Carolina. From Brinson (In. Prep. b)

Table II-1. Shoreline Categories, Albemarle-Pamlico Study Region (Riggs et al. 1978)

Shoreline category	Geographic region[1]				
	Albemarle	Pamlico	Neuse	Core-Bogue	Totals
		Distance in kilometers			
Low bank	256	180	200	122	758
High bank	95	31	39	14	179
Bluff	6	8	19	0	34
Swamp forest	163	11	3	0	177
Marsh	182	547	467	220	1416
Total km	702	777	727	357	2563
		Percent of total shoreline			
Low bank	36	23	27	34	30
High bank	14	4	5	4	7
Bluff	1	1	3	0	1
Swamp forest	23	1	0	0	7
Marsh	26	70	64	62	55

[1] Percent of county's shoreline in each geographic region as follows: Albemarle--Dare Co. has 23.9% and <15% each in Bertie, Camden, Chowan, Currituck, Pasquotank, Perquimans, Tyrrell, Washington. Pamlico–Beaufort Co. (100%), Hyde (100%), and Pamlico (15.3%). Neuse–Carteret Co. (34.6%), Craven (100%), and Pamlico (84.7%). Core-Bogue–Carteret Co. (65.4%).

Because of the sharp transition that fringe wetlands normally represent between a large body of open water and either upland or additional wetland on the landward side, they are potentially very important areas ecologically, geologically, and hydrologically. Fringe wetlands are distinguished from riverine wetlands discussed in Section D (Riparian/Alluvial Forested Wetlands) and basin or depression wetlands discussed in Sections F. 2 and F. 3 (Pocosins and Related Wetlands and Non-riverine Swamps) by hydroperiod, direction of water flow, and vegetation zonation (Lugo et al. 1988; Brinson 1988). Fringe wetlands occur in estuaries where tidal forces dominate or in lakes where water moves in and out of the wetland due to wind, waves, and seiches. In contrast, riverine wetlands tend to be dominated by unidirectional flow, shorter hydroperiod, and higher sediment loads. Basin wetlands (peat bogs, pocosins, wet forested flats) receive most of their water from precipitation, have strong seasonal fluctuations in water table, and have weak lateral flow, often limited to sheet flow. Fringe wetlands are essential fish habitat in brackish portions of estuaries, both in tidal and irregularly flooded wetland types.

One of the major issues posed by North Carolina's sea level controlled wetlands is whether they can be sustained under projected acceleration in sea-level rise as a result of global warming. To compound this problem is the fact that many of the wetland-upland transition zones are no longer available for movement inland because the land has been occupied by human structures and activities incompatible with overland migration of wetlands. Projected increases in economic

Table II-2. Surface Area Estimates, in Hectares, 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	1970-84 No. Permits
Pamlico Sound					
Carteret	4,047	15,621	0	20	595
Pamlico	0	6,071	0	310	210
Beaufort	0	182	1,639	30	240
Hyde	648	12,101	1,376	35	95
Dare	202	6,273	2,104	60	325
Total	4,897	40,247	5,119		
Albemarle-Currituck					
Tyrrell	0	0	223	1	50
Chowan	0	0	121	1	60
Camden	0	0	648	5	35
Currituck	0	0	9,551	120	140
Total	0	0	10,542		

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).

development and settlement in the coastal zone of North Carolina suggest this issue will become critical for those with coastal land holdings.

Because of the sparsity of information on fringe wetlands of the type that occur in the Albemarle and Pamlico sounds, management and protection of these areas have had to rely on management policies developed for wetlands that differ from them hydrologically and geomorphologically. This situation places the resource in a potentially vulnerable position if inappropriate management techniques are applied.

Typical responses of society to sea level rise are building levees, dikes, and bulkheads to thwart the intrusion of brackish water or deter the loss of land by coastal erosion (Carter 1987). Titus (1987) suggests that society's response to sea level rise depends upon the economic value and dedicated use of the land threatened. Wetlands will not be maintained, however, if barriers to their migration are constructed (Titus 1988).

Sea level controlled wetlands are discussed below in order of their proximity to oceanic and tidal influences: (1) tidal salt marsh, (2) nontidal brackish marsh, (3) fringe swamps, and (4) nontidal freshwater marshes.

C. 2. Tidal Salt Marsh

C. 2. a. Description. Tidal marshes have three major components: tidal creeks without vegetation, the regularly flooded *Spartina alterniflora 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 *S. alterniflora* community represents the core of the salt marsh. It is often further divided into zones occupied by tall, intermediate, and short forms of *S. alterniflora*. The high marsh contains an increasing number of species of which *J. roemerianus, S. patens,* and *D. spicata* are common dominants or co-dominants. At the highest elevation, high marsh grades into upland vegetation.

Tidal flushing, hydroperiod, and salinity are the principal abiotic factors that determine zonation in the salt marsh environment. Tidal flushing provides the hydrologic energy for transport of dissolved and particulate material. Inorganic sediments are transported by tidal currents from deltaic riverine sources or from long-shore currents in the ocean. They 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 toward the marsh interior. The presence of coarser sediments in the levee facilitates flushing of porewater in creek-side sediments.

The organic matter (OM) content of sediments in *S. alterniflora* is generally lower than that of the high marsh where suspended sediment supplies are limited because of infrequent flooding from estuarine waters and remoteness of the high marsh from the tidal creeks. Consequently, the *S. alterniflora* portion may contain only 10 to 20% OM (Pomeroy and Imberger 1981) while the *J. roemerianus* sediment may run as high as 70% OM (Brinson et al. In Prep.a).

Salinity of the rhizosphere is controlled by the balance of gains and losses of water and salt. Porewater salinity in the levee tends to be maintained close to that of adjacent estuarine waters because of frequent hydraulic exchange and better internal drainage than more isolated localities. Porewaters of the short *S. alterniflora* zone often reach hypersaline conditions during protracted periods of warm rain-less weather, high rates of evapotranspiration, and minimal hydraulic exchange because of 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 (*Myrica, Cerifera, Baccharis halimifolia,* and *Iva frutescens*).

When these and other factors are taken together, the abiotic environment prevents growth of vascular plants in tidal creeks because of long hydroperiod and strong currents. Species richness (number of species) is restricted in the *S. alterniflora* 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, *S. alterniflora* forms monospecific stands with occasional patches of barren sediment or *Salicornia* spp. It is not until the high marsh is reached that *J. roemerianus* and its associates, *S.*

patens and *D. spicata*, create most of the cover. There is an overall increase in species richness with decrease in stress as porewater salinity and inundation decreases.

Within the *S. alterniflora* zone, tall, medium and short forms are commonly recognized. 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 the levee, apparently due to the improved exchange of porewater with the tidal creek and flushing from precipitation which ameliorates salinities and hydrogen sulfide concentrations (Howes et al. 1986), and likely increases the supply of nutrients. The most poorly flushed form, toward the marsh interior, is exposed to a combination of high salinity stress and high sulfide concentrations. The intermediate height form is exposed to intermediate abiotic conditions. Ecologists have debated whether the growth forms are genetically or environmentally controlled. It has been recently demonstrated that form 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 not only may produce as much as 25% of the aboveground grass production, but also represent an easily digested food source for consumers relative to the grasses (Teal 1986). A number of insects and spiders utilize the marsh, numerous species of wading birds, waterfowl, and one species of turtle, *Malaclemys terrapin* (diamondback terrapin) feed on the marsh. Birds range from rails, willets, and ducks and geese that feed mostly on the marsh surface to marsh wrens and red-winged blackbirds that build nests in the grasses. Mammals are a less conspicuous part of the marsh fauna, and are represented by *Oryzonys palustris* (rice rat), *Sigmodon hispidus* (hispid cotton rat), *Procyon lotor* (raccoon), *Ondatra zibethicus* (muskrat), *Lutra canadensis* (otter), *Mustella visor* (mink), and *Myocastor coypus* (nutria), the latter representing a recent introduction into North Carolina.

Because of shallow flooded conditions on the marsh surface, fish size is restricted. Among the more common species that spend most of their time within the marsh are *Fundulus luciae* (striped killifish), *Fundulus heteroclitus* (mummichog), and *Cyprinodon variegatus* (sheepshead minnow). This is but a small proportion of the fish species that actually utilize the marsh surface. *Uca* spp. (fiddler crabs) may occur in dense numbers, and *Littorina irrorata* (periwinkle) is one of the most conspicuous faunal organisms on the marsh.

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 magnitude of water exchange with the estuarine environment, many questions have focused on the importance of nutrient and organic matter export or import relative to 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 sedimentary environments that require imports to exceed exports, especially for suspended sediments. While organic matter may be exported to adjacent waters (Hopkinson and Wetzel 1982), it is unlikely to be the only basis for the 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.

A more realistic functional tidal salt marsh paradigm is 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. Similarly, 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. Abiotic processes are especially difficult to separate from biotic ones because of their interdependence.

The importance of tidal salt marshes to estuarine fisheries has long been recognized. 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 (Section E. 4). 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). Export of organic matter no longer needs to be invoked to support 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). Hopkinson and Wetzel (1982) argue that nearshore ecosystem metabolism is dependent on organic carbon exports from riverine and wetland environments along the Atlantic coast of southeastern United States.

The geographic distribution of tidal salt marshes is limited relative to that of the nontidal marshes in the Albemarle-Pamlico Estuarine Study region for reasons discussed above. The same abiotic variables, tidal flushing, sediment source, and salinity, 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 induced activities such as the creation of impoundments, filling of dikes, 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 in an environment of relative sea level rise, increasing hydroperiod is responsible for the loss of the marsh ecosystem.

From the fisheries standpoint, these 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.

C. 2. b. Status of Information. Information on the components and functions of tidal salt marshes can be extrapolated from studies conducted elsewhere within geographic limits. Species composition of the irregularly flooded portion of tidal marshes change with latitude. For example, in Delaware, *Juncus gerardii* replaces *J. roemerianus* as a dominant species in the high marsh area of tidal marshes. In south Florida, *Rhizophora mangle* replaces *Spartina alterniflora* in the regularly flooded portion. However, even with changes in species of the dominant vegetation, processes are likely to remain similar because of the close relationship between physical processes and ecosystem structure.

The intense interest that geomorphologists have given to barrier island dynamics has been particularly helpful in our understanding of tidal salt marshes at the landscape scale (Pilkey and Howard 1987).

The surface area of tidal salt marshes reported by Wilson (1962) is listed by county in Table II-2. 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 impact of documented human- disturbance during 1970-1984 is listed in Table II-2 (Stockton and Richardson 1987). The largest areas permitted for alteration, 310 ha in Pamlico Sound and 120 ha in Currituck Sound, are principally nontidal brackish marsh.

Although our understanding of these ecosystems will likely change with increasing information of their function, it is unlikely that their ecologic and geomorphic significance will diminish.

C. 2. c. Trends. The high level of protection afforded these ecosystems suggests that future losses will not occur as a result of direct impacts such as dredging and filling. In addition, the technology for creating tidal salt marshes is very advanced. A "no net loss" policy for wetlands in general may place pressure on agencies and individuals to increase the area of tidal salt marshes simply because the establishment success is high (Broome et al. 1988). Indirect impacts such as building barriers to landward migration in response to sea level rise will diminish tidal marsh coverage.

Tidal salt marshes are of direct benefit for humankind due to their function in supporting finfish and shellfish fisheries, waterfowl populations, and esthetics.

We don't know how many hectares or how much shoreline is occupied by these ecosystems because the latest inventory by Wilson (1962) is quite old. Much time passed between Wilson's estimate and the losses recorded by Stockton and Richardson (1987). Some of the marsh area is a consequence of depositing dredge spoil along the Intracoastal Waterway. The quality or stability of some of these artificial wetlands might be questioned. Grazing is a major source of disturbance in areas where barrier island horses exist (Turner 1987).

Mosquito control through grid-ditching is no longer condoned. Apparently there are no records of how much tidal marsh was ditched and exactly where the ditching took place. Open marsh water management as a means of mosquito control will continue to place pressure on alterations as population centers encroach upon these ecosystems. Studies on the ecological effects of open marsh water management are currently in progress at West Onslow Beach (Alice Anderson, N.C. Division of Health Services, 1988, personal communication).

C. 2. d. Management/Regulatory Status and Trends. Agencies responsible for issuing wetland alteration permits are very reluctant to allow disturbance of tidal salt marshes because they are recognized to have strong connections with fisheries production. Many of the most pristine areas are owned by federal or state agencies. For example, tidal marshes near inlets on the Cape Hatteras and Cape Lookout National Seashores are under the management of the U.S. National Park Service. Of the losses that occurred during 1970-1984 (Table II-2), the majority of the surface area affected was due to a few very large projects.

C. 3. Nontidal Brackish Marsh

C. 3. a. Description. Nontidal brackish marshes are the single most important wetland type in the Albemarle-Pamlico Estuarine System in terms of surface area and proportion of shoreline. They occupy most of the 1416 km of marsh shoreline (Table II-1) and exceed the surface of area of tidal salt marshes by a ratio of 8:1 (Table II-2).

Many sources lump this wetland type with "irregularly flooded marsh" because it has virtually the same species composition as the irregularly flooded portion of tidal marshes. The distinction is made between the two marsh types because of their fundamentally different landscape position. This affects geomorphic and hydrologic processes which are fundamental to many wetland functions in spite of the similar species composition. High marshes of tidal regimes are isolated from direct lateral exchanges of water and nutrients between marsh and estuary by intervening *Spartina alterniflora* marsh. Nontidal brackish marshes, in contrast, are shoreline features in direct proximity to the estuary. These spectacular ecosystems often cover vast areas, and in places stretch as far as the eye can see.

For the majority of the shoreline of Pamlico Sound, this is the interface between the estuary and either upland ecosystems or interior wetlands such as pocosins (Table II-1). Porewater salinities vary according to the salinity of the adjacent estuary and decrease with distance into the marsh interior.

Where wave exposure is high due partly to long fetch, marshes have a levee 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 consists of a mixture of peat, clay, and sand. In protected embayments where levees are lacking, local wave activity undercuts the shoreline and appears to facilitate erosion.

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

Nontidal brackish marshes are often called "black needlerush marshes" or "Juncus marshes" because of the prevalence and frequent dominance by *J. roemerianus*. Gradients in salinity and flooding result in parallel changes in species composition. *J. roemerianus* usually occupies the most nearshore regions with highest salinity and longest hydroperiod. *Borrichia frutescens* and *Distichlis spicata* also are common. The elevated levee, however, may have additional species such as *S. cynosuroides* and *Iva frutescens*, presumably because of better drainage and lower salinity of porewaters.

Several floristic descriptions of nontidal brackish marshes exist. Cooper and Waits (1973) studied a backbarrier marsh near Hatteras inlet. Marshes dominated by *J. roemerianus*, *S. cynosuroides*, and other freshwater to brackish tolerant species were described in the South Creek area, and aboveground biomass accumulation for several community types was estimated (Bellis and Gaither 1985). 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). Finally, information is becoming available on broader expanses of marsh that occur on interfluves and islands in the Pamlico Sound (Brinson In Prep.a; 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 *J. roemerianus* with *Spartina patens, S. cynosuroides, Distichlis spicata*, and *Cladium jamaicense* either being locally dominant or mixed with *J. roemerianus*.

If Cedar Island marsh is representative of the brackish marshes of Pamlico Sound, fish are more widely distributed in this system than previously thought. Fish have been collected and observed over 2 km from the shoreline at Cedar Island marsh (Marraro et al. 1989). The long distance from shoreline, lack of current for orientation, and the impedance to movement created by the high density of the vegetation suggest that these fish are members of marsh resident populations rather than a migratory assemblage that moves between the estuary and the marsh interior. Their presence is likely to have a strong influence on aquatic food webs of the marsh. *Gambusia affinis, Cyprinodon variegatus*, and three species of *Fundulus* were the dominant species found on Cedar Island marsh. 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. 1989). Numerous species of transient fishes also move on to the marsh when it is flooded, utilizing this interface for feeding and refuge.

Many of the same species of mammals and birds that utilize tidal salt marshes also are found in nontidal brackish marsh, probably as a consequence of similar vegetation. For example, several species of rails nest and overwinter in brackish marshes. Marsh wrens, seaside sparrows, and red-winged blackbirds are the most abundant birds sighted during daylight hours (Davis et al. In Prep.).

Nontidal brackish marshes receive water from estuarine flooding and from precipitation. Estuarine flooding occurs when wind direction, force, and duration are sufficient to cause "set-up" of the estuary 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. In Prep.b). Lack of rainfall for extended periods during high evapotranspiration may cause drawdown of the water table below the surface, thus aerating the sediments.

Where the shoreline of these marshes is exposed to high wave energy, wetland is lost to erosion at the same time that a storm levee develops along the retreating margin. Because the elevation of this levee 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 can import salt dissolved in water but evapotranspiration removes water without transporting salt. Except for such impounded areas, salinity in nontidal brackish marshes decreases from the outer marsh edge, where inputs by estuarine flooding are common, to the marsh interior where rainfall dominates site water balance.

In some nontidal marshes, storms and deep flooding initiate wrack movement that may have profound effects on the vegetation. (Wrack is represented by windrows of dead vegetation rafted by storms.) Large wrack deposits can kill vegetation and leave the sediment barren once the wrack decomposes (Knowles et al. In Prep.). This phenomenon provides a site for renewed colonization, usually by species other than *J. roemerianus*, the original dominant.

The most important abiotic process of these wetlands is that of maintaining landscape in the face of rising sea level. Without the marsh surface, the remainder of the wetland functions and values would not exist. Although the master control of sediment accumulation is the hydrology, an abiotic process, accretion in these marshes is in part a biotic process because peat is derived from undecayed plant material. This contrasts with tidal marshes that normally depend upon deposition of inorganic sediments to maintain a surface elevation favorable to plant growth.

Aboveground primary productivity of *J. roemerianus* in the area appears to be modest (Williams and Murdoch 1972; Christian et al. In Prep.). There have been no reports of below-ground production. Decreasing salinities 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 common in the fringe wetlands of Pamlico Sound. The effects of hydroperiod and salinity are hard to separate because they both tend to decrease from marsh edge to interior.

An interesting finding revealed by a study of a marsh on the Cedar Island National Wildlife Refuge is the fact that several species of fish (*Fundulus* spp. and *Gambusia* sp.) on the marsh surface can be considered marsh resident species (Marraro et al. 1989). Unlike tidal marshes where twice daily flooding allows fish access to the marsh surface for feeding, the fish on nontidal marshes must endure the marsh surface environment for most of their lives.

Except for regions of the shoreline occupied by upland and forested wetland and the tidal salt marshes close to the inlets, most of the Albemarle-Pamlico Estuarine Study area shoreline is occupied by nontidal brackish marsh. This wetland type is ubiquitous in Pamlico Sound and is found in the eastern portion of Albemarle Sound. Table II-2 shows that the surface area by county in the Albemarle-Pamlico Estuarine Study region.

Free water exchange between marsh and estuary is necessary to maintain salinity gradients across the marsh. Any obstruction to water flow such as an impoundment is likely to change salinity patterns toward a fresher regime.

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. Supplies are insufficient and distribution is inadequate to compensate for shoreline losses due to wave activity. Because of the large size of the estuaries, fetch is usually adequate for strong wave activity to develop. Various sources have reported mean shoreline recession rates in the sounds to range up to 6 m per year (Stirewalt and Ingram 1974; USDA Soil Conservation Service 1975; Bellis et al. 1975).

These ecosystems may be among the most underrated in North Carolina because of their great aerial coverage and the ignorance that we have had about their landscape function. There seems to be a perception that because tidal salt marshes are so valuable, nontidal brackish marshes must be less valuable because they are similar in vegetation to the high marshes in tidal regimes. In North Carolina, where nontidal brackish marshes are the principal wetland type bordering estuaries, their position alone argues that they are filling some of the same functions that tidal marshes do elsewhere.

C. 3. b. Status of Information. The life history characteristics, salinity and flooding tolerance, and growing season dynamics for the dominant species, *J. roemerianus*, are well understood as they are for other common species like *Spartina patens*, and *Distichlis spicata* (Eleuterius 1975). In the lower salinity portion of marshes, the many possible factors that determine a given species composition are not easy to explain. In higher salinity regions, tolerance to saline conditions is a major factor.

The condition of altered marshes is not known and has not been studied. Studies are needed on ditched marshes to know whether they should be rehabilitated to their former condition and, if so, how this should be done. Since the most critical issue is accretion of the marsh surface relative to sea level rise, the influence of marsh alteration needs to be evaluated in relation to this process. North Carolina has an unknown area of ditched brackish marshes. Over two decades ago, Kuenzler and Marshall (1973) developed research recommendations for these marshes–recommendations that have not yet been completely implemented.

The status of waterfowl impoundments at Pamlico Point (Goose Creek) and other sites is not known. In efforts to increase waterfowl and wading birds, we do not have accurate and complete records of waterfowl use in either public or private impoundments. One of the biggest threats to the brackish marsh resource is that the accretion capacity of these areas may be impeded, effectively loosing them as sites for future wetland processes.

Wrack is important for habitat heterogeneity, at least in some marshes. Wrack deposits initiate cycles of succession that maintain a mixed plant species assemblage in the marsh (Knowles et al. In Prep.).

Nontidal brackish marshes are widely distributed along the mainland of Pamlico Sound and the backbarrier 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 species change toward dominance by *Cladium jamaicensis*, *Typha* spp., and *Scirpus* spp. Many of these species become more important in areas of nontidal fresh water such as Currituck Sound.

The landscape function of these marshes is fundamental to all other wetland functions. In the Pamlico Sound region, they are the principal buffer between activities in uplands and estuarine water. The vastness of this resource in the Albemarle-Pamlico Estuarine System is especially significant.

C. 3. c. Trends. The distribution of nontidal brackish marshes will not change unless inlets are altered either by storms or human activities. Creation of more abundant and wider inlets would decrease the proportion of nontidal marshes relative to tidal ones.

Traditionally these marshes have been altered to create impoundments to attract waterfowl. In addition large areas of marsh have been altered by digging ditches for mosquito control, a practice that elicited a call for a moratorium on ditching (Kuenzler and Marshall 1973). However, the potential for these areas to recover to their original, unaltered condition is not known.

We don't know the extent of alteration or how alterations are distributed among geographic areas. These would be fairly easy to document by using aerial photographs.

C. 3. d. Management/Regulatory Status and Trends. These wetlands are protected by the same mechanisms used for other wetlands. An assessment of the quality, along with analyses of the surface area and location of permitted alterations, represents minimal information necessary for developing a strategy for protection through cumulative impact analysis. The influence of sea level rise on these and associated ecosystems should be considered in all projections into the future. Failure to do so would be to ignore the most fundamental property of sea-level controlled wetlands.

C. 4. Fringe Swamps

C. 4. a. Description. Fringe swamps are forested wetlands that occupy the shorelines of Albemarle Sound and the mouths of some of its major tributaries. The sound is large enough to generate wind-induced water level fluctuations that are distinct from the hydrology and hydrodynamics of interior wetlands isolated from shoreline influences. Fringe swamps differ from interior swamps in the amount of flushing, the texture and elevation of surface sediments, and the structure of vegetation. The position of fringe wetlands at the interface between aquatic ecosystems and interior wetlands makes them important ecologically, hydrologically, and geologically.

Because this wetland type has not been recognized elsewhere and is presented here as an example of a unique situation for the Albemarle-Pamlico Estuarine System region, it is valuable to refer back to the introduction to this section for a definition of this wetland type.

A common and representative example of transition of vegetation in fringe swamps is a sequence of: (1) dead or dying cypress trees under permanently flooded conditions near the shoreline, (2) fairly well stocked forest on a slightly elevated levee near the shoreline, and (3) a subtle change in species composition that may be accompanied by diminished average basal area of trees toward the interior between 200 - 300 m from the shoreline (Brinson In Prep.b).

Swamps that occur between small brackish marsh creeks and the freshwater zone at the mouth of streams also may have attributes of fringe swamps. They are under sea-level control and are located too far downstream to have riverine characteristics. A transitional zone such as this was studied in the vicinity of South Creek on the Pamlico River (Brinson et al. 1985). These swamps are being overtaken by the upstream migration of brackish marsh in response to sea level rise.

Fringe swamps are exposed to wind generated water level fluctuations in estuaries. Hydrologically, they are exposed to a similar regime as nontidal brackish marshes. The periodicity and depth of flooding vary with their location and will depend upon the position of the site with respect to orientation of the estuary and direction and duration of the wind.

The substrate may be inorganic or organic depending on whether sea level has risen substantially above the base of the preexisting land surface. For example, many locations along the eastern shore of the Alligator River are underlain by highly organic sediments, either accumulated in response to rising sea level or exposed at a shoreline site due to erosion into organic deposits of previously interior wetlands. On the western shoreline, clayey deposits prevail which appear once to have been upland soils (Brinson In Prep.b).

Erosion by wave action is responsible for the structure of the most exposed portion of the fringe swamp. Isolated cypress trees are characteristic of this zone and represent relicts of a more complex forest. Behind this, most fringe swamps have a subtle storm levee, although on high energy shorelines it can be quite pronounced. Most commonly, however, the elevation of the nearshore sediment surface is only slightly higher than the wetland interior. Microrelief increases toward the forest interior as shoreline processes diminish and the forest assumes characteristics similar to the interior wetland. In most areas observed, shoreline processes are not evident 100 to 200 m from the shoreline (Brinson, personal observations).

In freshwater areas where forested fringe wetlands dominate, many sites develop a gradient in species composition and vegetation structure. At a representative site on the Alligator River, *Acer rubrum* (red maple) and *Persea borbonia* (red bay) increased in importance and *Taxodium distichum* (bald cypress) decreased in importance with distance from the shoreline. The outer eroding portion of fringe swamps has a great deal of habitat complexity as revealed by fallen logs, exposed roots, and sheltered areas. Beds of aquatic macrophytes occur in the shallow waters protected by trees. Erosion, and possibly sea level rise, is likely a necessary condition to maintain this complexity. Hence, the process of shoreline recession may be thought of as the cost of maintaining this habitat complexity.

Very little is known about the functions of fringe swamps. In comparison with their marine equivalent, fringe mangrove swamps, the hydrologic energy of these nontidal forests is minor.

Hydrology of forested fringe wetlands has not been resolved and is still poorly understood. Flooding is apparently controlled by wind direction and force as well as seasonal fluctuations in sea level (Brinson et al. In Prep.b). Consequently, hydroperiod varies according to the geographic position of the wetland in relation to the estuary.

In the lower Chowan River floodplain, accumulation of clastic and organic sediments began 4,600 years before the present in channels cut by tributaries of the river on the pre-swamp surface (Witner 1984). Deposits of peat and very peaty sediments occurred in as many as five individual layers separated by clastics. This layering increased in distinctness toward the upper reaches of the lower Chowan, apparently in response to greater fluvial influence. While this site is more riverine than most fringe swamps in the Albemarle Sound, it illustrates the structure of the sediments of a transitional environment between riverine and fringe.

Observed from the water, fringe swamps often give the impression that they consist primarily of bald cypress. From several sites examined, however, bald cypress is more abundant at the estuarine edge than toward the swamp interior. Several situations could explain this, but likely contributing factors are flooding tolerance, 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 of this species is both the reason that it remains standing and the factor that contributes complex aquatic habitat near the shoreline. Erosion is a necessary process that maintains habitat diversity through exposure of roots and lodging of trees.

Another variation of fringe swamp is the transitional zone between tributary marshes of brackish water regions and the floodplain forests of small tributary streams (Brinson et al. 1985). These areas represent a mixture of riverine and estuarine influences. Rising sea level and intrusions of brackish water during drought years were suggested as forces causing brackish marsh to migrate upstream and invade the forested wetland. Rather than migration occurring gradually year-by-year, trees are probably killed and marsh invades during drought years when salinities are high.

Biomass production and nutrient turnover of aquatic macrophyte communities in the protected littoral of the lower Chowan River are described by Twilley et al. (1985). *Nuphar advena* (spatterdock) and *Justicia americana* (water willow) are dominant species. These stands are interspersed among cypress snags along protected regions of the shoreline. The plants and associated invertebrate communities may represent an important source of food and cover for fish and food for terrestrial animals occupying the most exposed portion of the fringe wetland.

Little is known about growth rates of trees in fringe swamps relative to those in interior swamps.

Extensive fringe swamps are limited to the exposed shorelines of the Albemarle Sound where water is fresh enough to maintain trees. Swamps of similar species composition occur in the Pamlico Sound region in tributaries of small creeks where water level fluctuations in the estuary dictate the hydroperiod.

The southern shoreline of Albemarle Sound between the Roanoke River and Alligator River is 72% fringe swamp and 28% upland. Only 1% of the shoreline of Alligator River is upland, the remainder being fringe swamp. However, the shoreline of Croatan and northern Pamlico sounds where salinity is higher is 87% wetland, but most of this is nontidal brackish marsh (Brinson In Prep.b). The position and linear configuration of both fringe swamps and fringe marshes require that they be assessed for the linear extent of the resource, rather than the surface area that they occupy, which is small relative to other wetland types.

There are insufficient data to determine how far back into the wetland the fringe effect is manifested in terms of physical and biological attributes of the ecosystem. Most of these wetlands do not gently slope upwards to merge with uplands. Rather many are the shoreline expression of a large interior wetland that is presumably responding to sea level rise. The extent of fringe swamps in drowned stream valleys is quite small because of the limited number of tributary streams undergoing submergence and the narrow zone in which fringe swamps occur on a given tributary.

C. 4. b. Status of Information. Fringe swamps as an ecological entity have not been recognized elsewhere, probably because the special hydrologic and landscape conditions of Albemarle Sound are uncommon along the Atlantic coast. National Wetland Inventory (NWI) maps do not distinguish them, because their species composition and their cover type are not sufficiently different from other palustrine forested wetlands nearby. However, NWI maps can be used to infer their presence based on location (Brinson In Prep.b).

The value of fringe swamps as fish habitat is not known. Because submerged and floating-leaved aquatic plants are often part of the fringe ecotone, these sites should provide both habitat structure and food for aquatic organisms.

The hydrology of these wetlands is not documented and needs description before its significance to ecosystem function can be understood. Flooding presumably is dependent on wind direction and force. Consequently, hydroperiod varies according to the geographic position of the wetland in relation to the estuary. However, it is not known how hydroperiod compares with hydroperiod of other types of fringe wetland.

We know the general distribution of fringe swamps. NWI maps are being completed for northern Albemarle Sound and can be used to infer the locations of fringe swamps along the Chowan, Perquimans, Pasquotank, Little, and North Rivers and Big Flatty Creek. These extensive areas will rival those already described on the Alligator River and southern Albemarle Sound. The upstream portions of the rivers along northern Albemarle Sound probably grade into wetlands with riverine characteristics in contrast to those along southern Albemarle Sound.

Because of the distinct geomorphic setting of fringe and interior wetlands with respect to uplands in the Albemarle-Pamlico Estuarine Study region, commonly used approaches for predicting effects of rising sea level on the coastal plain are inappropriate and misleading. One current approach assumes that fringe wetlands gently rise in elevation from the shoreline to uplands, and sea level rise will result in the overland migration of these wetlands (Titus 1988). For most areas of the Pamlico and Albemarle sounds, this condition is absent. Instead, fringe wetlands gently grade into interior swamp forests and pocosins with no meaningful change in elevation. Transition to uplands is virtually nonexistent or occurs only over long distances in some cases, making overland migration an irrelevant process. Another approach uses contour lines on topographic maps to predict future shoreline positions as sea level rises. If this approach were valid, many parts of Dare County would now be under water, rather than having accumulated peat and maintained swamp forest and pocosin as they did. The use of contour lines ignores the dominant role that wetlands have played in the landscape development in the coastal plain. Alternative approaches need to be developed for the situation as it exists in North Carolina. An important uncertainty is whether wetlands can sustain themselves when exposed to accelerated rates of rising sea level.

C. 4. c. Trends. The distribution of fringe swamps is unlikely to change unless a major inlet north of Roanoke Island changes the salinity and hydrologic patterns in Albemarle Sound. Some of these swamps represent transitional zones between forest and marsh. These are likely a result of past salinity regimes and are represented by cypress-gum swamps having an understory of *Cladium jamaicense* (saw grass) and other marsh species.

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 for cutting and removal of timber. In many places now, poor stocking may make these forests of limited timber value, especially where shoreline erosion is exposing gum-maple-bay assemblages of relatively small trees.

One of the landscape attributes is the extensive areas of interior wetlands adjacent to some of the fringe swamps. This is one of the unique features of the Alligator River National Wildlife Refuge. Management of this refuge seems to be appropriately directed toward maintaining large contiguous areas in a relatively natural and inaccessible condition.

Poor stocking, mentioned above, may make some fringe swamps of limited timber value. The extent of ditching, diking, and other methods of alteration have not been documented. However, they appear to be minor in comparison to nontidal brackish marshes where ditches for mosquito control and levees for waterfowl impoundments have had a striking impact on the resource.

C. 4. d. Management/Regulatory Status and Trends. The same regulations apply to filling these wetland as others discussed above. However, they probably don't receive the surveillance that coastal marshes get. The effects of timber harvest on fringe swamps is unknown. Studies are needed to determine if regeneration of forest or marsh will occur after timber removal.

C. 5. Nontidal Freshwater Marsh

C. 5. a. Description. Nontidal freshwater marshes have many affinities with nontidal brackish marshes. They are simply part of a continuum toward lower salinity regimes that results in plant communities in which the abundance or dominance by halophytes is greatly diminished. However, species such as *J. roemerianus* may be common in some areas in spite of prevalence by species less tolerant to salt. One of the puzzling issues is why these marshes persist in areas that otherwise might be conducive for establishment of fringe swamp. Generally the environmental conditions of nontidal freshwater marshes cannot be distinguished from those that allow the development of forested wetlands (Figure II-3).

Emphasis will be placed on the 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 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.

These areas are similar hydrologically to nontidal brackish marshes. 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. Salinities vary, but tend to remain below about 2-3 ppt except in the southern portion of Currituck Sound where freshwater vegetation is more restricted in abundance. Historically, salinity has periodically increased due to the intrusions of seawater through 8 major and numerous smaller breaks in the barrier island during storms. The highest recorded salinity in Currituck Sound was about 33 ppt (Sincock 1966).

The species richness of these marshes tends to be higher than for brackish marshes. Common species reported for northern Currituck Sound are: *Typha ormal* spp. (cattails), *Sagittaria* spp. (arrowheads), *Scirpus olneyi* (olneyi three square), *Kosteletzkya virginica* (seashore mallow), *Polygonum* spp. (smartweeds), *D. spicata* (salt grass), *Scirpus americanus* (chair-maker's rush), and *J. roemerianus* (black needlerush) (U.S. Department of Interior 1980). Additional species may include *S. patens* (salt-meadow cordgrass), *Eleocharis* sp. (spikerush), *Erianthus giganteus* (sugarcane plumegrass), *Hydrocotyle umbellata* (pennywort), and *Panicum virgatum* (switchgrass) (Data provided by Refuge Manager, Mackay Island National Wildlife Refuge 1989).

The nontidal fresh marsh ecosystem probably functions much like nontidal brackish marsh, but modified by the extent to which salinity has an effect on the variables being considered. For example, evapotranspiration might be higher than in brackish marshes because of less osmotic stress required for water uptake.

Fish habitat utilization of the marshes is largely unknown. Young fish are likely to find both cover and food in abundance. Much of the attraction to the region depends on waterfowl hunting and bass fishing. Currituck Sound obviously represents good habitat for these organisms, but the functional relationship of the fresh marshes to other components of the larger estuarine ecosystem has not been well established.

It is 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-2). Nearly half of the coverage appears to be in Currituck County alone.

The Draft Environmental Impact Statement (EIS) 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 to the north and the brackish marsh to the south. Sincock (1966) contains maps of the Back Bay and Currituck Sound depicting dominant marsh types during 1958-64. Most of the aforementioned species occurred north of Monkey Island, while *Juncus roemerianus, Spartina cynosuroides*, and *Cladium jamaicense* were prevalent to the south. For the northern marshes, Sincock (1966) stated that annual dominance responds to burning every 2 or 3 years and use by snow geese. Burning is initiated by muskrat trappers when the marshes are dominated by rank growths of *Typha*. After fires, succession is thought to begin with *Cyperus* spp., *Eleocharis palustris*, and *Polygonum* spp., to *Scirpus olneyi*, *S. robustus*, and *S. validus*, and finally to climax of *Typha* spp. and *Hibiscus* spp.

The transitional nature of these marshes and the presence of salt tolerant species intermixed with non-halophytes makes it difficult to identify environmental requirements except in a very crude way. Some of the marshes may be invaded by shrubs and forest species.

This marsh type is not nearly as widespread as nontidal brackish. Regardless, where it is abundant much importance is given to waterfowl and sports fishing resources. Although SAVs provide most of the food for waterfowl in the area, Sincock (1966) estimated that the marshes contribute 1/4 of the demand.

C. 5. b. Status of Information. Most of the research and surveys in the Currituck Sound are limited to the submerged aquatic vascular plants (SAVs) (Sincock 1966; Davis and Carey 1981; Davis and Brinson 1983), which have recognized importance for waterfowl. There are no records of research papers on the emergent freshwater community except for the brief descriptions in Sincock (1966). However, there is no reason to believe that the environmental conditions in which the species of vegetation live differ greatly from their habitat in other geographic regions. Fish utilization of these marshes probably differs greatly from freshwater tidal marshes (Odum et al. 1984), however, which share some of the same plant species.

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

C. 5. c. Trends. Of the wetlands affected by development in the Albemarle-Currituck area, those in Currituck County and presumably Currituck Sound have undergone considerable loss, second only to Pamlico County during 1970-84 (Table II-2). The proximity of this area to a major metropolitan area (Virginia Beach, Virginia) makes it very attractive for outdoor recreation and 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.

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 extent of nontidal fresh marshes because so much of the state's resource is located in this area.

Waterfowl hunting and sports fisheries remain fundamental uses. 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. 5. d. Management/Regulatory Status and Trends. A portion of the Currituck Sound wetlands is managed by the U.S. Fish and Wildlife Service, the Nature Conservancy, and the N.C. Department of Environment, Health and Natural Resources. Private wetlands are subject to the same regulations as other coastal wetlands.

D. RIPARIAN/ALLUVIAL FORESTED WETLANDS

D. 1. Description

The wetland classification system of Cowardin et al. (1979) identifies these areas as palustrine forested and estuarine forested wetlands, with additional modifiers more explicitly defining the wetlands by vegetation type and hydrology. Elements that interact to create riparian forested wetlands include a complex mix of geomorphology, energy distribution–primarily driven by hydraulic energy-physiochemical-nutrient characteristics, and hydrology. Much variation exists within and among riparian forested wetlands, but some unifying characteristics occur. These include their linear form, the corridor transport of water and erodible material, and the profound connection to ecosystems upstream and downstream (Brinson et al. 1981).

Plant species that characterize riparian forested wetlands are adapted to soil conditions and hydroperiod which exclude other vegetation. Plant communities function as buffers which absorb and dissipate the physical energies of the riverine system, slow and reduce the depth of the water column, and trap the sediments dropped from suspension as the water is slowed. Mineral nutrients from the water are fixed in plant tissues and later released as detritus, fueling the floodplain and downstream ecosystem metabolism. 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 determined predominantly by the species' toleration of anaerobic conditions. Other factors influencing the distribution of plant species include soil characteristics, detrital decomposition rates, soil and water pH, nutrient availability and turnover rates, flood depth and water velocity, light intensity, and disturbance, both human and natural (Wharton et al. 1982) The variability and interaction of these factors produces a very diverse assemblage of floral species.

As mentioned previously, distribution of anaerobic conditions as determined by hydrology is a primary factor differentiating the types of wetlands classified as riparian forested. Vegetation in Albemarle-Pamlico Estuarine Study area riparian forested wetlands ranges from bald cypress (*Taxodium distichum*) and water tupelo gum (*Nyssa aquatica*) in semipermanently flooded areas to diverse assemblages of trees including American elm (*Ulmus americana*), red maple (*Acer rubrum*), sycamore (*Platanus occidentalis*), and sweet gum (*Liquidambar styraciflua*) in temporarily flooded areas. Other vegetation commonly occurring in riparian forested wetlands includes giant cane (*Arundinaria gigantea*), green ash (*Fraxinus pennsylvanica*), laurel oak (*Quercus laurifolia*), river birch (*Betula nigra*), swamp cottonwood (*Populus heterophylla*), water hickory (*Carya aquatica*), water oak (*Quercus nigra*), willow (*Salix nigra*), and willow oak (*Quercus phellos*). This flora, in turn, supports a variety of indigenous invertebrates, amphibians, reptiles, mammals, birds, and fish. The corridor function of riparian systems also provides migratory paths for mammals and birds. During flooded periods the riparian forested wetlands serve as spawning habitat for many species of fish, including anadromous clupeids.

D. 2. Trends

The lack of consistent, comprehensive studies precludes precise identification of historical acreages of riparian forested wetland types in the Albemarle-Pamlico Estuarine Study area. While various wetland inventories have been undertaken in the past, they were done for a variety of reasons and used different methodologies and terminology. Thus, the results are not directly comparable. Furthermore, results of surveys have been reported primarily in terms of statewide totals. However, Wilson (1962) reported approximate acreages by county from data extracted from the Office of River Basin Studies (1954). In the Albemarle-Pamlico Study area "bottomlands" occupied 302,850 acres and "wooded swamps" occupied 501,250 acres. These figures represent 66.0% and 50.7%, respectively, of the state total for these forested wetland types. Forested wetland losses have occurred at a high rate on a national basis in recent years (Frayer et al. 1983). These losses may not necessarily reflect the trend in the Albemarle-Pamlico Study area, however. The Roanoke River floodplain is considered to be the largest intact and least disturbed bottomland forest ecosystem remaining in the Mid-Atlantic Region. The Fish and Wildlife Service's National Wetland Inventory is underway in North Carolina but is not yet completed. When mapping is complete, a definitive and accessible source of wetland acreage will be available.

D. 3. Management/Regulatory Status and Trends

Discharge of dredged or fill material into waters of the United States is regulated by Section 404 of the Clean Water Act of 1977, as administered by the U.S. Army Corps of Engineers. Water quality certification under Section 401 of the Clean Water Act of 1977 is administered in North Carolina by the N.C. Division of Environmental Management. The Food Security Act of 1985 provides for withholding of Federal farm subsidies associated with agriculture land converted from wetlands. While the Food Security Act may be an effective tool for maintaining wetlands, other regulatory measures have had limited success in protecting riparian forested wetlands. General permits, jurisdictional disputes and categorical exclusions, particularly for silviculture, have contributed to wetland losses.

E. SPECIAL FISHERIES HABITATS

E. 1. Bay Scallop Beds

E. 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 seagrass blades (Thayer et al. 1984b). This attachment holds the juvenile scallops above the bottom and prevents their burial under sediments, helps lower turbidity in the scallop's immediate vicinity, and provides greater flux of foods than would occur on the bottom (Eckman et al. 1989). The food supplies of bay scallops also may be enhanced by microbial production (attached microalgae and bacteria) generated on the seagrass blades and within the seagrass bed. Predation rates on juvenile scallops are reduced by the structural complexity of emergent substrate (seagrass shoots and blades), which is 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 still remain within seagrass beds despite their ability to move elsewhere through swimming (Peterson et al. 1982). When placed outside seagrass, adult bay scallops emigrate more rapidly than when placed inside seagrass; this process tends to return them to seagrass beds even if displaced by some process (Peterson et al. 1989). Adult bay scallops outside seagrass suffer much greater predation from whelks (*Busycon* spp.) than those maintained inside seagrass beds (Peterson et al. 1989; Prescott 1990), and experimental reduction of seagrass cover resulted in proportionate declines in resident bay scallop abundance (Peterson et al. 1987).

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 larger highly saline rivers such as 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 these areas are limited.

Historically, 60% of the bay scallop harvest in North Carolina comes 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).

Bay scallop habitat is controlled by all the factors affecting seagrass abundance (turbidity, bottom disturbance especially from fishing practices, disease, temperature, etc.) and 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, this could create substantial bay scallop habitat in that sound.

The bay scallop is the most physiologically sensitive of all North Carolina shellfish. Consequently, it might act as the fisheries "canary" to indicate future problems in the health of estuarine systems. Similarly, the seagrass beds themselves serve as an indicator of ecosystem health, as shown by the Chesapeake Bay history (Orth and Moore 1983). Bay scallops also have 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.

<u>E. 1. b. Status of Information</u>. The function of bay scallop habitat is reasonably well understood. Among the least understood phenomena is the role of recruitment in determining bay scallop abundance. Bay scallop recruitment appears to be limited in part because specific seagrass beds vacillate greatly from year-to-year in the abundance of bay scallops, as if vagaries of larval transport dictate where the population will be concentrated in any given year. Understanding this issue of the role of recruitment requires much future effort.

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

E. 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 habitat is potentially threatened by lack of controls on freshwater runoff and turbidity, both of which may be expected to increase as development paves more surfaces.

E. 1. d. Management/Regulatory Status and Trends. The habitat for bay scallops is managed only to the degree that bullraking, "kicking" clams, 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. Most scallop habitat is included in two of the areas (Core Sound and western Bogue Sound) that have been nominated by the N.C. Division of Marine Fisheries for designation as Outstanding Resource Waters (ORWs). 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 address maintenance of high salinity and low turbidity.

E. 2. Hard Clam Beds

E. 2. a. Description. *Mercenaria mercenaria* (hard clams) 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). Hard clams are limited to waters of relatively high salinity (permanently above about 12.5 ppt). No hard clam beds exist in Albemarle Sound because of low salinity, and few beds exist in the Pamlico Sound for the same reason. Water temperature is suitable for hard clams everywhere in the North Carolina estuaries.

Hard clams could potentially be limited in distribution, abundance, or productivity by low food supply, but that factor apparently is not limiting in North Carolina estuaries (Peterson and Beal 1989). Hard clams are often limited in both abundance and distribution by predation. Whelks probably limit productive hard clam habitat in clean sand in high salinity near Ocracoke, Hatteras, and Oregon Inlets (Peterson 1982). Blue crabs are an even more important enemy (Arnold 1984) in many areas but probably do not restrict hard clam distribution in Pamlico Sound. Hard clams are not afflicted by any significant disease problems in North Carolina.

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

The habitat serves to provide food resources for hard clams. Such food resources, mostly phytoplankton, are extremely abundant in North Carolina estuaries. 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 clam habitat does not exist in the Albemarle Sound because of low salinities. Low salinity reduces hard clam habitat in the Pamlico Sound to a relatively narrow band along the Outer Banks from Cedar Island to around Buxton, including the area from Oregon Inlet westward to mid-Pamlico Sound on Bluff Shoal. Nevertheless, the area of hard clam habitat in Pamlico Sound supports a significant commercial clam catch.

The habitat for hard clams in the Albemarle and Pamlico sounds is limited almost solely by low salinity. Hard clams are tolerant of a lower salinity than bay scallops so that the hard clam habitat includes all the bay scallop habitat plus a substantially larger area of lower salinity and reduced or absent seagrass.

Because hard clams are very long-lived (in excess of a 40-year life span in North Carolina: Peterson 1983, 1986b), they are a fishery resource that, if not over-harvested, can be conserved from year to year and can thus be available for fishing income when times are hard. In other words, the maintenance of a healthy hard clam resource provides an economic safety factor for fishermen. In addition, the economic value of hard clams has risen high enough to make this fishery ($6.2 million in 1988) extremely significant to North Carolina. This high price can justify aquaculture of hard clams, which is now economically feasible over large portions of southern and eastern Pamlico Sound.

E. 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). However, the degree to which larval events and settlement phenomena influence hard clam distribution is a current area of active interest and research (Butman et al. 1988).

The function of shell hash and seagrass cover in inhibiting predation is well established (Castagna and Kraeuter 1977; Peterson 1982). The physiological processes by which low salinity acts are also clear. Less obvious is the importance of substrate (sediment grade) versus flow regime because these two factors are badly confounded in nature (Grizzle and Morin 1989).

Fishing pressure is intense enough on hard clams that fishermen collectively 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 N.C. Division of Marine Fisheries (DMF) is now engaged in preparing such a map.

Knowledge of the critical nature of maintaining high salinity, seagrass cover, and intact shell bottoms 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 also limit fecal coliform pollution, which is a major cause of closure of clam beds to shellfishing.

E. 2. c. Trends. No data exist concerning the temporal pattern of change in hard clam habitat in North Carolina. Habitat distribution probably changes mostly due to variation in salinity regimes. Such variation occurs on a large scale from 3 sources. 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, this process may have reduced hard clam habitat in Pamlico Sound over the past 10-20 years, but no distributional data exist to assess this idea. Second, the clearing and impervious paving of land in the watershed also acts to reduce estuarine salinity and may have restricted somewhat the hard clam habitat over this same time period. Third, rainfall variation influences salinity regimes. The drought period between 1985 and 1989 increased clam habitat. Clams were caught incidental to oyster dredging around the mouth of West Bay, which is not known as a clam-producing area.

Use of the hard clam resource has escalated greatly in North Carolina in recent decades, with an approximately 8-fold increase in landings from the 1960's and early 1970's to 1985. In the past two years, catch is down to the level of the late 1970's, but fishing effort is still high, suggesting continued high use of the hard clam habitat.

The habitat quality for hard clams in Pamlico Sound remains high, except to the degree that declining salinities because of inlet shoaling and stormwater runoff are restricting the extent of the habitat. The full extent of restriction or devaluation of hard clam habitat through reduced salinity has yet to be experienced because the last few years have been drought years. Clam Kicking and over-fishing, however, are jeopardizing the sustained yield of hard clams in most habitats.

<u>E. 2. d. Management/Regulatory Status and Trends</u>. Hard clam habitat is protected in North Carolina by stormwater runoff regulations promulgated by the N.C. Environmental Management Commission and by management of bottom-disturbing practices by the N.C. Marine Fisheries Commission. Mechanical harvesting of hard clams is prohibited by N.C. Marine Fisheries Commission regulation in seagrass beds so as 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. Existing stormwater runoff regulations may not be protecting hard clam habitat, but no convincing evidence exists. A number of the major hard clam beds in the state are included in the areas that have been nominated for Outstanding Resource Waters designation.

E. 3. American Oyster Beds

<u>E. 3. a. Description</u>. Oysters (*Crassostrea virginica*) require a hard substrate for larval attachment and subsequent growth to adulthood. This hard substrate is ordinarily provided by biogenic calcium carbonate, namely the shells of dead or still living older oysters. Nevertheless, oyster habitat can include abiotic hard substrates, such as seawalls, bulkheads, and pilings (Ortega 1981). Oysters can tolerate lower salinities than hard clams or bay scallops, but they are limited to salinities of about 5-30 ppt (Chanley 1957; Galtsoff 1964; Burrell 1977). Intertidal oysters in North Carolina occasionally experience massive winter kills from intense freezes, but these events do not greatly restrict the oyster habitat in the Albemarle or Pamlico Sound, in part because there is virtually no tide and no intertidal zone in these bodies of water. Intense summer heat may contribute to oyster mortality by interacting with diseases to enhance mortality rates. This interaction between factors also does not limit oyster habitat in Pamlico or Albemarle sounds because summer maximum water temperatures are probably high enough everywhere in these water bodies to induce some stress. Summer anoxia in the deeper basins of the Albemarle and Pamlico sounds also greatly limits oyster habitat (Tenore 1972).

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 estuaries (Peterson and Beal 1989). The presence of 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), oyster enemies, including especially the oyster drill (*Urosalpina cinerea*) greatly limit the abundance of adult oysters (Wells 1961). Such high salinities occur only in close proximity to Ocracoke, Hatteras, and Oregon Inlets in Pamlico and Albemarle sounds. Consequently, the area where oyster production is restricted by predation at high salinities is virtually negligible in these water bodies.

The hard substrate, biotic or abiotic, functions by providing hard surface for larval attachment up above the sediments. This allows feeding by the newly metamorphosed oysters without suffocation under sediment cover. Oyster reefs also provide important habitat for several commercially and recreationally significant fishes.

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 are created by planting mollusc shells in the N.C. Division of Marine Fisheries' oyster management program. Oyster beds are absent from deeper depositional basins in Pamlico Sound, where summer anoxia is a routine event (Tenore 1972). No oyster beds exist in waters of less than about 5 ppt salinity. 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.

Oyster habitat is limited by (1) the presence of adequate hard substrate sufficiently elevated above the estuarine seafloor to prevent it from being covered by sediments, (2) the availability of sufficiently shallow habitat to avoid anoxia in summers, (3) the availability of waters with salinity always greater than about 5 ppt, and (4) the activity of protozoan diseases, MSX and "Dermo".

E. 3. b. Status of Information. The physical and biological factors that define oyster habitat are reasonably well known (Carriker 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 functional process affecting oyster habitat is the epidemiology of the two oyster diseases, MSX and Dermo. The other functions of oyster habitat variables are reasonably well appreciated.

The N.C. Division of Marine Fisheries 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.

E. 3. c. Trends. With recent drought years, oyster distributions have tended to move substantially upriver in many Pamlico Sound tributaries, presumably in response to salinity increases. The incidence of MSX and Dermo was especially great in the summer of 1988, but whether this represents a trend or a consequence of the extremely hot 1988 summer remains unclear.

Oyster habitat is devalued by the increasing extent and intensity of anoxia events in Pamlico Sound. These are a reflection of increased eutrophication of the Pamlico Sound tributaries through excessive nutrient inputs by farm runoff, municipal sewerage discharges, and industrial nutrient and organics sources. Oyster habitat may also be affected adversely by the use of heavy oyster dredges instead of tongs. Heavy dredges destroy, scatter, and bury the critical shell material necessary for larval settlement and perpetuation of the oyster bed. Oyster habitat may also be impacted negatively 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 also make potential settlement surfaces unacceptable to oyster larvae.

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

E. 4. Nursery Areas

E. 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, and fish populations consist uniformly of very early 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, and 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 the inlets (Purvis 1976).

Although the classification of nursery areas given above is that of common usage, Ross and Epperly (1985) divided Pamlico Sound nursery areas into five groups on the basis of Morisita's and Czekanowski's indices and 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).

During 1979-1984, 128 species were taken in the N.C. Division of Marine Fisheries' estuarine trawl survey (the entire program includes 119 stations from Pamlico Sound to the Cape Fear River). Despite this apparent species diversity, 10 species each year comprised over 97% of the individuals taken, and 7–*Leiostomus xanthurus* (spot), *Micropogonias undulatus* (croaker), *Brevoortia tyrannus* (menhaden), *Penaeus aztecus* (brown shrimp), *Callinectes sapidus* (blue crab), *Paralichthys lethostigma*, (southern flounder), and *Bairdiella chrysoura* (silver perch)-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 about 60% of all individuals taken; croaker was second, 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 occur 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 and 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 production of frequently unwanted plankton or, alternatively, can poison desireable estuarine organisms (Epperly 1984). Because of the complexity of the estuarine system and synergy among environmental factors, the degree to which any one is limiting estuarine productivity at any particular time is difficult to demonstrate. Any or all may have a profound impact upon environmental conditions in primary nursery areas and their continued contributions to estuarine and marine fisheries.

E. 4. b. Status of Information. The N. C. Wildlife Resources Commission and N.C. Division of Marine Fisheries 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, personnel of the former agency surveyed waters of 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 N.C. Division of Marine Fisheries conducts routine fisheries surveys in the area, beginning in 1972 with anadromous fisheries investigations in Albemarle and Croatan sounds and their tributaries. In 1974, and continuing until fall, 1975, N.C. Division of Marine Fisheries 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, N.C. Division of Marine Fisheries sampled 51 stations in designated primary nursery areas on a monthly basis from March through November during 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 obtained (Ross and Epperly 1985). Supplementing this broad-based survey were more intensive N.C. Division of Marine Fisheries studies of Rose and Swanquarter Bays during

1977-1980 directed toward determining the effects of freshwater drainage upon the nursery areas (Pate and Jones 1981; Jones and Sholar 1981) and North Carolina State University sampling in the same area between 1979 and 1983 (Gerry 1981; Woodward 1981; Currin 1984; Epperly 1984).

Although questions concerning the adequacy of gear and sampling design used in the N.C. Division of Marine Fisheries surveys have been raised from time to time (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 N.C. Division of Marine Fisheries 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.

E. 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.

E. 4. d. Management/Regulatory Status and Trends. Designated primary nursery areas are protected against damaging fishing practices through regulations of the Marine Fisheries Commission enforced by the N.C. Division of Marine Fisheries. Trawling, oyster and clam dredging, and clam "kicking" (using propeller wash to excavate clams) are prohibited in such 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 N.C. 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 U. S. Army Corps of Engineers. Development in estuarine waters, coastal wetlands, and estuarine shoreline Areas of Environmental Concern (AECs) is regulated by permits from the N.C. 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 N.C. Environmental Management Commission and Coastal Resources Commission. At the present time, however, no definitive action has been taken in either area.

E. 5. Anadromous Species Spawning Habitats

E. 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 seven anadromous species representing three families: *Morone saxatilis* (striped bass), *Alosa sapidissima* (American shad), *Alosa mediocris* (hickory shad), *Alosa aestivalis* (blueback herring), *Alosa pseudoharengus* (alewife), *Acipenser oxyrhynchus* (Atlantic sturgeon), and *Acipenser brevirostrum* (shortnose sturgeon). The status of these anadromous populations was determined by a 1980 survey (Rulifson et al. 1982), results of which are summarized for the Albemarle-Pamlico Estuarine Study area in Table II-3. The shortnose sturgeon remains on the U.S. Fish and Wildlife Service Endangered Species List and is believed extirpated in the Albemarle-Pamlico Estuarine area.

Spawning habitats of anadromous species are located in several primary rivers and many tributaries throughout the Albemarle-Pamlico Estuarine Study area, always upstream of tidal influence and saltwater intrusion. 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 again are characteristics of 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 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 is temporal as well as spatial in nature. 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 (sufficient water flow for survival of eggs and larvae). All species spawn during the spring. The primary trigger for spawning activity is water temperature. However, 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. Additionally, dams, dikes, roadways requiring culverts, and other barriers may restrict access to traditional spawning grounds (Collier In Prep).

<u>E. 5. b. Status of Information</u>. Field work in the 1970's and 1980's 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 - 9. Of the 7 anadromous species documented in these waters, spawning areas of 3 are not well known: hickory shad, Atlantic sturgeon, and shortnose sturgeon (if still present at all). An important document, in preparation by Ries Collier (U.S. Fish and Wildlife Service, Raleigh), will identify 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. 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.

E. 5. c. Trends. In general, populations of all anadromous species continue to decline in numbers 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 1950's (Manooch and Rulifson 1989).

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 1800's, 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 U.S. 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 U.S. 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 U.S. 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 1800's, 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 U.S. 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 U.S. 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).

E. 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 coastwide 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 North Carolina Division of Marine Fisheries (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 on the spawning grounds. A summary of striped bass harvest regulations was presented by Manooch and Rulifson (1989). 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 between the U.S. Fish and Wildlife Service and the two state agencies to manage striped bass in North Carolina is being negotiated (W.C. Cole, U.S. Fish and Wildlife Service, personal communication).

F. OTHER CRITICAL AREAS

F. 1. Barrier Islands: Beaches, Dunes, Flats, Thickets, Woodlands, Marshes, Impoundments, Inlets, Dredged Islands, and Aquifers

F. 1. a. Description. The North Carolina Outer Banks extend from the Virginia-North Carolina line 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 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 Banks and the mainland, waters of the Roanoke, Chowan, Pamlico-Tar, 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).

Table II-3. Results of a 1980 Survey Indicating Status of Anadromous Fish Populations within the Albemarle-Pamlico Estuarine Systems Study Area (Rulifson et al. 1982)

	Anadromous species						
Watershed	SB	AS	HS	BH	AW	AS	SS
Currituck Sound	-	-	-	D	D	-	E
Albemarle Sound	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
Scuppernong R.	-	-	-	D	D	-	E
Alligator R.	-	-	-	D	D	-	E
Pamlico Sound							
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.

Table II-4. Spawning Criteria of Striped Bass within the Albemarle-Pamlico Estuarine System Study Area

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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). Flakland 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.).

Table II-4. (Striped bass continued)

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).

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%; plastic, 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 surival 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:

Rehwoldt et al. (1971); Setzler et al. (1980).

Table II-5. Spawning Criteria of American Shad within the Albemarle-Pamlico Estuarine System 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 SSR 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 Durhams 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).

Table II-5. (American Shad continued)

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).

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).

Table II-5. (American Shad continued)

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 0.1 g/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 Albemarle-Pamlico Estuarine System Study Area

Location:

ROANOKE WATERSHED - no spawning documented

TAR WATERSHED - no spawning documented; adult fish are caught by fishermen occasionally, 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 Albemarle-Pamlico Estuarine System 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).

Table II-7. (Hickory Shad continued)

Fertilization:

Hickory shad eggs released in open water areas of rivers where they are fertilized; typically demersal and somewhat adhesive, but easily didslodged 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

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 Albemarle-Pamlico Estuarine System 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 bridsge to mouth

LITTLE SWIFT CREEK - SR 1627 bridge to mouth

BATCHELOR 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

Entire creeks: Pinetree Creek, Turkey Quarter Creek, Pitchkettle Creek, Taylor Creek, Halfmoon Creek, Kitten Creek, Village Creek (Hawkins 1979)

TRENT RIVER - Pleasant Hill to SR 1121 (Marshall 1977)

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)

Table II- 8. (Blueback Herring continued)

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)

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 Batchelor 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 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).

Table II-8. (Blueback Herring continued)

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, and 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 LC_{50} of total residual chlorine for eggs ranges from 0.20-0.32 ppm; sublethal concentrations resulted in deformed larvae (Morgan and Prince 1977).

Table II-9. Spawning Criteria of Alewife within the Albemarle-Pamlico Estuarine System 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 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)

Table II-9. (Alewife continued)

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).

Water Quality:

Hatching success of alewife eggs is not affected be 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

Moving water also affects the Banks. The average rate of beach erosion is 2-6 ft per year (Benton 1981). These forces are more evident near the inlets, which move southward or westward at rates up to 25 feet per year (Benton 1981). Thus the physical forces of nature are a profound, continuous, and varying component of the Outer Banks–wind and wave, storm and erosion, tides and salt spray (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 *Ammophila breviligulata* (northern beach grass), *Uniola paniculata* (sea oats), *Spartina patens* (saltmeadow cordgrass), *Fimbristylis castanea* (sand rush), *Andropogon scoparius* var. *littoralis* (broom-sedge), *Solidago sempervirens* (seaside goldenrod), *Strophostyles helvola* (wild bean), and other salt-tolerant species (Schafale and Weakley 1985).

Landward (soundward) herb-shrub habitats become increasingly dominated by *Myrica cerifera* (wax myrtle), *Ilex vomitoria* (yaupon), *Iva frutescens* (marsh elder), and young and/or stunted *Quercus virginiana* (live oak). 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 landward (soundward), the thicket woodlands increasingly become dominated by *Juniperis virginiana* (red cedar), *Persea borbonia* (red bay), *Zanthoxylum clava-herculis* (Hercules club), live oak, and *Pinus taeda* (loblolly pine), with much *Smilax* (greenbriar) and *Vitus* (grape).

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

Sloping into the sound side are first the high marsh (irregularly flooded) and finally the low marsh (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 made 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 and was 1,707,000 in 1973 (Quay 1980). In 1988, the annual visitation was 2.1 million for Cape Hatteras National Seashore, 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 planned for expansion but still 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 desalinization plant (reverse osmosis process) 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, from deep wells, is now being planned with the hope of becoming functional by 1990-91. This facility will be at Rodanthe.

The freshwater supplies for the Roanoke Island-Nags Head-upper Currituck Banks regions have been from wells of various depths in the different locations—more recently, 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, again by the reverse osmosis method, using brackish water from deep wells, has become functional here in the summer of 1989, with a 3-million gallons-per-day capacity. Consideration is already being given to expansion of this new source, which is located at Kill Devil Hills.

The freshwater available for all of Currituck County is relatively poor both in 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 N. C. Outer Banks in the A/P Study area is in some kind of state, federal or public land trust ownership, including Cape Hatteras National Seashore (CHNS), 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 N.C. Coastal Reserve, and the North Carolina Nature Conservancy in the Swan Island-Monkey Island region (U.S.Fish and Wildlife Service 1980; Taggart and Henderson 1988). All of these lands are held and managed as natural areas, excluded 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 U.S. Fish and Wildlife Service and have been since the refuge was established and the freshwater impoundments constructed in brackish marshes during the late 1930's. Waterfowl and other wildlife abound at Pea Island, as compared with the rest of the CHNS. Vegetation on Pea Island is managed intensively for waterfowl by cutting, burning, discing, plowing, and the use of water-control structures on the sound side (and herbiciding, formerly) to keep the natural communities more open, wetter, and in the earlier stages of plant succession.

The Park Service management, in contrast, is the classical "protect and leave alone" system. Park Service lands have been protected from cutting, burning, plowing, and four-wheel vehicles, and 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 becoming taller, denser, and more woody, for a 43% change of area 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 U. S. Army Corps of Engineers have been an ecological feature of the Outer Banks region and A/P estuaries since the 1930's. 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 U.S. Fish and Wildlife Service, the National Audubon Society, scientists from the University of North Carolina at Wilmington, the N. C. Nature Conservancy, the N. C. Wildlife Resources Commission, and the N. C. 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. The 23 species of colonial-nesting waterbirds, of which 18 are on "threatened" or "of special concerns" lists (Cooper et al. 1977; Parnell 1985), nest almost exclusively in dredge island habitats–from freshly-dumped bare sand and muck to thicket woodlands (Parnell and Soots 1979).

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 conformance with dredging cycles (Parnell and Soots 1975).

F. 1. b. 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; U.S. Fish and Wildlife Service 1980).

F. 1. c. 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 degrade (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 1930's), by roads and increasing urbanization with their accompanying dredging and filling, by off-road vehicles in recent years, and by the construction of hardened structures on beaches and at inlets and, (until recently) 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–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. 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 higher 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, and 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 U. S. Fish and Wildlife Service, National Park Service, N. C. Wildlife Resources Commission, N. C. Division of Coastal Management, N. C. Division of Parks and Recreation, N. C. Nature Conservancy, N. C. National Estuarine Research Reserve, and N. C. 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, 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 starting to rise at a rate of 3-7 feet by 2030 (Benton 1981; Wilms 1988)), the coming changes in the coastal zone are sobering.

F. 1. d. 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 (U.S. Fish and Wildlife Service 1980) lists, identifies, and explains 21 sets of North Carolina environmental laws and regulations (legislation), and similarly 17 sets of federal legislation which apply to the North Carolina Outer Banks (barrier islands) (U.S. Fish and Wildlife Service 1980). While many of these management efforts may need to be more strict, and some added, better monitoring and enforcement of existing controls could be effected immediately.

F. 2. Pocosins and Related Wetlands

F. 2. a. Description. Pocosins are classified by Cowardin et al. (1979) as palustrine or nonalluvial wetlands. These peatlands are dominated by a dense, nearly impenetrable cover of evergreen and deciduous shrubs, with scattered emergent trees. They share many species in common with bay forests and Atlantic white cedar forests which are also considered here. Shrub and tree stature ranges along a gradient from < 1 m in the lowest pocosins to > 15 m in Atlantic white cedar forests. Richardson et al. (1981) estimated that this continuum of ecosystems once occupied 2.24 million acres in the Albemarle-Pamlico region.

Within the region, pocosin vegetation is most common on lower terraces of very flat topography where poor drainage has favored peat accumulation (paludification), this process began approximately 5-7,000 years ago along small stream channels and in depressions on these landscapes (Whitehead 1981). Peat subsequently accumulated to create "high-center" bogs, with deepest peats (1-4 m) occurring in the bog centers. Thus, rainfall is the only input of surface water to such bogs (i.e., they are ombrotrophic) and water tends to flow out of them 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 limited nutrient inputs in rainwater and the separation of plant roots from mineral 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 *Cyrilla racemiflora* (ti-ti), *Lyonia lucida* (fetterbush), *Ilex glabra* (gallberry), and *Zenobia pulverulenta* (honeycup). *Pinus serotina* (pond pine), *Magnolia virginiana* (sweet bay), and *Gordonia lasianthus* (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 pine may grow to heights of over 10 m in these so-called high-pocosins.

In the most nutrient-limited situations, pocosin vegetation represents a successional climax. Although fires burn through these ecosystems with a return interval of 30-50 years (Christensen 1981), they show no sign of succeeding to other community types in the absence of fire. However, many pocosin species are preadapted to invade in disturbed situations 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 *Acer rubrum* (red maple), *Nyssa sylvatica* (black gum), and *Pinus taeda* (loblolly pine) and are widespread in the Albemarle-Pamlico region (see Schafale and Weakley 1985; Christensen 1988).

Atlantic white cedar forests in the Albemarle-Pamlico area are most common on deep peats over sandy substrates. *Chamaecyparis thyoides* (Atlantic white cedar) forms an even-aged, closed canopy in such stands. Understory shrubs such as fetterbush, *Ilex coriacea* (sweet gallberry), and *Clethra alnifolia* (pepper bush) may dominate the understory. Sweet bay, loblolly bay, and *Persea borbonia* (red bay) are also common and may co-dominate with white cedar. Because white cedar does not establish in the dark shade of mature stands (Korstian and Brush 1931), fire is critical to the regeneration of Atlantic white cedar ecosystems. In the absence of fire, the natural thinning process in the white cedar canopy permits invasion of bay forest species.

Bay forests appear to represent a successional endpoint on the most productive peatlands (Buell and Cain 1943). The dominant species in this forest include red bay, loblolly bay, sweet bay, and *Ilex cassine* (dahoon holly). Understory species include *Smilax* spp. (greenbriar), *Arundinaria gigantea* (cane), and *Woodwardia virginica* (chain fern).

F. 2. b. Status of Information. Because of their extent and debated wetland status, 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). Considerably less information is available on bay forests and Atlantic white cedar forests. General references for these ecosystems include Buell and Cain (1943); Laderman (1987); and Christensen (1988).

F. 2. c. Trends. Pocosins and related wetlands are among the most rapidly changing landscapes in the Albemarle-Pamlico region. As of 1979, only 31% of pocosin land in this area remained in its natural state (Richardson et al. 1981). Thirty-four percent of the area's peatlands had been "totally developed;" i.e., they had been drained and the native vegetation permanently removed or altered. Richardson et al. (1981) classified the remaining pocosin areas as "in transition." These areas had been sufficiently disturbed by drainage and timber activities to significantly change ecosystem processes.

Frost (1987) cited historical evidence that Atlantic white cedar forests were considerably more widespread in the Albemarle-Pamlico region in the past than today. Logging and repeated disturbance have limited opportunities for regeneration of white cedar. Indeed, a host of land uses and perhaps more frequent fires have converted many bay forest and white cedar forest areas to pocosin-like shrublands.

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, although actual mining has been limited to demonstration areas and small horticultural peat operations to date. Extensive tracts of these vegetation types have been preserved, especially in Dare County in the Alligator River National Wildlife Refuge (for a listing of other preserved sites see Lynch and Peacock 1982a,b; Peacock and Lynch 1982a,b).

F. 2. d. Management/Regulatory Status and Trends. The status of pocosins relative to Section 404 of the Clean Water Act was, until recently, a matter of considerable debate. It is now generally agreed that such wetlands are indeed regulated by this legislation. Permits for development of pocosin wetlands must be obtained from the U.S. Army Corps of Engineers. Where section 404 permits are required, certification must also be obtained from the North Carolina Division of Environmental Management in compliance with Section 401 of the Clean Water Act.

F. 3. Nonriverine Swamps

F. 3. a. Description. Nonriverine swamp forests are communities dominated by species similar to those on river floodplains, but occurring on sites not associated with river or tidal flooding. The Natural Heritage Program community classification (Schafale and Weakley 1985) recognizes two community types within this category: the cypress and gum dominated Nonriverine Swamp Forest type on the wettest sites and the oak dominated Nonriverine Wet Hardwood Forest type on less wet sites. Other forested wetlands on organic soils, such as Atlantic white cedar, bay, and pond pine forests, are considered more closely related to pocosins and are discussed with them.

Non-riverine swamp forests occur on broad flat areas, where poor drainage and high water tables keep them flooded for part or much of the year. They frequently occur near the edge of large peatlands, grading to pocosins or related communities toward the interior of the peatland. They may grade to mesic upland communities on the better drained periphery, or to fringe swamps along freshwater estuaries.

Soils of the Nonriverine Wet Hardwood Forest community type are hydric clayey or silty mineral soils, while those of the Nonriverine Swamp Forest type may be mineral or organic. Where the communities occur on organic soils, the location usually allows occasional input of sediment, either from adjacent uplands or from rare tidal flooding. These communities are less oligotrophic than pocosins and related communities.

The Nonriverine Swamp Forest type, in its primary state, was dominated by *Taxodium distichum* (bald cypress) and black gum, with some *Pinus taeda* (loblolly pine) and Atlantic white cedar. After early logging, bald cypress frequently did not regenerate. Logged areas generally became dominated by a low canopy of black gum and red maple, or sometimes by Atlantic white cedar 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, including *Liquidambar styraciflua* (sweetgum), *Quercus laurifolia* (laurel oak), *Q. pagoda* (cherrybark oak), *Q. michauxii* (swamp chestnut oak), *Q. phellos* (willow oak), black gum, *Ulmus americana* (American elm), and red maple. The shrub layer was generally sparse. Some areas may have been canebrakes, with dense *Arundinaria gigantea* (cane) and an open tree canopy. With logging, loblolly pine and sweetgum became dominant.

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 served to store fresh water, releasing it gradually to the streams and estuaries, and damping flow peaks. By their position at the margin of large pocosin areas these communities may have mediated the flow of water out of them.

<u>F. 3. b. Status of Information</u>. Nonriverine swamps have received little study in comparison to marshes, pocosins, and bottomlands. No quantitative studies of the type are known. Lynch and Peacock (1982b) and Peacock and Lynch (1982a) gave qualitative descriptions of remnant areas included in county natural areas surveys. More attention has focused on the more extensive Nonriverine Swamp Forest type, particularly the Great Dismal Swamp. A variety of aspects of the Dismal Swamp system have been studied (Carter and Gammon 1976; Musselman et al. 1977; Kirk 1979). However, information is largely lacking on most other examples of Nonriverine Swamp Forest. Limited information on natural condition, dynamics, fire regime, and hydrology make management difficult.

<u>F. 3. c. Trends</u>. Nonriverine Wet 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 in the Coastal Plain, 1/4 of the swamp area (apparently not including river floodplains, which they discussed separately). Peacock and Lynch (1982b) estimated based on soils that this community type was once the most common in Pamlico County, and the same was undoubtedly true in other counties in the region. Because these sites are relatively fertile and easily drained,

most have been converted to agriculture. Additional acreage has been drained and put into timber plantations. These activities continue to reduce the few known remnants.

The wetter Nonriverine Swamp Forest type also occupied vast areas on the outer Coastal Plain and has been much reduced by agricultural conversion and timber plantations. Substantial acreage remains; however, most or all of it has had its hydrology altered by canals and its vegetation altered by repeated logging.

F. 3. d. Management/Regulatory Status and Trends. Nonriverine swamps, as wetlands, are covered under Section 404 of the Clean Water Act. A permit from the U.S. Army Corps of Engineers is required for any deposition of dredged or fill material. Projects requiring 404 permits must also be certified by the N.C. Division of Environmental Management under Section 401 of the Clean Water Act. Wetlands are also covered under the Swampbuster legislation, which denies federal farm subsidies to any farmer who newly clears wetlands for agriculture.

The existing regulations have not prevented loss of these wetlands. The major destructive activities, agricultural and forestry operations, are exempt from 404 permitting requirements. Other destructive activities which do not involve deposition of material in the wetlands are also not covered. In addition, 404 regulation has been limited by questions about jurisdiction over isolated wetlands. The recent Swampbuster legislation should provide protection from destruction from agriculture, but forestry activities, the largest threat, remain unregulated.

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 critical areas not fitting one of the preceding classes.

G. 2. Description

Beds of submerged aquatic vegetation (SAVs) 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 SAVs which were largely replaced by Eurasian watermilfoil during the 1960's and 1970's. The milfoil decreased dramatically during the latter 1970's and was replaced in turn by widgeongrass (a native submerged aquatic). Similarly, SAV was common in the Pamlico River until the mid-1970's, 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 include (progressing generally from the ocean or inlet landward or upstream) 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, this ecotone consists of swamps and bottomland hardwood communities. Baldcypress and water tupelo characterize the former, whereas the latter contain many flood-tolerant species. In this system, flooding induced by streams replaces the lunar and wind-driven system of the previous class.

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 area of SAV and marsh streams, and anadromous species may spawn in the waters of fringe and riverine swamps.

While their specific function differs, all the preceding are essential to continued production of estuarine organisms. They filter sediment and excess nutrients from overland runoff, provide detritus and other nutriment 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 swamps found in depressions without an obvious connection to 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 exists currently. 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. 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 fertilizers and pesticides, flood-control and drainage programs, channelization, and other man-caused and natural phenomena? And perhaps the most important question–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 U.S. 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 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 N.C. Division of Coastal Management (DCM). Discharge of pollutants into these areas is similarly regulated by a combination of federal and state laws, generally implemented through permits issued by the Division of Environmental Management (DEM).

A number of areas and activities which may have a profound effect on critical areas escape this regulatory matrix, however. Nutrients, pesticides, and other pollutants currently may enter these areas 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 [33 U.S.C. ***] address this subject). 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 unless fill is involved, and neither the state nor the nation has legislation directly addressing the wetland issue.

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 the future of the Albemarle/Pamlico region.

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III WATER QUALITY

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A. WATER QUALITY ISSUE IDENTIFICATION

A. 1. Freshwater Drainage

There are five major hydrologic pathways by which water and chemical constituents can enter the Albemarle-Pamlico 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 on 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 impact 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 exchange through the tidal inlets are important hydrologic processes affecting Albemarle-Pamlico water quality. Yet, there is essentially no information on these processes for the system, although there is a Sea Grant study currently underway in Oregon and Ocracoke Inlets (Dr. L. J. Pietrafesa, N. C. State University, Personal Communication). Consequently, the discussion of groundwater contributions to the Albemarle-Pamlico System and of tidal exchange through the inlets is quite limited in this presentation. Atmospheric deposition of chemical constituents is discussed in Section A. 2. 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 very 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 river 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, 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 information is presently 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 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 enough 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).

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 impact 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 impacts 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 impacted 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.

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. Then, as long as tidal, meteorological, inflow and salinity data are available, computations of transport may be made.

A. 2. Nutrients

A. 2. a. Eutrophication. Eutrophication is the process controlling the rate at which primary production increases in water bodies. 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 (CO_2) 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.

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 man's interference with this process, events have led to undesirable (often termed "cultural") eutrophication. Eutrophication is the ominous characteristic frequently associated with perceptible water quality degradation (Hasler 1947; Likens 1972b).

Primary production is regulated by the fundamentally- important physical-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. However,

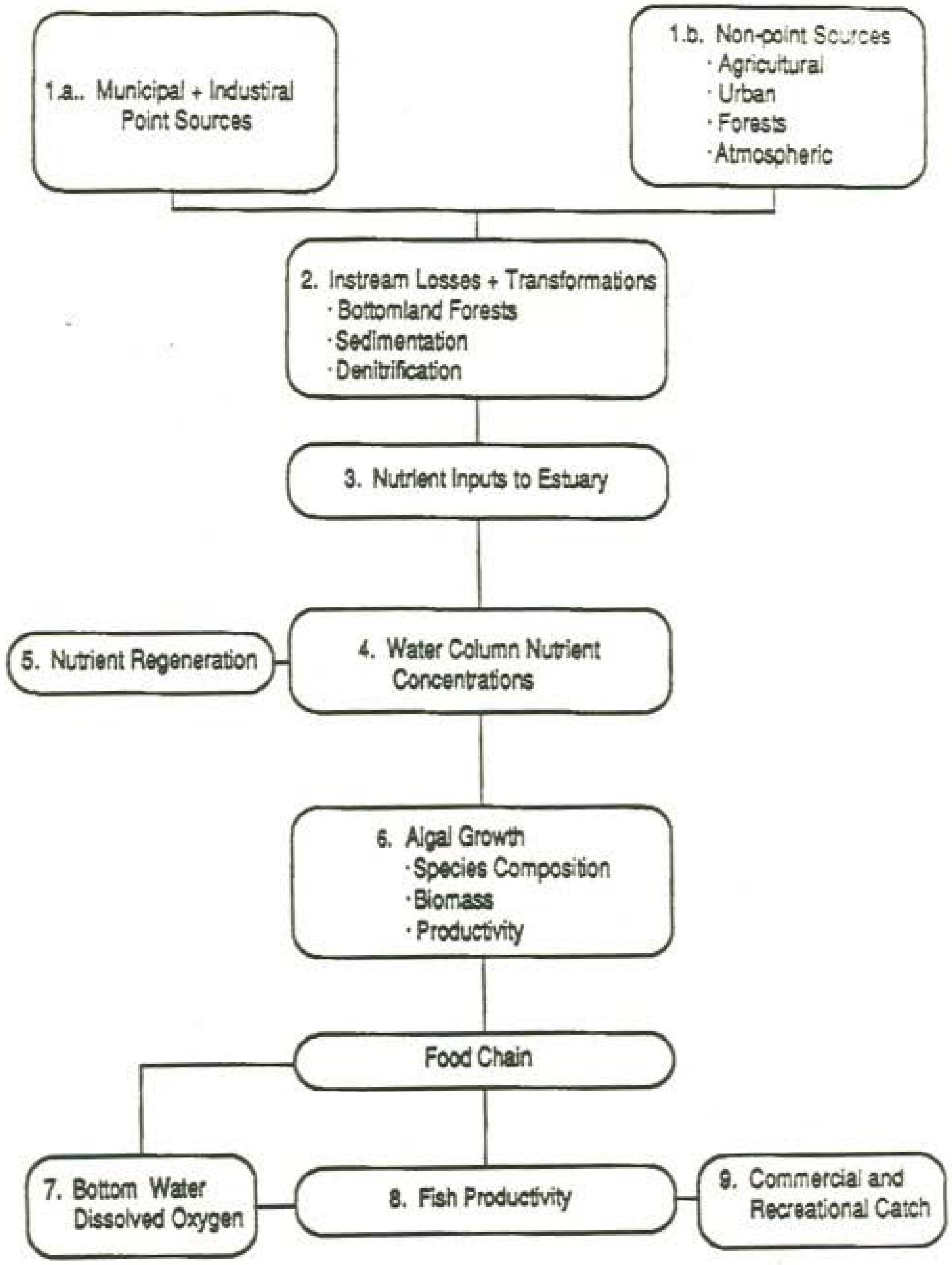

Figure III-1. Compartmentalized Model of Events leading to Consequences of Eutrophication (D.W. Stanley, East Carolina University, Personal Communication) this secondary set acts on nutrients once they have already been discharged or loaded into a system and accordingly reflects the productive, or trophic, 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 and relative to nutrient inputs. A flow diagram depicting the diagrammatic relationships in an ecosystem is given in Figure III-1.

With respect to nutrients, eutrophication is a natural process of ecosystem "aging", where chronic nutrient loading results from combined erosional, hydrological and terrestrial biogeochemical processes in a watershed, leading to gradual accumulation of biologically-available nutrients in sediments and the water column. Man's 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).

A. 2. b. Impact of Nutrients. Among the vast suite of 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 frequently are 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). Coupled to 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), 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 growth-limiting roles (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 include:

1. Toxicity to members of resident food chains, such as during various cyanobacterial (blue-green algal) and/or dinoflagellate (red tide) blooms;

2. Toxicity to drinking water, fish and shellfish consumers, and recreational users of affected waters (including domesticated animals and humans);

3. Hypoxia and/or anoxia of hypolimnetic (non-mixed subsurface) and near bottom waters, resulting from increased biological and chemical oxygen demands resulting from decomposition of high productivity/biomass micro-algal blooms and macrophyte growth events (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 shape or size of colonial nuisance algae) or avoidance (due to toxicity or undesirable taste) of primary producers;

5. Increased incidences 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 (see Section A. 6.) 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 a serious short- and long-term threat 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 posed a persistent negative impact 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 in order to arrest and reverse long-term water quality degradation?

A. 3. Metals and Toxics

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 a well documented fact (Crounse et al. 1983a, 1983b).

Many factors affect the availability, transport and concentration of metals and toxics into and through the natural 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 factors frequently engineered into point source discharges often maintain trace metal concentrations in water below toxic or even detectable limits. On the other hand, the sedimentary regime is much less transient and metals can become incorporated into sediments by several different mechanisms and partitioned among a variety of sedimentary phases. 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. 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).

The Albemarle-Pamlico estuarine system acts as a large settling basin for sediments, organic matter, heavy metals and organic toxins resulting 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 bringing materials to the estuary, there are several historic waste disposal sites around the estuary. These virtually unknown and 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 past and present potential impacts to the estuarine system could be significant (Riggs et al. 1989). This subject is currently under study, with specific results due in 1990.

A. 4. Sediments and Their Role in Nutrient Cycling

Bottom sediments play an important role in nutrient cycling in North Carolina estuaries. The hydrology of these estuaries causes them to be traps for suspended sediments and nutrients, resulting in bottom deposits of sand and mud, as well as overlying eutrophic waters. High productivity of phytoplankton, and sometimes bordering salt marshes and macrophyte beds, gives abundant particulate organic matter for deposition 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 cycling of nitrogen, phosphorus, sulfur, iron, and other elements besides carbon. Soluble chemical species released to the bottom waters are transported up the estuary by the residual currents and then advected back to the photic zone again to grow more phytoplankton. 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 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.

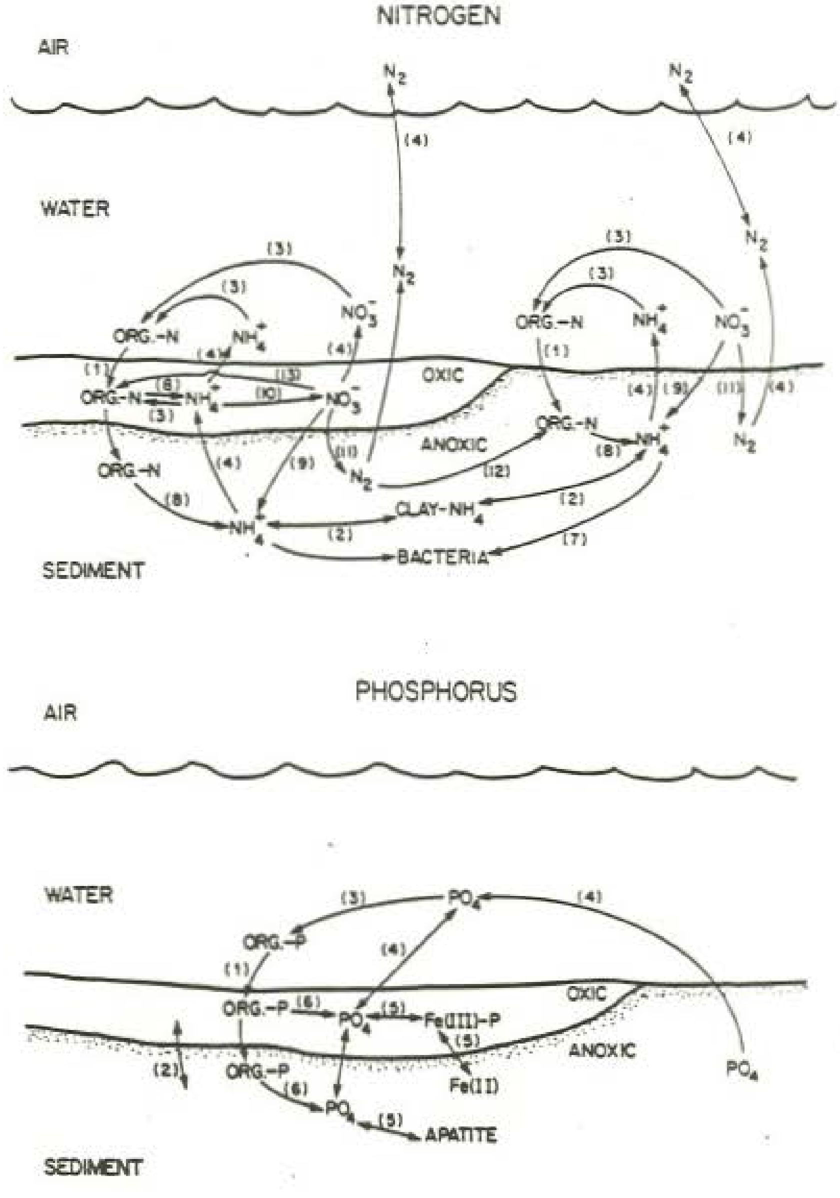

Fig. III-2. Major Pathways of Phosphorus and Nitrogen Cycling in Estuaries. 1) Sedimentation, 2) Sorption, 3) Assimilation, 4) Diffusion, 5) Precipitation-Dissolution, 6) Heterotrophic Regeneration, 7) Immobilization, 8) Ammonification, 9) Dissimilatory Nitrate Reduction, 10) Nitrification, 11) Denitrification,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

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. 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-2):

1. Major amounts of particulate organic carbon, nitrogen and phosphorus derived from phytoplankton and allochthonous organic matter sink through the water column onto the bottom deposits. 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 become anoxic. The concentration gradients in the sediments become steeper, which drives the diffusive flux (Figure III-3). Under anoxic conditions, metabolic byproducts such as carbon dioxide, ammonium and phosphate diffuse upward and into the water (Figures III-4 and III-5). 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-6).

3. When stratification is weak, the bottom water maintains sufficient oxygen for an oxidized zone to exist at the sediment surface. Microbes there oxidize ammonium to nitrate (Table III-1), which then diffuses either (a) upward into the water or (b) 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. Although the rates of nutrient regeneration in bottom sediments are 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-2). Thus, it was concluded that water column regeneration, sediment regeneration and external sources (e.g., watershed runoff, precipitation, wastewaters and seawater advection) (Table III-3) are all important sources of phytoplankton nutrients in the Pamlico River estuary (Kuenzler et al. 1984).

A. 5. Point Sources vs. Nonpoint Sources

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 (or point), usually a discharge pipe. Point sources are composed of 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, agricultural lands and construction sites. Nonpoint source pollution is addressed through a combination of regulatory, cost incentive and voluntary programs.

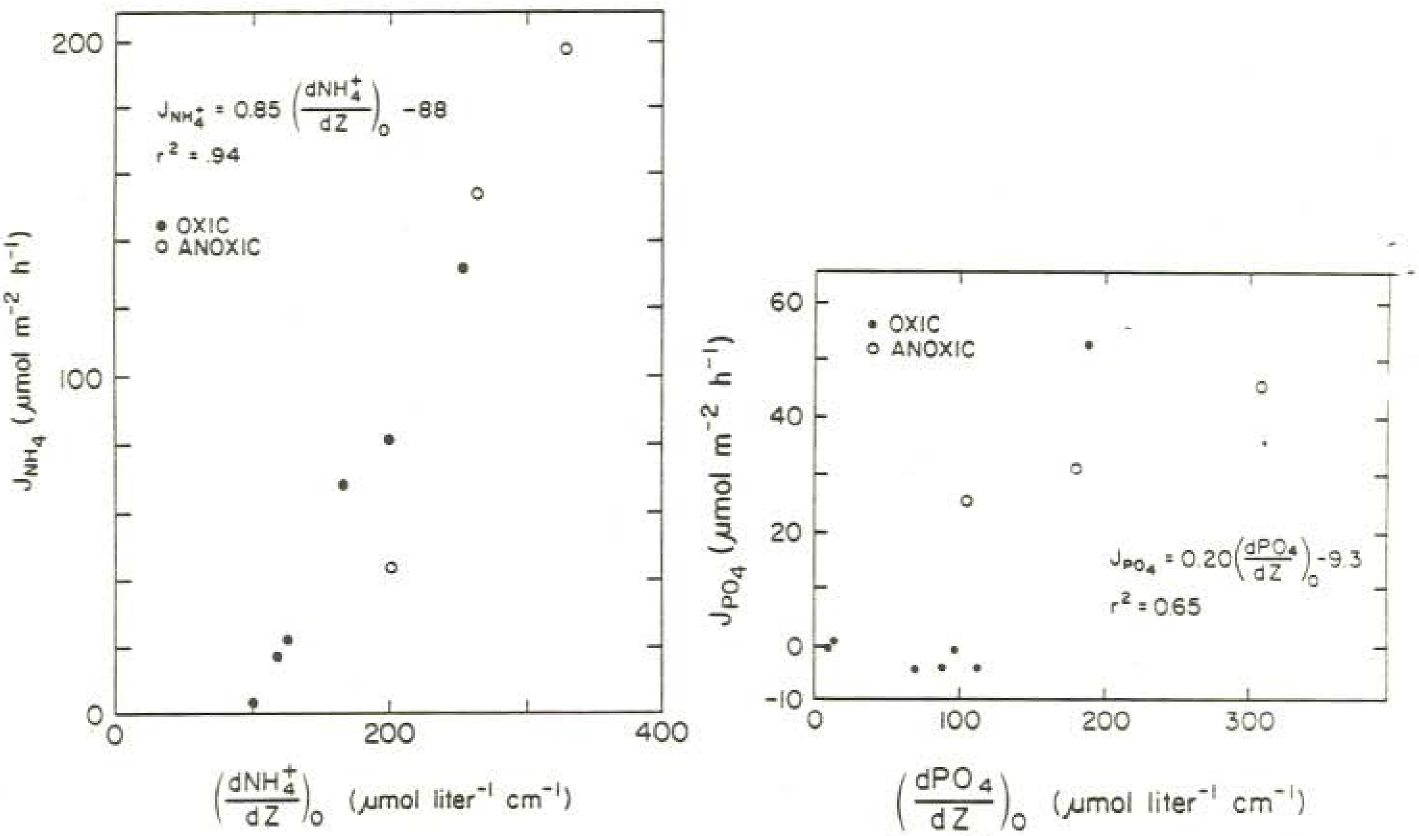

Fig. III-3. Ammonium and Phosphate Flux in Relation to the Pore-Water Concentration Gradient at the Sediment Interface in the Pamlico River. From Kuenzler et al. (1984).

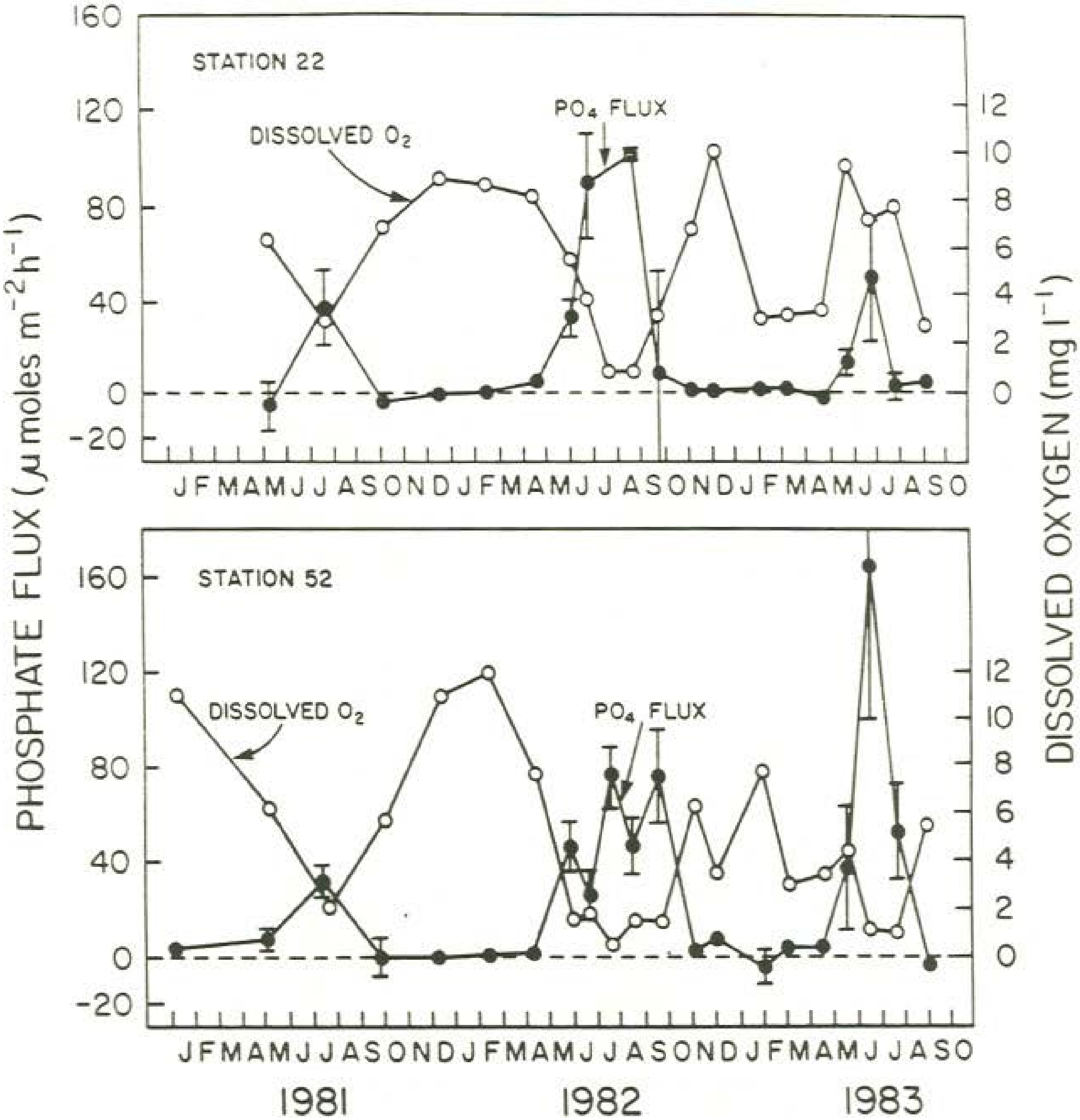

Fig. III-4. Seasonal Pattern of Bottom Water Dissolved Oxygen and Sediment Phosphate Flux in the Pamlico River Estuary. From Kuenzler et al. (1984).

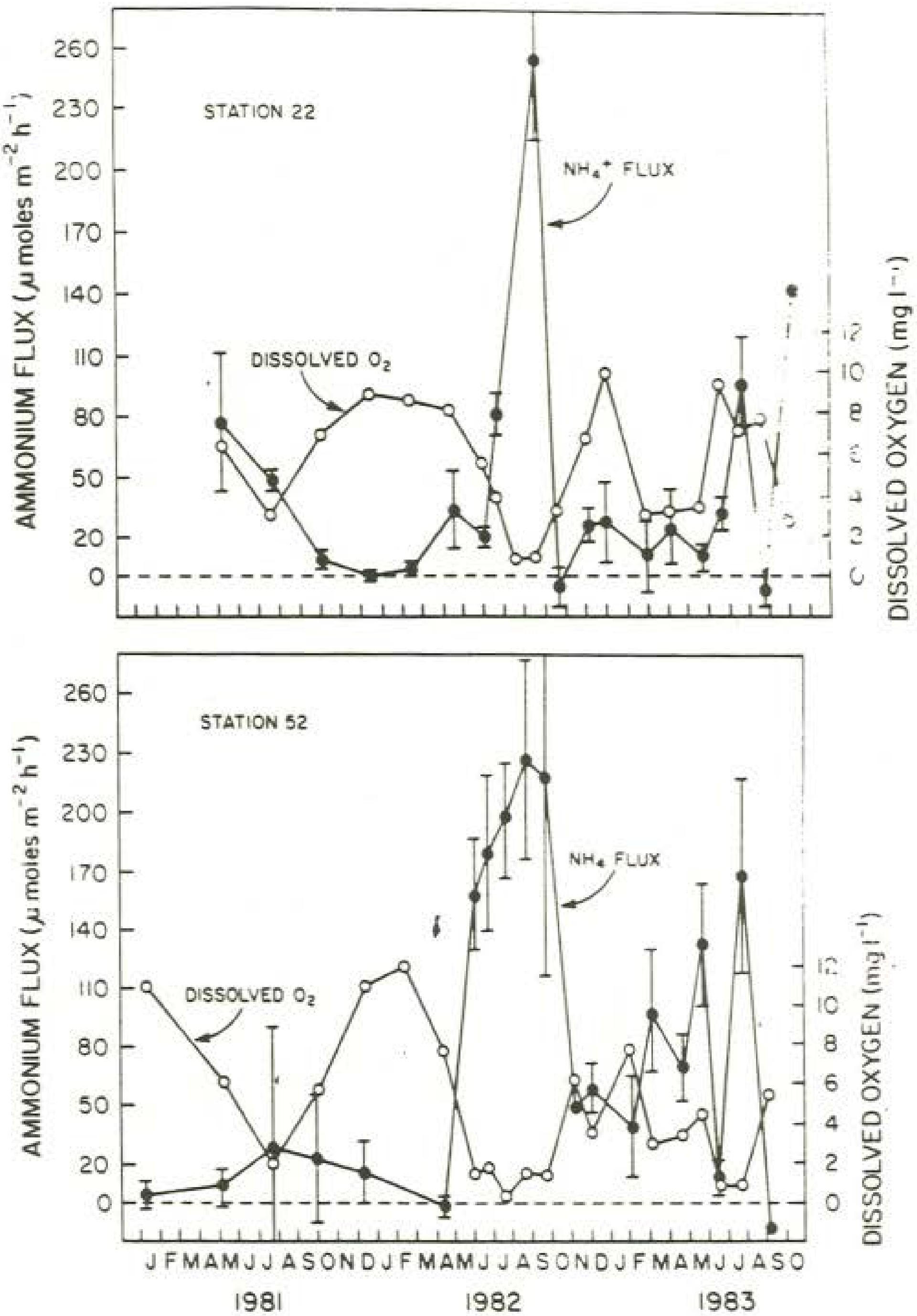

Fig. III-5. Seasonal Pattern of Dissolved Oxygen Concentration and Sediment Ammonium Flux in the Pamlico River. From Kuenzler et al. (1984).

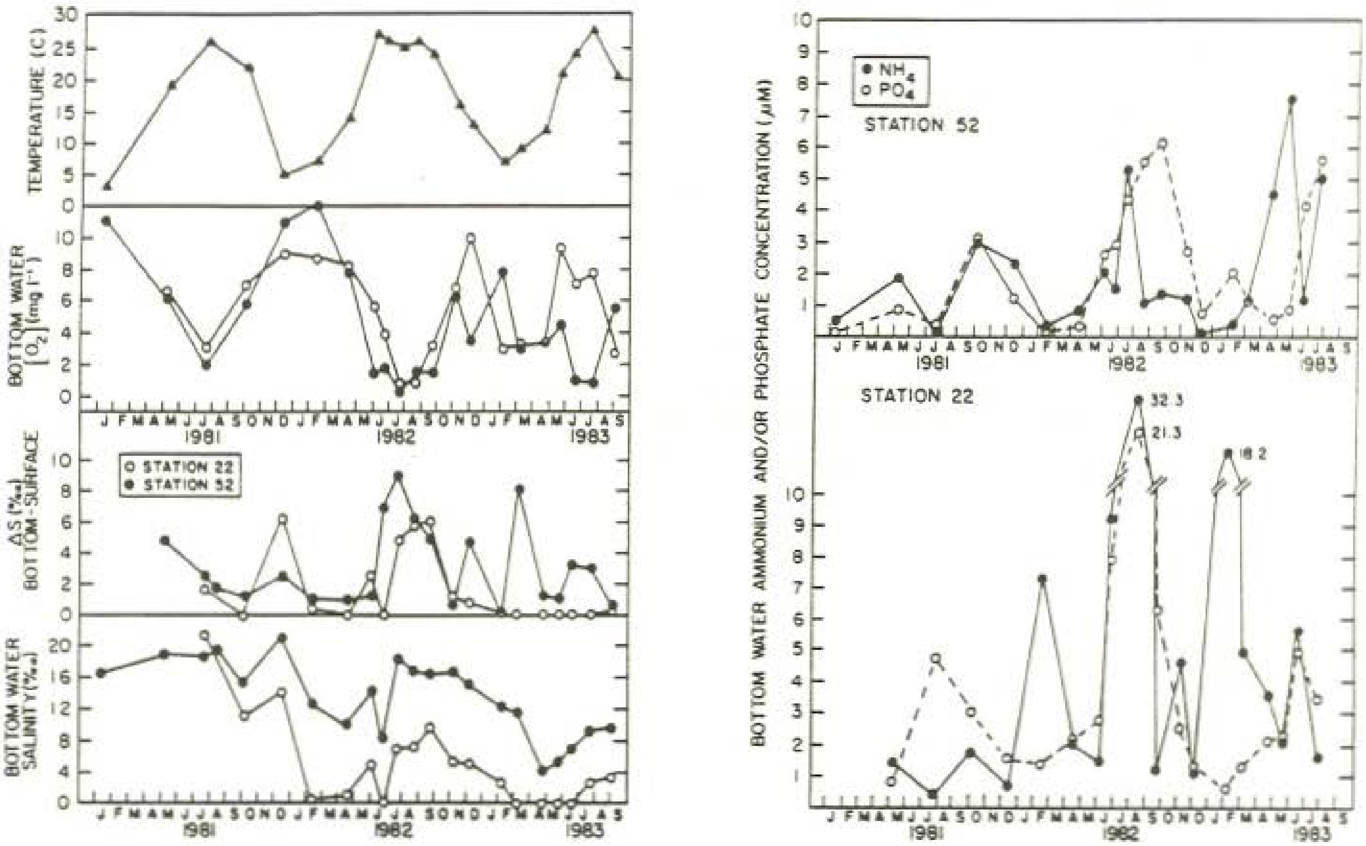

Fig. III-6. Annual Patterns of Bottom Water Temperature, Dissolved Oxygen, Salinity, Salinity Difference between Surface and Bottom, Ammonium, and Phosphate in the Pamlico River. From Kuenzler et al. (1984).

Table III-1. Nitrification potential rate (x + sd) at four depths in the sediment during 1982-83 in the Pamlico River estuary (rates in nmoles NH_4^+ oxidized $cm^{-3}d^{-1}$; integrated rates in nmoles $cm^{-2}d^{-1}$) 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	56	42	57	145	51
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	38	9	16	35	71

Table III-2. Phosphate, dissolved inorganic nitrogen (DIN), and oxygen fluxes (μmole $m^{-2}h^{-1}$) 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**
Annual Average Rates				
Phosphate	225	19.1	8.5	43
DIN	807	51.4	6.4	7.2
Oxygen	-	275	5.8*	-
Carbon	4760	-	-	-
Summer Average Rates				
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-3. Nitrogen and phosphorus loading (MT/yr) of the Pamlico River estuary (1976-77) compared to phytoplankton needs. From Kuenzler et al. (1979).

	Sources				
Chemical Form	Watershed	Precip	TGI	Pamlico So.	Algal Ann.Needs
Nitrogen					
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
Phosphorus					
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

North Carolina adopted its first comprehensive, modern water pollution control law in 1951. The essentials of the 1951 law (originally designated as the 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 hat were classified "E", which designated 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 as a minimum designated use for 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. 5. a. 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. The requirements needed to maintain a 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 are imposed uniformly nationwide, and based on the type, age and size of the discharging facility.

These requirements are enforced through a permit program–the National Pollutant Discharge Elimination System (NPDES). The U.S. 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 1950's and 1960's focused primarily on the first two types of pollutants; organic matter which depleted the dissolved oxygen in the water and pathogenic bacteria.

Many organic substances in wastewater are broken down by aquatic organisms in streams and in doing so consume dissolved oxygen in the water. Significant reductions in the amount of dissolved oxygen can hinder fish propagation and in more severe cases result in fish kills and odor problems. Wastewater facilities are generally classified as to the percentage of carbonaceous organic matter that is removed during treatment, which can be roughly summarized as follows:

Type	Percent Removed
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 about 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. The minimum allowable treatment is secondary, and many are required to provide tertiary and 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 when drinking water supplies 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 are closed to shellfishing in the vicinity of dischargers as a safety precaution against accidents, no new domestic discharges are allowed to 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 serous problem in several of the estuaries of the Albemarle-Pamlico area. The Chowan River was the first in the early 1970's to experience massive algal blooms, 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 1970's. Strategies to reduce nutrients to the Tar-Pamlico, Chowan and Neuse rivers have been adopted. 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. 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. 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 (see Table III-3). 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).

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 such as polychlorinated biphenyls (PCB) or 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.

A. 5. b. 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, on a large watershed or river basin approach, the concept of relating pollution loading to land-use categories is a relatively quick and simple, first-cut method to use in NPS problem investigations (Novotny and Chesters 1981). After a preliminary land-use analysis is conducted in a watershed, more complicated efforts can be undertaken to further differentiate the diffuse sources of pollution.

B. CURRENT STATUS

B. 1. Availability of Information

B. 1. a. Freshwater Drainage. 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 16-year-old statement about the Albemarle-Pamlico system is still generally true. In addition, 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 U.S. Geological Survey (USGS). Ragland et al. (1987) summarized the existing USGS stream-gaging network in North Carolina. Most of the gaging stations are, however, 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. A few of the smaller tributaries to the sounds are also 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 Albemarle-Pamlico Estuarine System consists of flow from the Roanoke River basin, which constitutes only about 48% of the total Albemarle-Pamlico drainage basin.

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 above natural conditions of low flows from the Roanoke River has apparently resulted in a decrease in the magnitude and frequency of saltwater intrusion into western Albemarle Sound (N. C. Division of Environmental Management 1982). The decrease in saltwater intrusion may, in turn, have resulted in an increase in nuisance algal blooms in western Albemarle Sound (N.C. Division of Environmental Management 1982). This relationship has been documented by Christian et al. (1986) who showed that the occurrence of blue-green algae blooms in the Neuse River estuary was directly related to Neuse River flow rates.

Giese et al. (1979) used long-term records at the downstream-most gaging stations and drainage-area ratios to develop a gross monthly water budget for Albemarle Sound and for Pamlico Sound (Tables I-3 and I-4). Using more recent records, Pietrafesa et al. (1986) also developed a gross monthly water budget for Pamlico Sound, which is similar to that of Giese et al. (1979). Likewise, a similar water budget was also developed for Albemarle Sound by the N. C. Division of Environmental Management (1982).

Because of a naturally high water table, relatively high rainfall (between abut 50 and 55 inches per year, depending upon location), and the flat terrain of the region, much of the land surrounding the Albemarle-Pamlico estuary needs to be drained to accommodate agriculture, as well as silviculture and other types of development. More than 20 miles of field ditches, collector canal 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. For the period 1968 to 1986, Stanley (1988b), on the other hand, 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.

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 U.S. Coast Guard stations in the region. Analysis of long-term meteorological data has been provided by, among others, Carney and Hardy (1967) and Pietrafesa et al. (1986).

<u>B. 1. b. Nutrients.</u> It is intuitively obvious that increased estuarine nutrient loading ought to occur with increasing population, use of nitrogen and phosphorus fertilizers and 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 changes in estuarine loading have not increased in a similar manner over time.

A study (Stanley 1988a) was conducted to use existing data to try 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) 6 categories of farm animals, (2) agricultural cropland, (3) idle cropland, (4) forestland, (5) pastureland and (6) urban land area. Data on harvested acreages of individual crops were tallied and summed to give the total cropland acreage. Results of this study are given in Section C.1.b.

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-1970's. 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 in Section C.1.c.

An extensive survey of the nutrients and their fates was conducted in Albemarle Sound during the 1970's (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).

B. 1. c. Metals and Toxins. The first detailed study of the metals and toxins in the Albemarle-Pamlico estuary is currently underway. The U. S. Fish and Wildlife Service has sampled a large number of estuarine animals for the presence of toxins and is currently evaluating results. The first phase, heavy metal pollutants in organic-rich muds of the Pamlico River Estuarine system has been completed (Riggs et al. 1989). Analysis and mapping have been completed for eight of the EPA "priority pollutant metals" (As, Cd, Cr, Cu, Pb, Hg, Ni and Zn) plus fluoride and phosphorus in the sediments. Permitted point discharges and nonpoint sources were identified as contributors of significant concentrations of pollutants to the estuary. A similar evaluation of the Neuse River and Albemarle Sound is currently underway.

B. 1. d. Sediments. There have been 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-4). We cannot depict precisely the magnitude of research results in a table of this size, but a considerable body of knowledge of sediment characteristics and elemental cycling has been acquired. Research questions, experimental design and methods of sampling and of 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.

B. 1. e. Point Sources vs. Nonpoint Sources. 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 (N. C. Division of Environmental Management 1989a, 1989b). The assessment concentrated on waterbodies which partially or do not support their designated uses because of NPS pollution. The following describes methods employed to identify NPS pollution problems in the Albemarle-Pamlico Estuarine Study area.

Table III-4. 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 NH_4; I = Extractable P; J = Percent Water; K = LOI; L = NO_3; M = NH_4; N = Extractable Fe; O = Total Fe; P = Acid-vol. S; Q = Pyrite S.

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 judgement. 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 (N. C. 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 summarized biological and chemical data (N. C. 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 to obtain further biological information on streams. Some references in the 1985 assessment report date to the 1960's.

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 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 where federal, state, municipal and county representatives and the general public were invited to attend. 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 sources (i.e., point or nonpoint) and causes (e.g., sediment or dissolved oxygen) responsible for partially supporting and non-supporting ratings. All data, evaluations and source information were added to the water quality monitoring data and overall water quality ratings assigned to streams and segments.

Water Quality

Overall ratings were determined as follows:

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. However, ratings for water supply segments relied on chemical data.

2. Chemical Ratings (when biological was unavailable) were preferred over Assessment Document (N. C. Division of Environmental Management 1985) information or workshop "evaluations".

3. Workshop "Evaluations" or Best Professional Judgement were preferred over Assessment Document (N. C. Division of Environmental Management 1985) information generally because the Assessment Document information is older.

4. Assessment Document information was used (N. C. Division of Environmental Management 1985) when no other information was available.

After overall ratings were assigned, sources of pollution (point or nonpoint) for partial support and non-supporting streams were sought (Tables III-5, III-6), as were the actual pollutant or cause of degradation (e.g., sediment, toxicants; Table III-7). The N. C. 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, were 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 also consulted to identify facilities known to have toxic effects based on chronic and acute bioassays. Of course, groundwater and precipitation are also sources of nutrients and other substances.

The Shellfish Sanitation Unit within the North Carolina Department of Human Resources is responsible for determining the status of shellfishing waters and keeps a historical record of the opening and closing of waters for the collection of shellfish. This information is extremely valuable as it can be readily interpreted in terms of use-support. With respect to this information, partially supporting waters are those that are permanently closed to shellfishing while support-threatened are those that are temporarily opened. Waters closed for shellfishing are considered partially supporting because they still support recreational and other aquatic life uses. Non-supporting areas are those with excessive algae blooms as noted by N. C. Division of Environmental Management regional offices and documented through special studies. The area subdivisions are based on the Department of Human Resources (N. C. Division of Shellfish Sanitation) segments.

The N. C. Division of Environmental Management also has chemical ambient monitoring stations in estuarine waters. These data 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, metal violations were not used to determine use-support 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 N. C. Division of Environmental Management Water Quality regional staff, the N. C. Division of Shellfish Sanitation (Morehead City, N. C.), and during the workshops. Ratings were then modified according to comments from the workshops and from chemical and biological special studies performed by the

Table III-5. Nonpoint Source Impacts in the Streams of the Albemarle-Pamlico Estuarine Area (N. C. Division of Environmental Management 1989b).

Water Quality Rating	Mileage	Percentage
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

coastal regional offices. Evaluated areas (areas lacking data) were assigned the same use-support as the closest monitored areas within about 15 miles. Only the middle and northern Currituck Sound and the central portion of the New River are evaluated. The remaining estuarine areas are monitored. Distribution of nonpoint source impacts in the estuary are given in Table III-8.

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 N. C. 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 N. C. Division of Shellfish Sanitation Surveys or from other sources were evenly weighted to yield acres degraded. The actual pollutants or causes of degradation were either listed as the most important cause (often using best professional judgement) or listed as 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 classifications are based on 'actual' use criteria, rather than a 'desired' use criteria, and that 'support' merely means that a body of water or stream has not been degraded enough to not meet the actual use criteria.

B. 2. 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 197522). It had been speculated that artificial drainage activities would not significantly alter the annual water budget (Heath 1975), with the primary effect being 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).

Table III-6. Sources of Nonpoint Pollution Impacts in the Streams of the Albemarle-Pamlico Estuarine Area (N. C. Division of Environmental Management 1989b).

Sources of Degradation*	Mileage		Percent of Total	
Nonpoint Sources		3,489.1		96.6
Point Sources		441.6		12.2
Agriculture		2,415.6		66.9
Runoff	510.7		14.1	
Animal Waste	480.6		13.3	
Other	240.0		6.6	
Forestry		93.2		2.6
Harvest		94.5	2.6	
Forest Management	5.3		0.1	
Construction		284.0		7.9
Highways and Bridges	0.0		0.0	
Land Development	71.6		2.0	
Urban		376.8		10.4
Sewers	61.4		1.7	
Runoff	104.4		2.9	
Other	17.4		0.5	
Mining		0.0		0.0
Land Disposal		144.6		4.0
Landfills	63.6		1.8	
Septic Tanks	89.5		2.5	
Other	39.8		1.1	
Hydromodification		227.9		6.3
Channelization	4.0		0.1	
Other		27.0		0.7
Unknown	591.8			16.4

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

The effect of artificially drained systems on runoff from individual events is apparently even 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 on lands with drainage than on natural lands, and the increase in peak outflow from small events seems to be more noticeable than for natural conditions (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 increased as a result of channelization (Figure III-7), but the total annual runoff volume appears to be changed very little from natural conditions (Winner and Simmons 1977; Gregory et al. 1984). An additional consequence of lowering natural water tables is the reduction of recharge to the deep aquifers; thus, saltwater encroachment into the deep aquifer, which is a continuing process, may be increased (Heath 1975).

Table III-7. Major Causes of Degradation in the Streams of the Albemarle-Pamlico Estuarine Area (N. C. Division of Environmental Management 1989b).

Causes of Degradation	Mileage	Percentage
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 a	0.0	0.0
Phosphorus	0.0	0.0
Multiple	501.9	13.9
Undifferentiated	1,155.7	31.9

Table III-8. Nonpoint Source Impacts in the Estuarine Portion of the Albemarle-Pamlico Estuary (N.C. 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 a	44,030	48.7
Sediment	3,300	3.7
Multiple	33,060	36.6

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

Water Quality

The ratio of total length of all stream segments in the basin to the basin area gives the drainage density, which defines the drainage efficiency. Drainage densities for the Piedmont is about 2.5 miles per square mile, with about 1.5 miles per square mile in 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. Thus, 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, result in changes to the salinity regime in small tidal creeks and bays (in many cases the end points for drainage canals) and under certain meteorological conditions (Overton et al. 1988).

There have been several efforts to investigate various aspects of artificial drainage and salinity changes in receiving waters. Kirby-Smith and Barber (1979) found that drainage from Open Ground Farm sometimes decreased surface salinities in tidal creeks tributary to South River, but the bottom salinities were unaffected. Drainage from Mattamuskeet Canal lowered surface salinities in the upper portions of Rose Bay (Gilliam et al. 1985), but salinity at the mouth of in Rose Bay appears to be controlled by wind-induced circulation and tidal exchange processes. Salinity changes in Broad Creek changed in response to the availability of freshwater when the winds pushed saltier water away from the canal (Overton et al. 1988). The effect of freshwater drainage and the associated salinity changes on the living resources of nursery areas is not entirely clear.

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, improved water quality and reduced impacts of drainage on receiving waters. Two studies, currently underway, should result in better understanding of the impacts (Dr. Wayne Skaggs, N. C. State University; Dr. Jerad Bales, U. S. Geological Survey).

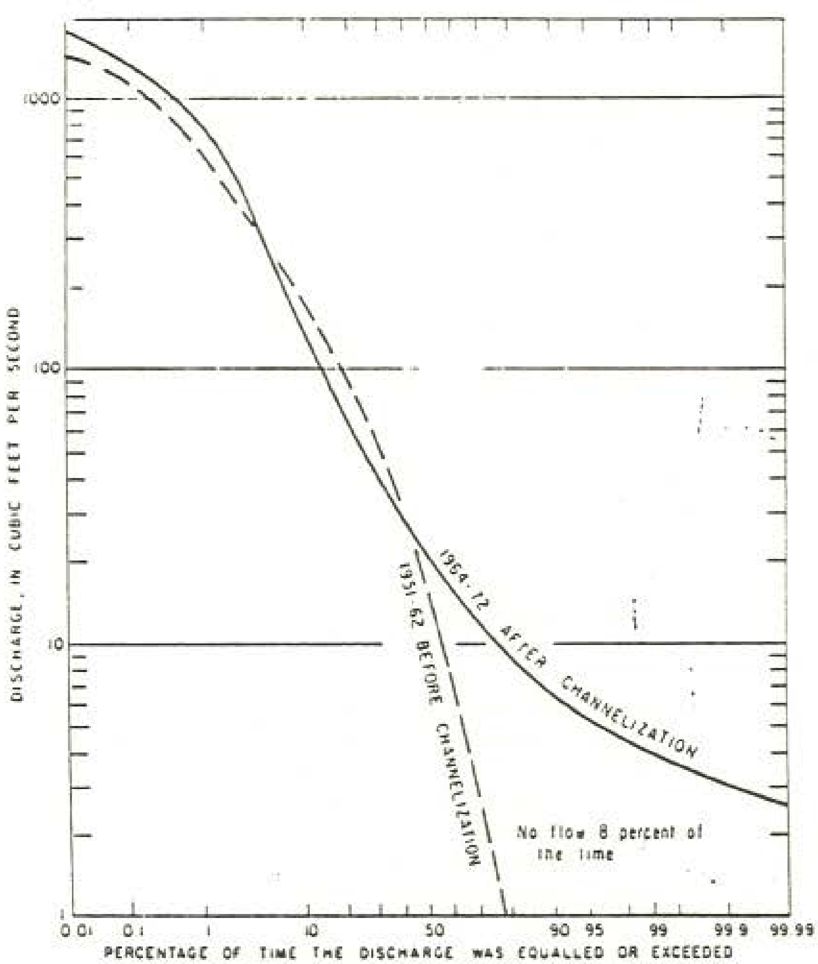

Fig. III-7. Flow Duration Curves for Ahoskie Creek at Ahoskie Before and After Channelization. From Winner and Simmons (1978).

Water Quality

Controlled drainage affects both nitrate and phosphorus losses from agricultural fields. When a high water table is maintained in the field by placing a control structure across the field ditch outlet, nitrate export is reduced. Because of greater opportunity for denitrification (which occurs in anaerobic environments) in the saturated soil profile, export of nitrate may be reduced by as much as 50% with the use of controlled drainage (Gilliam et al. 1978). While nitrate export may be decreased by controlled drainage, losses of organic nitrogen may be increased; but, 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 underway by the U. S. Geological Survey (Dr. Jerad Bales, U. S. 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-8) and that water from the tide gate controlled ditches tended to be more stable in its conductivity (Dr. Jerad Bales, U. S. Geological Survey; Personal Communication).

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 very 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 recognize the importance of understanding the off site effects of agricultural water management: i.e., "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).

Historical tidal-elevation records exist for numerous sites around the Albemarle-Pamlico Estuarine region, but a synoptic array of tidal-elevation gages were installed along the Pamlico and Neuse Rivers during February 1988 by the U. S. Geological Survey (Figure III-9). U.S. Army Corps of Engineers' (COE) needs are typically project related and, as a consequence, COE gages tend to be short-duration installations. Short-duration historical records exist for numerous other COE and National Ocean Service (NOS) gages in North Carolina. Chronologies of COE of 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 1970's and early 1980's (Daniel 1977). In addition, tidal-elevation data having a period 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 U.S. 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).

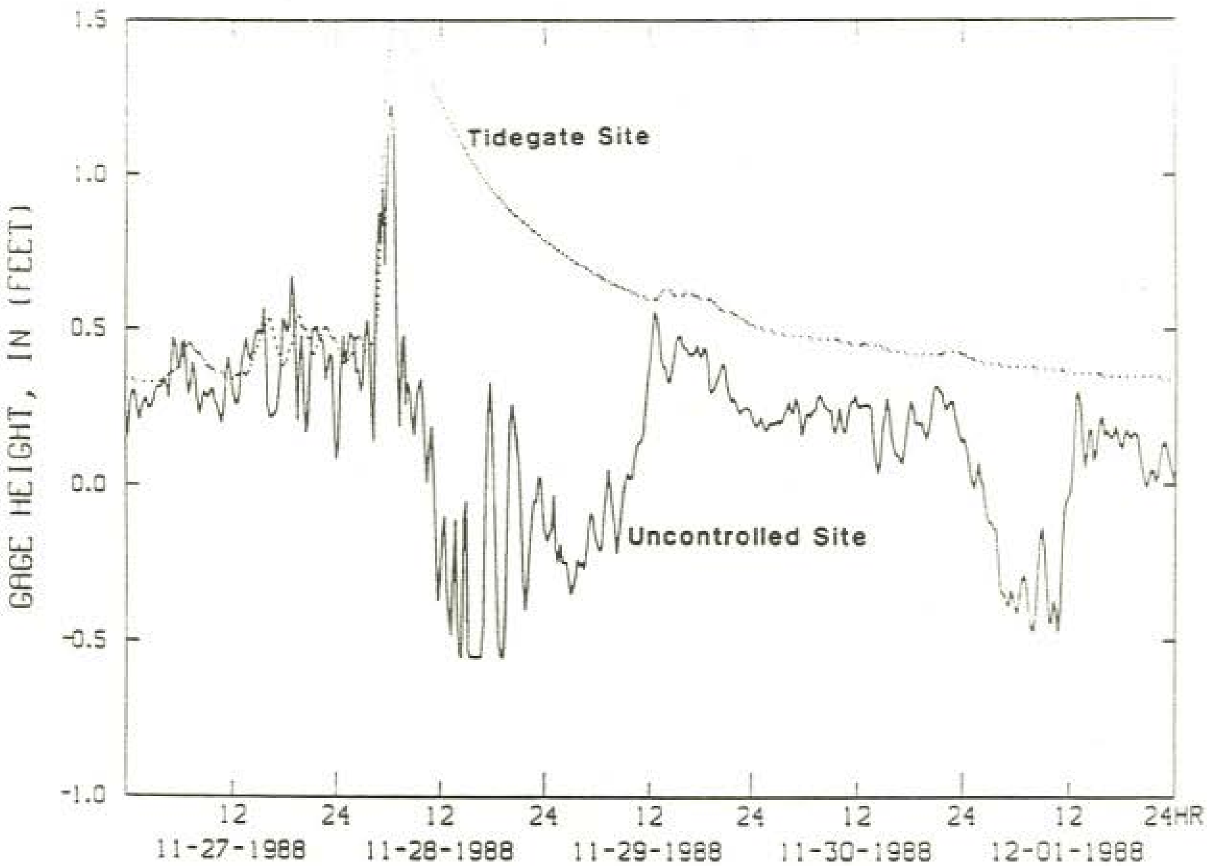

Fig. III-8. Water Level Response to Rainfall at a Tidegate Site versus an Uncontrolled Site. J.D. Bales, USGS, Provisional Data.

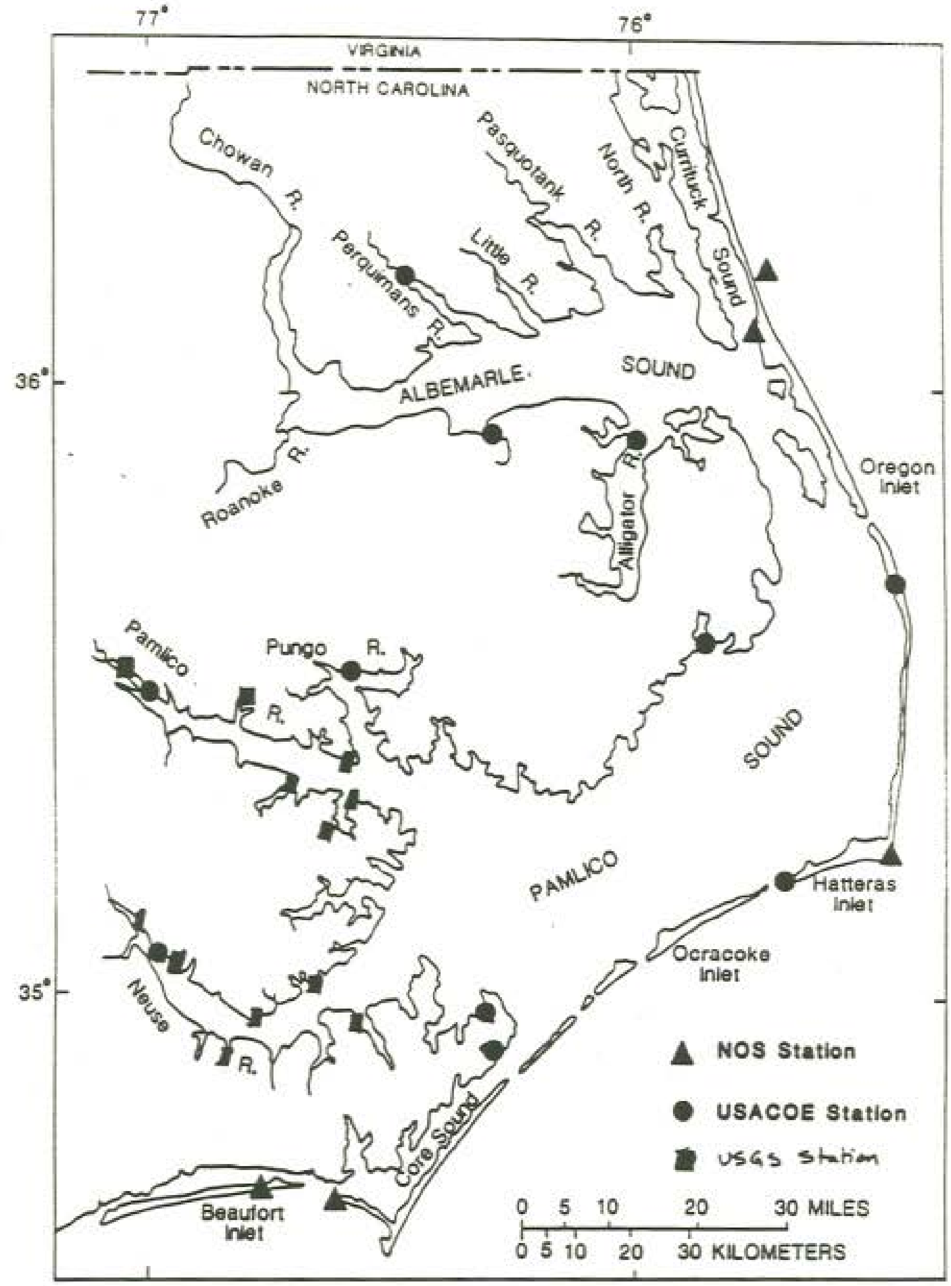

Fig. III-9. Tidal Elevation Gage Sites in the Albemarle-Pamlico Estuarine System, March 1989. J.D. Bales, USGS, Personal Communication.

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). 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 (in other words, without regard to flow conditions), which renders the salinity data relatively useless for assessing transport processes. In addition, salinity fluctuations are such that samples collected at monthly, or even daily, frequencies may be difficult to reasonably interpret other than to perhaps obtain 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). Observed salinity distributions in Albemarle Sound and the Chowan River for several months in 1981 and 1982 have been reported, along with estimates of the frequency of occurrence of various salinities in Albemarle Sound (N. C. 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 hourly to daily basis) and occasionally persists (days to weeks) in central basins and main stems of tributaries/estuaries (Matson et al. 1983; Paerl et al. 1984). Significant hypoxia/anoxia can accompany stratification, including salt wedges extending up into highly productive meso- to oligohaline segments of slow-moving rivers (Chowan, Pamlico, Neuse). During these events sedimented organic matter is entrained and rapidly decomposed with rapid conversion 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.

Water residence characteristics are also factors to be considered in susceptibility to accelerated eutrophication. Winter and early spring months (November-March) traditionally represent the rainy period in North Carolina, with between 50-75% of annual precipitation falling during this interval (N.

C. State University Climatological Report 1988). Relatively high flushing and short water retention characterizes the tributaries and sounds at this time, yielding maximum flushing and discharge rates. Typically, water residence times vary from a few weeks to 2 months in major tributaries (Chowan, Pamlico, Neuse Estuaries), with nitrogen-rich (and to a lesser extent phosphorus-enriched) discharge present. After May, hydrological conditions abruptly change (during a "normal" rainfall year); discharge decreases substantially (generally on the order of 2-3 fold for most tributaries) while retention times dramatically increase from 1 to 3-4 months (Figure III-10). During ensuing spring, summer and fall months 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 where 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. In Prep.). This overlap between nutrient enrichment, increasing water temperatures, stability, residence time and day length (light availability) represents excellent conditions for phytoplankton as well as 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 some of the most problematic nuisance blue-green (both non-nitrogen fixing and nitrogen fixing) blooms on record (N. C. 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, especially during summer, in the middle reaches of this oligo-mesohaline (2-15 ppt salinity), shallow, turbid estuary. By comparison, inorganic nitrogen concentrations are low relative to phytoplankton needs, except for 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 compared to nitrate, with ammonium providing 82% of the nitrogen taken up annually. There was evidence that algal abundance and primary productivity increased in the Pamlico River estuary during the 1970's, 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 concerning the dynamics and susceptibility to algal blooms in the open waters of Albemarle-Pamlico sounds. Moreover, whether or not "analogous" nuisance blooms of cyanobacteria, microflagellates or dinoflagellates occur and/or proliferate in these waters is uncertain. The potentials for such blooms as well as factors regulating their development and persistence are subjects of current study (Dr. H. W. Paerl, University of North Carolina at Chapel Hill Institute of Marine Sciences, Personal Communication). Studies in poorly, but occasionally, stratified estuaries like Chesapeake and Delaware Bays, however, indicate that micro- 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

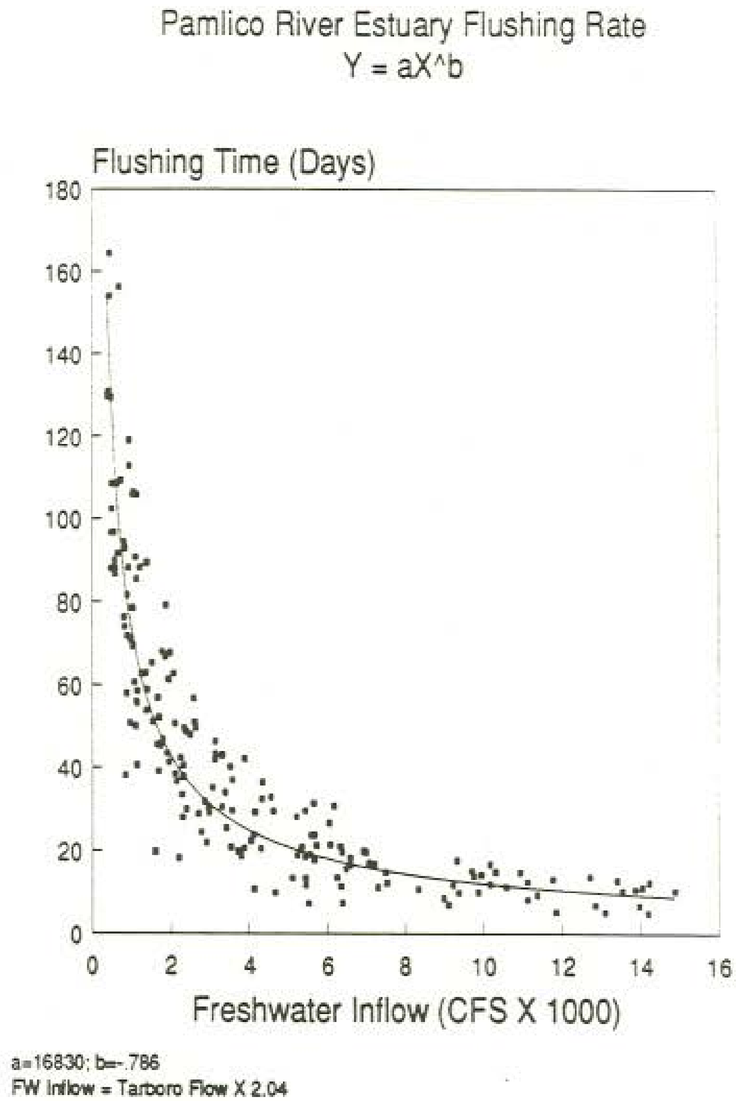

Fig. III-10. Flushing Time of the Pamlico River Estuary versus Freshwater Inflow. From D.W. Stanley, ECU, Unpublished Data.

1983). Therefore, it is prudent to assume that a similar potential scenario for periodic micro- and dinoflagellate blooms exists in the open sound components of 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 total days, excluding thunderstorm events) during spring, summer and fall months. This assures adequate supplies of photosynthetically available radiation and leads to maximum water column heating. Second, waters are periodically receiving nitrogen-enriched acid rain generated in upwind (north, northwest and west) urban, industrial regions as far as 1,500 miles away (National Acid Precipitation Assessment Program 1988). The shallow 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 (compared to deeper and more expansive coastal ocean waters). Added to locally-generated point and non- point input 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 being 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 as well as its chief tributaries (Chowan-Roanoke, Pamlico-Tar and Neuse Rivers) are exceedingly 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 attached primary producers. Although transparency is restricted in the turbid, highly colored (in part due to humics and fulvics as well as biogenic production) waters (extinction coefficients range on the order of 2->6), frequent and thorough vertical mixing (on the order of a few minutes to <1 h for the entire water column to mix) 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 reveal resident phytoplankton to be well-adapted to such illumination regimes. Maximum rates of primary production were observed for rapidly-mixed (15-20 min for total water column mixing), as opposed to longer high-light conditions (M. Mallin, H. Paerl and R. Luettich, UNC-CH, Personal Communication). 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, a reasonably diverse and comprehensive data bank has been established for the main tributaries and some estuaries over the past decade. 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). With respect to nitrogen and phosphorus sources and inputs, cycling and seasonal concentrations, some generalized findings and characteristics appear to apply to 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-8) 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 systems (N. C. 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 tributaries and estuaries. It is generally believed that NH_3 is relatively more important as an "internally cycled" nitrogen nutrient, periodically being 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). Accordingly, seasonal NH_3 concentrations are consistently low and fairly uniform, more or less independent of major hydrological events (runoff, droughts) (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 (some anoxic events) to annual periodicities, although shorter and longer periods may exist. Many elements are tightly linked to the redox state of the sediments and we can thus recognize the end-members: oxic sediments contain elements predominantly in their oxidized forms (O_2, $SO_4^=$, NO_3^-, Fe^{+++}, etc.); whereas, anoxic sediments are dominated by reduced forms (CO_2, HS^-, NH_4^+, Fe^{++}, etc.). Linked closely to inorganic biogeochemistry are the enormous number of species of organic chemicals and microbially mediated reactions, almost none of which have been studied in North Carolina estuaries.

Definitive studies only began in North Carolina estuaries during the early 1970's. Although much has been done since that time, large gaps still exist in our knowledge of cause and effect. A pilot nutrient study was 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 1960's (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 U. S. Geological Survey, in cooperation with the Albemarle-Pamlico Citizens Monitoring Program, have initiated a program network of physical, chemical and biological information with 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.

B. 3. Impact of Probable Causes

Phytoplankton production, including blooms in North Carolina rivers and estuaries, generally exhibits heavy reliance on inorganic nitrogen availability during peak summer growth periods in the

Chowan, Pamlico and Neuse Rivers. The fact that nitrogen-fixing blue-green algal species can periodically exert dominance and bloom activity 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). Lastly, while the Neuse River receives relatively high NO_3^- loading and exhibits hypereutrophic conditions with respect to NO_3^- (and NH_3) concentration vs. phytoplankton demands during winter and spring months (Paerl 1983, 1987; Paerl and Bowles 1986), low flow summer blue-green algal bloom conditions can lead to significant inorganic nitrogen "drawdown", resulting in periodic nitrogen limitation, which has been substantiated with in situ bioassays (Paerl 1983; Paerl and Bowles 1986) (Figure III-11).

Point source inputs (such as sewage treatment plants, 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 (N. C. 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 1970's was responsible for aggravating and intensifying an already problematic summer bloom (dominated by blue-green algal nuisance species) situation (N. C. 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 (chlorophyll a content in excess of 40 μg/l) have appeared during late winter-early spring and late summer months in these regions, where NO_3^- concentrations and loading is 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 in their downstream travel (Hobbie 1974; Paerl 1983, 1987). Secondly, increased clarity due to settling of (previously) suspended riverine sediments in these regions promotes transparency, thereby alleviating light limitation of 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 NO_3^--laden upstream waters (containing from 200-500 μg N-NO_3^-/l) enter the oligohaline bloom regions; whereas, waters leaving this region commonly contain close to undetectable (<10 μg N-NO_3^-/l) concentrations (Hobbie et al. 1972; Harrison and Hobbie 1974; Paerl 1982a; Showers et al. In Prep.). Such findings strongly implicate nitrogen (as NO_3^-) availability as being the nutrient limiting the development and proliferation of such blooms at these times of the year.

Upstream NH_3 concentrations entering the bloom region are generally low (<20-30 μg N-NH_3/l). Because of their relatively low concentrations (relative to NO_3^-), NH_3 supplied via stream inputs are not thought to be strong determinants in regulating magnitudes of phytoplankton production in

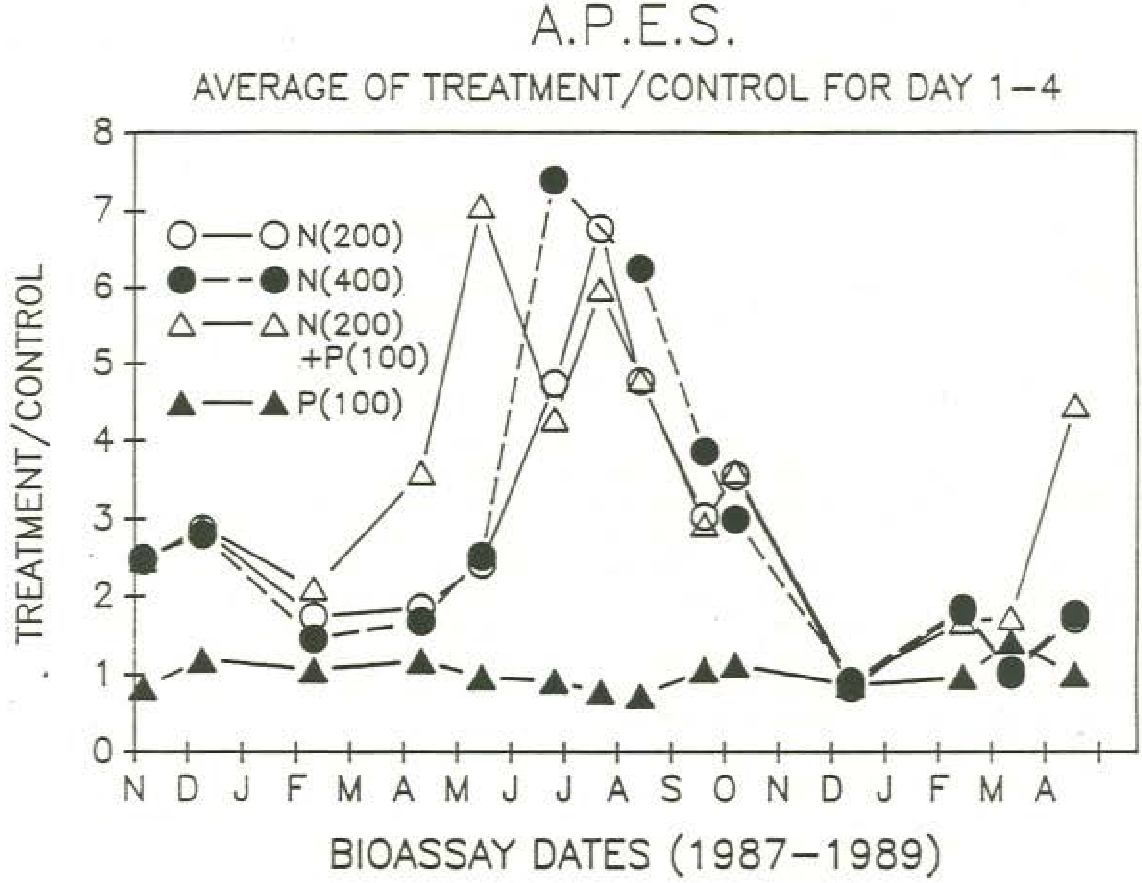

Fig. III-11. Relative Impacts of Nitrogen, Phosphorus and Nitrogen-Phosphorus combination Enrichment on Primary Productivity in Pamlico Sound. From H.W. Paerl, UNC-CH, Personal Communication.

these estuarine regions. On the other hand, NH_3 does play an important role in 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.

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

Phosphorus loading, cycling and utilization by phytoplankton presents quite a contrasting picture to that discussed for nitrogen. There is virtual agreement based on previous studies and monitoring efforts that the combination of both natural and anthropogenically derived sources of loading leads 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 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-11) conducted by a variety of investigators on diverse riverine and estuarine habitats have come to the same general conclusion; i.e., 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 such periods can at times lead to parallel 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 maximum bloom development.

Phosphorus discharge sources include: 1) natural erosion and solubilization of rocks, sediments and soils in tributary basins, 2) industrial discharges, 3) sewage treatment plants (a major point source contributor), 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). Also, soils 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 (N. C. 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) but also substantial summer loading (from the continuous discharge of sewage treatment plants). In this manner, adequate phosphorus loading is often assured throughout the year. This scenario is particularly critical with respect to assuring summer phytoplankton phosphorus demands.

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 incidences of violations of chlorophyll a standards, periodic microflagellate and dinoflagellate blooms, ephemeral anoxia, associated fish kills) involves more closely monitoring and (in specific watersheds) controlling nutrient inputs (both nitrogen and phosphorus) as well as elucidating mechanisms and dynamics of nutrient-growth/bloom interactions. In particular, the latter must be dealt with and addressed with long-term (5-10 years) research efforts in lower estuarine-open sound waters, where an information void currently exists.

Specific problem areas involving anthropogenic nutrient/sediment inputs in part supporting accelerated eutrophication include:

1. Land Use. Critical areas which have, over the past two decades been shown to be major nutrient contributors are: a) conversion of forests to agricultural, municipal and industrial activities, b) conversion of native 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 translate into major nonpoint and point nutrient/sediment sources. Their relative contributions (of both 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 (Feb-May) 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 key criteria in controlling unwanted aspects of eutrophication. Allowable discharges (including both point and nonpoint sources) 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 additional roles in determining the nature, extent and duration of nuisance algal bloom events (chlorophyll a concentrations exceeding 100 μg/l) 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 enhanced 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 loose their dominance, generally being replaced by mesohalophillic flagellates and dinoflagellates. The latter can be responsible for substantial chlorophyll a concentration in nutrient enriched waters, frequently exceeding 50 μg/l (Paerl 1987; Stanley 1988b).

   Although impacts of freshwater salinity dilution on phytoplankton species composition and biomass are currently being examined further downstream at the meso-euhaline intersection of the Neuse Estuary-Pamlico Sound (H. Paerl, Personal Communication), 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 with respect to both the nature and magnitudes of algal blooms (Paerl 1982a, 1983, 1987). It can also be concluded that enhanced freshwater runoff and associated nutrient loads have increased the risk for cyanobacterial blooms extending and proliferating further downstream in the estuaries (Paerl et al. 1984). Accordingly, freshwater runoff dynamics (magnitudes and timings) 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 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 (detritus) sediments periodically discharged into the estuaries represent a source of nutrients, both in adsorbed (subsequently desorbed) and particulate forms. The specific roles of sediments vs. soluble (non-sediment associated) nutrients in eutrophication mechanisms have not been adequately addressed and is 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 events. 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 events represent particularly effective means of dispersing nutrient sources which can subsequently be solubilized and made available (during ensuing summer months and perhaps future years) as algal nutrient source. Certainly, the well-mixed characteristics of the Albemarle-Pamlico Estuarine System ensures subsequent 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 eutrophicating impacts of sedimentation, the positive impacts of associated nutrient enrichment must be weighed against the potential negative impacts of decreased light availability on phytoplankton. However, sediment related turbidity frequently disappears (through sinking of sediments) shortly after acute erosional-runoff events, while associated soluble nutrient loads remain available 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 eutrophicating impacts of sediment loadings.

5. Precipitation (Acid Rain). As a source of freshwater runoff and dilution, precipitation has historically been featured as a factor qualitatively and quantitatively affecting eutrophication. Until recently precipitation has not been considered a highly significant nutrient source. Even in the mid-1970's, precipitation-related nutrient inputs were thought to be only 9-10% for nitrogen and less than 5% for phosphorus (N. C. Division of Environmental Management 1989a). Our recent awareness of the magnitudes and frequencies of nitrogen-enriched acid rain altered our appreciation and concern of this important nutrient source impacting the Albemarle-Pamlico Estuarine System (Paerl 1985). 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.

   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 a biological "filter", stripping out biologically-available nitrogen before it enters the larger meso- to euhaline segments of estuaries, the sound systems (Albemarle and Pamlico) and coastal (Atlantic) waters. As a result, these vast water bodies remain chronically nitrogen deficient. Because riverine nitrogen inputs are effectively 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 μmoles per liter during non acid rain events (pH >4.5). By contrast, during acid rain events (pH <4.5) NO_3^- concentrations can exceed 100 μmoles per liter (Paerl 1985). If we consider 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 our open sounds and coastal waters. Accordingly, this largely ignored source of nitrogen can at times account for a bulk of the nitrogen input into these waters. This estimate may be conservative, since dry deposition of nitrogen has not been included in these calculations.

B. 4. Status of Management Activities

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 must be achieved (Paerl and Bowles 1986; Paerl 1987). This is a formidable, if not impossible, task to undertake 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 (commonly levels of from 100-450 μg/l P-PO_4^{3-} are 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 by the time the rivers discharge into the Pamlico River Estuary (50-300 μg/l P-PO_4^{3-}). 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 appear to exhibit the strong growth-limiting characteristics that NO_3^- and NH_3 reveal 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; parallel phosphorus input constraints. **Hence, dual nutrient (N + P) input controls should be practiced in this as well as other systems susceptible to blue-green algal blooms.**

A second argument for dual nutrient input control is based on recent findings (H. W. Paerl, UNC-CH, Personal Communication) concerning high runoff during spring months, combining the influences of excessive nitrogen (chiefly as NO_3^-) loading and dilution (by rainfall) of phosphorus. This combination can result in periods of exclusively phosphorus limited as well as phosphorus-nitrogen co-limited growth conditions in the lower Neuse River Estuary-Pamlico Sound region (see Figure III-11). It would appear that the combined impacts of heavy (and increasing since the 1940's) nitrogen fertilization, increased atmospheric nitrogen loading (due to the enhanced generation of the oxides of nitrogen) in rainfall (acid rain) and recent decreases in phosphorus loading due to improved sewage treatment and a phosphate detergent ban 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 the potential relationship to water quality, it is interesting to note the evolution of efforts to control nonpoint source (NPS) pollution. In addition to the National Estuary Program (Section 320 of the Water Quality Act of 1987), there are seven 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 arrive at the proper mix of regulatory and voluntary controls.

<u>B. 4. a. Section 208.</u> Traditionally, pollution control efforts were directed toward point sources. In 1972, however, Section 208 (Area-wide Waste Treatment Management) of the Federal Water Pollution Control Act Amendments 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.

<u>B. 4. b. Sedimentation Control.</u> 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 N. C. Division of Land Resources is responsible for administration and enforcement of the requirements of the Act under the authority of the N. C. 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 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 to the approved plan is not achieved and violations occur, the Land Quality Section will pursue enforcement through civil penalties and injunctive relief.

<u>B. 4. c. Coastal Area Management Act.</u> In order to foster protection of sensitive coastal areas, the North Carolina General Assembly enacted the Coastal Area Management Act (CAMA) in 1974. The basic premise of the Act was to provide protection of areas of environmental concern (AEC) by requiring permits for development in these areas. The N. C. Division of Coastal Management (N. C. Department of Natural Resources and Community Development) 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 N. C. Division of Coastal Management in implementing CAMA. First, land use plans are to be developed by each coastal county 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 projects to ensure that the policy and provisions of CAMA are satisfied.

B. 4. d. Nutrient Sensitive Waters. To address the need for limiting nutrients in certain waters, the N. C. Environmental Management Commission (EMC) adopted a nutrient sensitive waters (NSW) classification in May of 1979. This classification gave the EMC the authority to limit nutrients in 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. 4. e. 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 Best Management Practices (BMPs). The N. C. 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 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 N.C. General Assembly also appropriated funds in 1984 to establish a Forestry Cost Share Program to compliment 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. 4. f. Food Security Act of 1985. Several provisions authorized by the Food Security Act of 1985 (FSA) offer excellent opportunities for the abatement of agricultural nonpoint source pollution in the Albemarle-Pamlico Estuary area. The FSA makes the goals of the U. S. Department of Agriculture farm and conservation programs more consistent by encouraging the reduction of soil erosion, reducing the 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 U. S. Soil Conservation Service. Other cooperating agencies include the N. C. State University Agriculture Extension Service, N. C. Division of Forest Resources and Local Soil and Water Conservation

Districts. The CRP was established to encourage removing 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. Vegetative filter strip establishment has been incorporated into the CRP, which 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 equal to eight times or greater than the rate at which the soil can maintain continued productivity. This rate is determined by the U. S. 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 U. S. 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 U. S. 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 U. S. 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 U. S. 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 U. S. 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.

<u>B. 4. g. Coastal Stormwater Management Regulations.</u> Coastal stormwater control has been an important issue before the Environmental Management Commission (EMC) for nearly three years. The initial debate focused primarily on stormwater and 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 N. C. Division of Coastal Management) or a Sediment/Erosion Control Plan (through the N. C. 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 N. C. 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. Perhaps the most important measure accomplished with the new regulations has been the applicability of stormwater controls to development activities within all 20 CAMA coastal counties, which includes those 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% 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 rather than a limit on effective impervious cover. Development exceeding these levels is required to have a engineered stormwater system.

B. 4. h. Section 309. The Water Quality Act (WQA) of 1987, which was essentially 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 N. C. Division of Environmental Management was designated as the coordinating agency for nonpoint source pollution management.

Consequently, two reports were prepared in fulfillment of Section 319 (N. C. Division of Environmental Management 1989a, 1989b). The first report focused 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 is balanced between 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 either improve degraded water quality or minimize nonpoint source impacts to high quality waters. Ideally, 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 to control NPS pollution in the Albemarle- Pamlico Estuarine area (and throughout North Carolina) is through a combination land-use control and technology-based best management practices (BMPs). In urban areas, the preferred method of treatment is land use control through low density development because of long-term maintenance requirements associated with structural BMPs. In unavoidable 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 installation 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 our best knowledge were extremely rare prior to World War II. Prior to the late 1960's 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 do describe hydrological (flow characteristics, salinity regimes), hydrographic and very limited chemical (major ions, total dissolved solids, particulates but no nutrients) 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 1960's and 1970's (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 1970's the N. C. Division of Environmental Management and the U. S. 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 1970's and early 1980's 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, 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 were likewise investigated among agricultural field sites (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 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 as well as discoveries 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 vs. 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), to help prioritize and set specific target levels for future nutrient input cutback 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) and the summary below was taken from the study. According to estimates made in the study, basin-wide changes in major land use category acreages 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 1800's to around 64% of the total by the 1930's 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 important now than in the past, while others have become relatively unimportant 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. The second most widely planted crop today, soybeans, was first planted in significant acreages in the 1930's and 1940's, but up until about 1960 never made up more than 5-10% of the total. However, by 1985 there were 290,000 acres (117,450 ha) of soybeans, which was about one-third of the total harvested cropland (Stanley 1988a).

On the other hand, tobacco and, especially cotton, acreages have declined in the Neuse basin. Annual tobacco plantings peaked in the 1930's and 1940's 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 acreage. Cotton production in the basin was very important up until the 1930's, but then it declined rapidly and had practically ceased by about 1970. At it's peak in the 1920's, 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. Finally, 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 now there are about 500,000

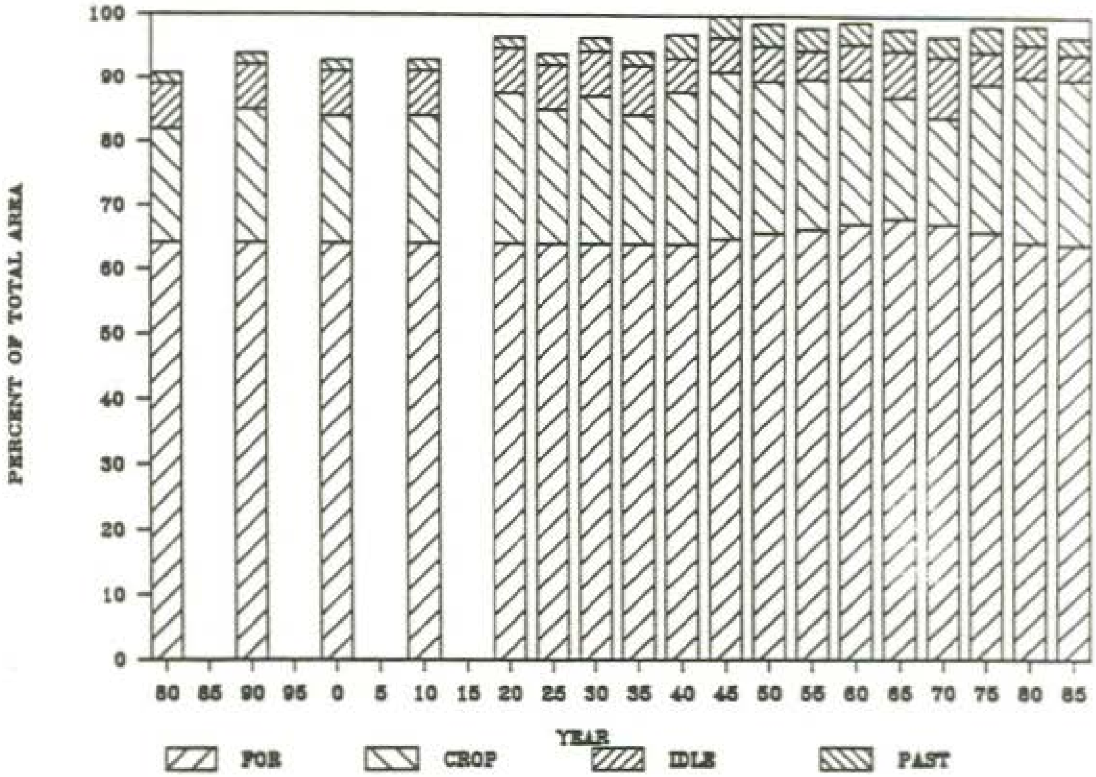

Fig. III-12. Land Use in the Neuse River Basin, 1880-1985. From Stanley (1988a).

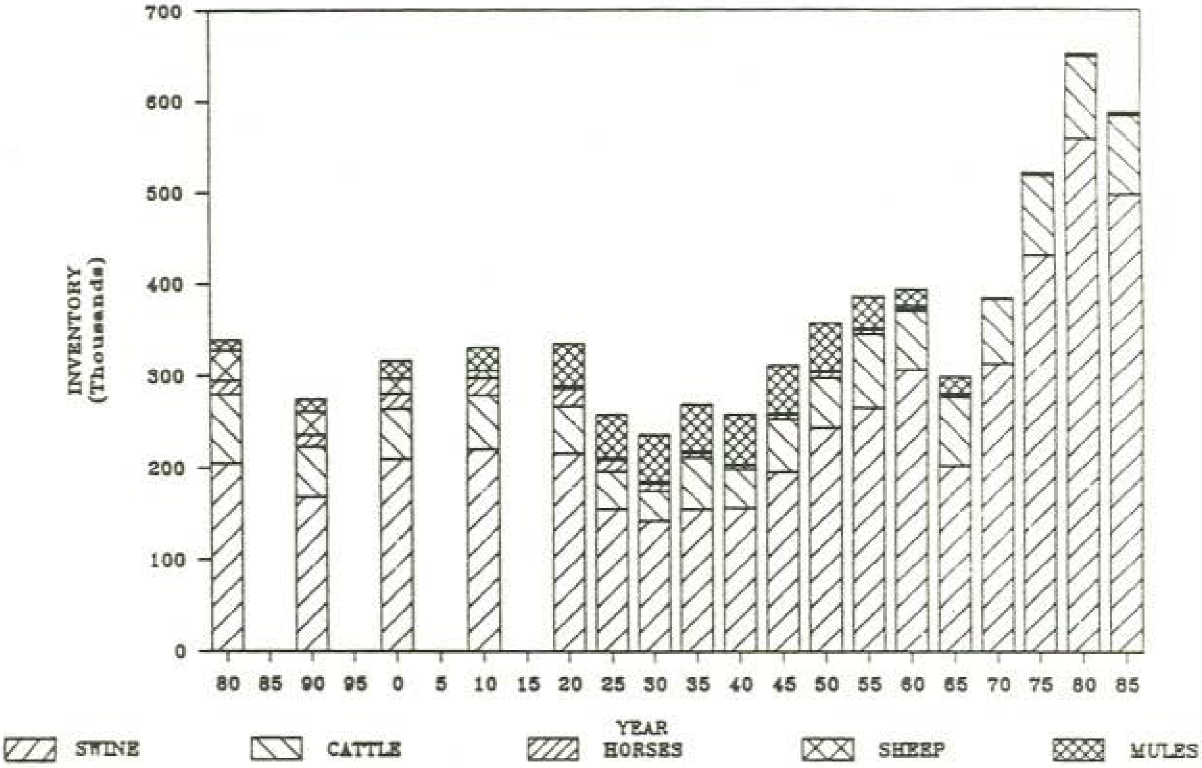

Fig. III-13. Inventory of Large Farm Animals, 1880-1985, in the Neuse River Basin, Poultry not Included. From Stanley (1988a).

of these animals. Cattle numbers, on the other hand, have ranged between 25,000 and 75,000, but with no particular pattern, and the numbers in recent years are no higher than those 100 years ago. Inventories of mules peaked in the 1940's 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 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 N or P removal from wastewater discharged into the river. As secondary treatment came into widespread use in the 1950's and 1960's 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 it 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, which is no surprise 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 1950's, then declined slightly before increasing rapidly in the 1970's and 1980's. This pattern can be explained partly by improvements in nitrogen removal at waste treatment plants in the 1950's and 1960's, 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-1970's, the nitrogen loading began to increase sharply as population continued to increase. Another factor leading to reductions in nitrogen loading in the late 1960's 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

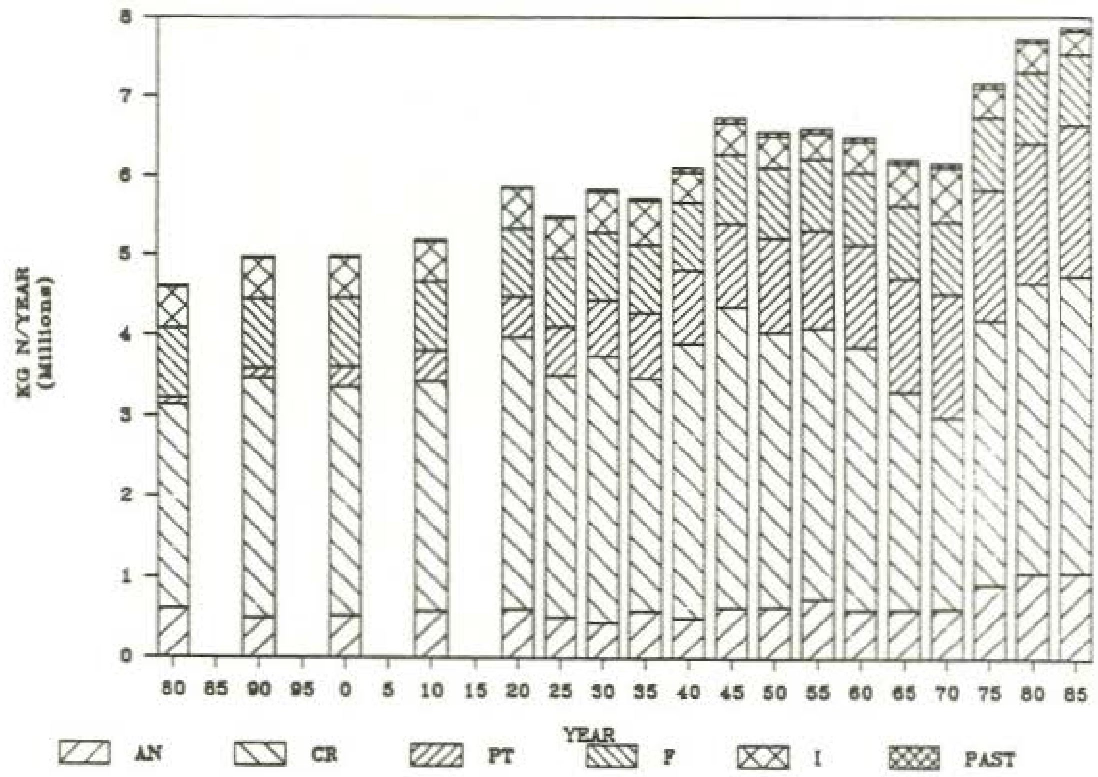

Fig. III-14. Estimated Phosphorus Loading to the Neuse River Estuary, 1880-1985. AN = Farm Animals, CR = Cropland, PT = Point Sources, F = Forestland, I = Idle Cropland, and PAST = Pastureland. From Stanley (1988a).

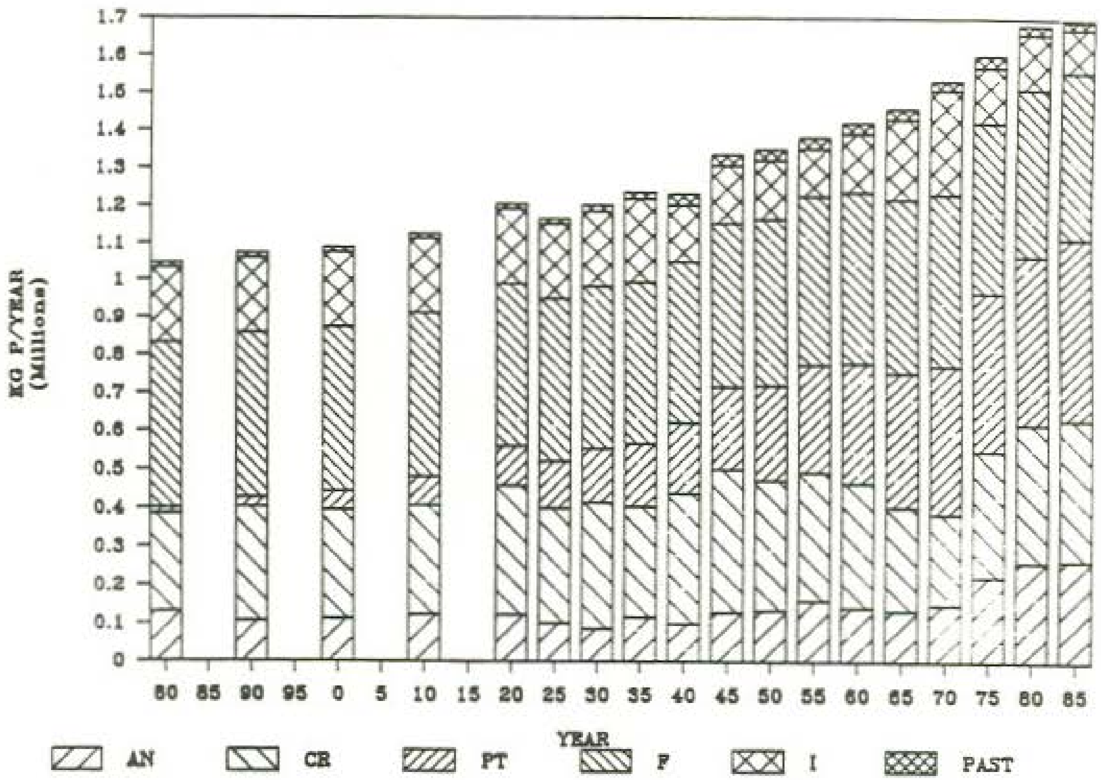

Fig. III-15. Estimated Nitrogen Loading to the Neuse River Estuary, 1880-1985. Symbols same as in Fig. III-14. From Stanley (1988a).

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 N. C. Division of Environmental Management (1989b). The N. C. 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 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 times mean daily river flows to give total annual instream loading estimates. Their results, 3.5 million kg/year nitrogen and 0.8 million kg/year 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 be too high 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 1930's and 1940's, 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 into the streams draining the farmland, the difference in nitrogen used in 1932 and 1984 (50 million kg/year) 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. And, 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 simply using 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, storages 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 denitrification rate, erosion rates, nitrogen fixation rates, etc.

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 (N. C. Division of Environmental Management (1989a).

<u>C. 1. c. Pamlico River Estuary Water Quality Trends.</u> A detailed analysis of historical trends in nutrient data for the Pamlico River Estuary has been developed by Stanley (1988b). A nonparametric 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 deemed not serious enough to interfere with the trend analyses.

Three climatic variables, along with Tar River discharge, were tested for trend 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 °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.

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, counterbalanced 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-1970's; which 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 μg/liter <1 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 μg/liter) are usually more common in the winter than in the summer (Figure III-16). 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 upper Neuse Estuary and the lower Chowan River, where significant blue-green algae blooms have occurred in several years over the past decade.

Water column nutrient ratios (dissolved inorganic nitrogen/ orthophosphate) calculated for the Pamlico indicate that nitrogen is more likely than phosphorus to be limiting phytoplankton growth during the summer (Figure III-17). 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. Also, nitrogen, rather than phosphorus, is thought to be the nutrient most limiting to 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.

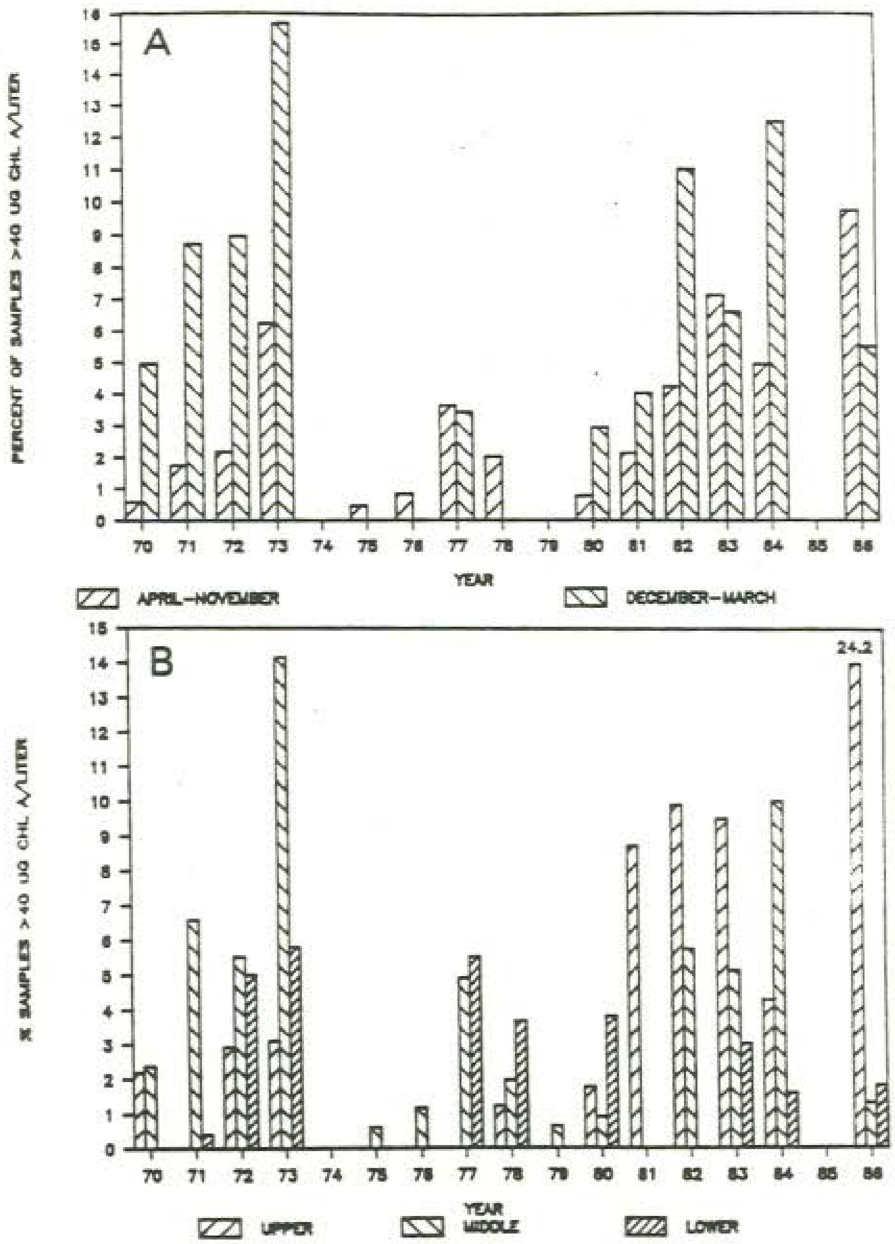

Fig. III-16. Pamlico River Estuary Chlorophyll a in Percentage of Sample Values Greater than 40 µg/l for each year (1970-1986). A = Data Grouped by April-November and December-March Periods; B = Data Grouped by Upper, Middle and Lower River Segments. From Stanley (1988b).

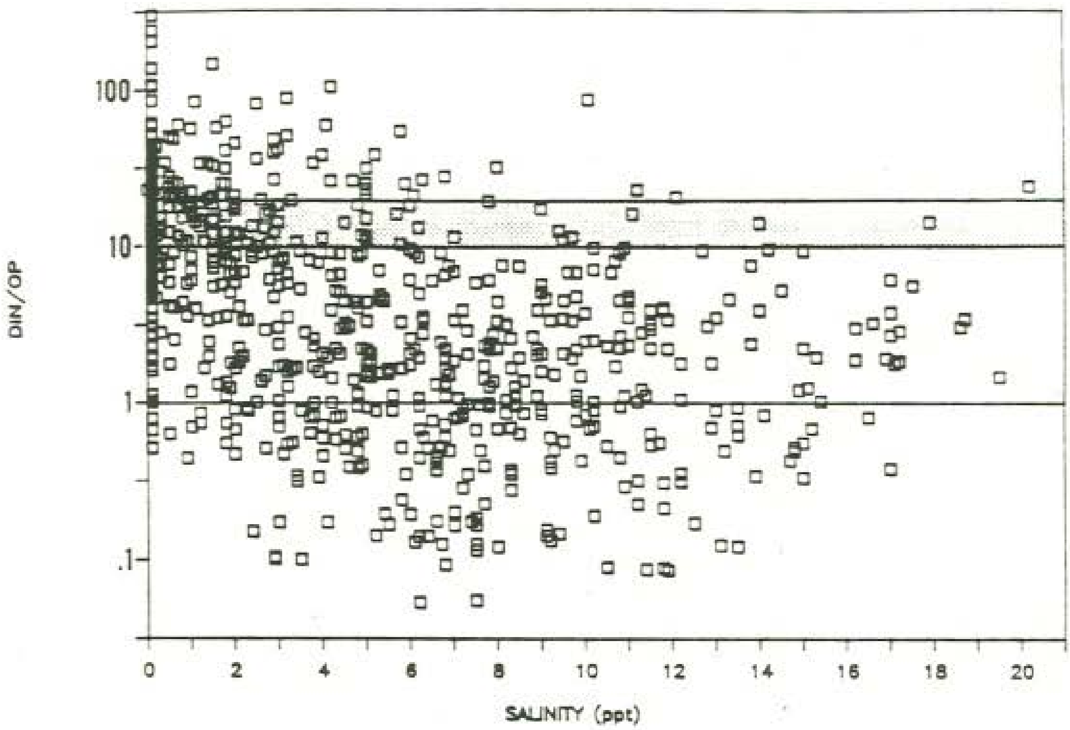

Fig. III-17. Dissolved Inorganic Nitrogen (DIN): Ortho-Phosphate (OP) Ratio Versus Salinity in the Pamlico River Estuary, 1979-1986. Shaded Area Indicates Usual Range of N:P Ratio in Algal Cells. From Stanley (1988b).

C. 2. Potential Effects of Current Trends

C. 2. a. Anoxia (Hypoxia)-A Case 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 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, leading 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, leading 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 very quickly. 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 in 1976. We will discuss two sequences to 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 breakup of bottom water hypoxia in less than a week was detected in the August samplings. 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 in an attempt 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 then. However, vertical salinity gradients greater than 1 ppt (an indication of stratification) are 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 which factors have the most influence on dissolved oxygen in the Pamlico during the summer. Several variables were tested for correlation with dissolved oxygen concentration at four stations sampled between 1975 and 1986. The results indicated that three

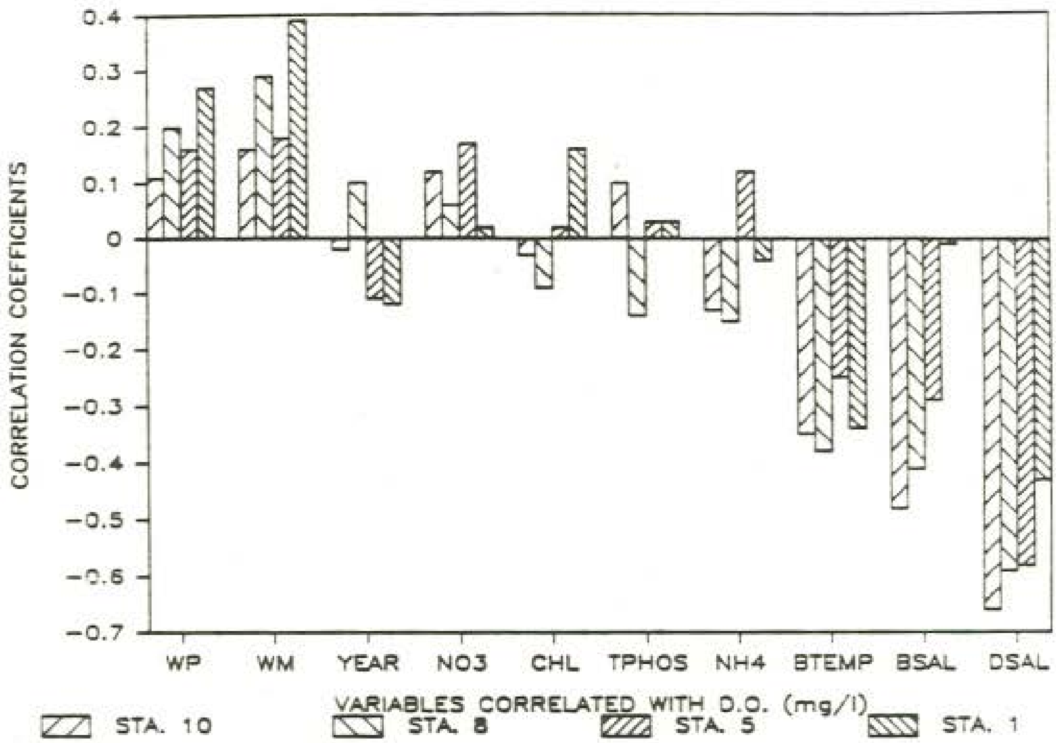

Fig. III-18. Spearman Rank Correlation between Bottom Water Dissolved Oxygen (mg/l) and Total Wind Miles on the Previous Day (WP), Average Total Wind Miles on the Sampling Date and the Previous Day (WM), Year, Nitrate Nitrogen (NO_3), Chlorophyll a (CHL), Total Phosphorus (TPHOs), Ammonia Nitrogen (NH_4), Bottom Water Temperature (BTEMP), Bottom Water Salinity (BSAL), and Vertical Salinity Gradient (DSAL) in the Pamlico River. From Stanley (1988b).

factors (vertical salinity gradient, water temperature and wind velocity/direction) were (statistically) significantly correlated with bottom dissolved oxygen concentration (Figure III-18). 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-19); i.e., river flow and wind velocity (Stanley 1988b). The river flow data are from the nearest gauging station on the Tar RIver (Tarboro), which is 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 guidance on 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 this 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, I could find no evidence of such a relationship. 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 (greater than 2%) vertical salinity stratification 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

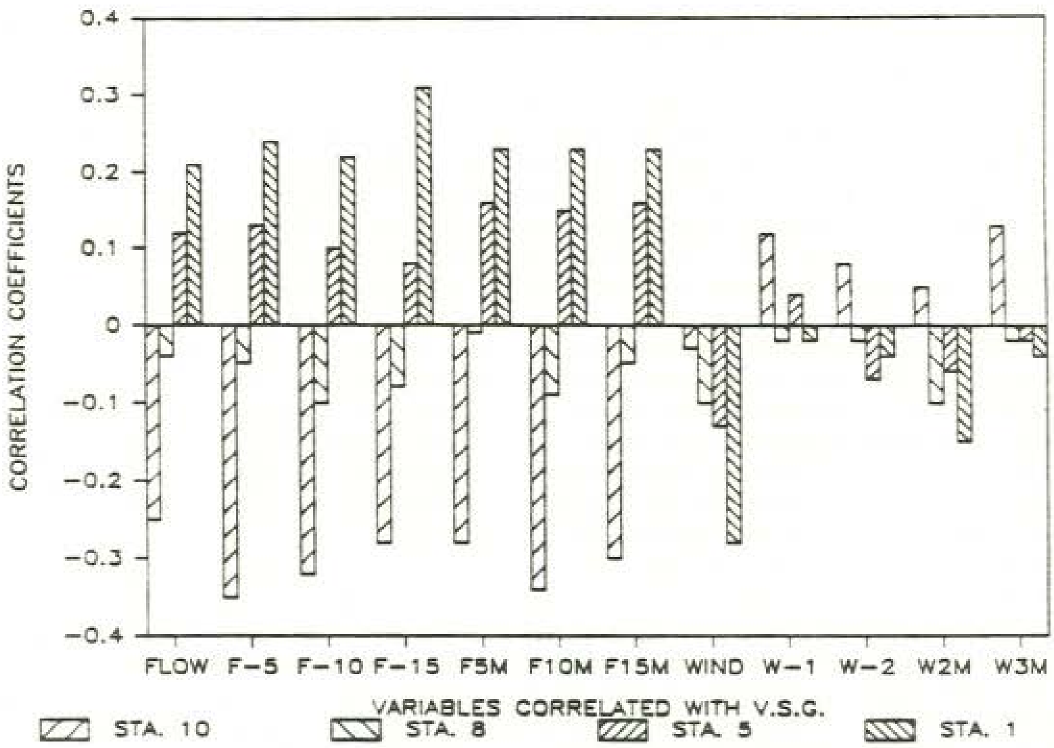

Fig. III-19. Spearman Rank Correlation between Vertical Salinity Gradient and River Flow on Sampling Date (FLOW), Flows 5 Days before Sample (F-5) 10 Days before (F-10) and 15 Days before (F-15), Average Flows for 5-Day (F5M) 10-Day (F10M) and 15-Day (F15M) Intervals before Sampling, Total Wind Miles 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).

recurrence interval of the strong winds that determines the magnitude of the summer "dead water" problem.

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 1960's by Tenore (1970, 1972). He found that 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 Term (PERT) has the potential of enabling the N. C. 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. They summarized their new findings as follows:

> Analysis of the complete data base on measurements of dissolved oxygen in the Chesapeake Bay for the period 1950-1985 results in two conclusions: a) there has been no statistically significant pattern of increase in summer anoxia of bay waters over the past 36 years, and b) annual streamflow-induced stratification is the controlling factor in the annual volume of summer anoxic waters in the bay, at greater than the 99.99% confidence level. These conclusions are in sharp contrast with those of an EPA-funded 5-year study of the

bay and with those of a major review of anoxia published in Science [Officer et al. 1984]; i.e., that anoxia in the bay has increased by a factor of 15 since 1950 and that benthic respiration, rather than stratification, has been the controlling factor in this 15-fold increase in anoxia. This apparent increase in anoxia has been attributed to increased nutrients and has been assumed to be a major factor in the decline of fish and shellfish species in the bay. A federal and multi-state program for restoring the bay biota is based on reversing this 15-fold increase in anoxia by reducing nutrients in the bay. In the absence of any evidence for increased summer anoxia since the 1950's the scientific basis of this program should be re-evaluated.

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 space limited.

C. 2. b. Nutrient Enrichment. In situ nutrient (nitrogen, phosphorus and trace metals) addition bioassays conducted on four to six week intervals have thus far proven valuable in identifying those nutrients responsible for regulating and limiting algal growth as well as algal community growth potentials in response to nutrient loading (enrichment) events (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 2 parallel (and relevant) indicators of algal growth (carbon dioxide assimilation, chlorophyll content) in highly replicated treatments.

Hans Paerl, University of North Carolina Institute of Marine Science, is currently conducting an analyses of nutrient additions to the productivity and growth of estuarine phytoplankton (A/P Study Project). Analyses of at least 9 bioassays conducted over a 11 month period (November 1987-October 1988) reveal the following characteristics concerning nutrient-algal growth relationships in the Albemarle-Pamlico Estuarine System:

1. Nitrogen availability clearly is a key factor regulating algal growth potentials–throughout much of the year, inorganic nitrogen (either as nitrate or as ammonia additions, by themselves, led to highly significant ($P<0.01$) stimulation of both photosynthetic productivity and chlorophyll a production (compared to untreated controls). Constraints in nitrogen availability appeared most severe during mid to late summer months. During these times even small nitrogen enrichments led to substantial stimulation of algal growth. Both nitrate and ammonia additions led to equivalent (per amount of nitrogen added) algal growth yields.

2. Phosphorus availability, while appearing sufficient on 7 of 9 occasions, does at times play a role in regulating algal growth potentials; we observed distinct stimulation of algal growth following phosphorus enrichment during April and May of 1988.

3. Phosphorus stimulation of algal growth only occurred in the presence of nitrogen enrichment; without parallel nitrogen addition, phosphorus added alone failed to exhibit growth stimulation during April-May 1988.

4. The pattern (thus far observed) of phosphorous stimulation appears to closely follow periods of relatively high dissolved inorganic nitrogen:phosphorus ratios in the water column.

Following periods of relatively high nitrogen:phosphorus ratios (in excess of 10), phosphorus enrichment can play a role in mediating algal growth potentials.

5. Trace metals, either added alone or in combination with nitrogen and/or phosphorus, fail to exhibit any impacts on algal growth potentials; we therefore conclude that natural availability of metals far exceeds algal growth requirements in the Albemarle-Pamlico Estuarine System.

6. Responses by algal production to both nitrogen and/or phosphorus stimulation are either short-term seasonal (related to the combined impacts of runoff, land use/management, fertilization and other human activities in the watershed, hydrological conditions including rainfall, irradiance and turbulence) or long-term inter-annual in nature. It is not currently possible to ascertained what types of trends are occurring.

7. A multi-year continual study of nutrient limitation, relative to both natural climatic (relatively dry vs. wet years, for example) and human use (fertilization, urban and industrial runoff, land development) patterns will help delineate both the time scales and trends of observed fluctuations/oscillations in nutrient-growth relationships.

It can be concluded that the availability and hence discharge/loading of both nitrogen and phosphorus must be addressed in future management efforts aimed at regulating eutrophication/bloom potentials. The growth of certain filamentous and coccoid blue-green algal species is enhanced in the presence of both nitrogen and nitrogen plus phosphorus treatments. In particular, growth of attached (periphytic, epilithic) filamentous species (*Oscillatoria, Lyngbya, Microcoleus*) appears more profound under nutrient enriched conditions. Parallel work in North Carolina coastal (Atlantic) waters (H. Paerl, Personal Communication) indicates that growth of such attached potential fouling communities is greatly enhanced in the presence of phosphorus enrichment. Accordingly, emphasis will be placed on examining the selective stimulation of periphytic/epilithic fouling communities in the Albemarle-Pamlico Estuary in response to nutrient enrichment during 1989-1990.

<u>C. 2. c. Sediment Conditions.</u> 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, nor is there evidence that they are functionally different. If differences exist, they most likely result from recent unnatural anthropogenic loadings and to other human disturbances, than to changes in bottom sediment nutrient processing routes or rates. Furthermore, anoxic and other adverse water quality episodes have probably been common in past centuries also. 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 to sediment types and functioning, which is just now beginning under the A/P Study (Riggs et al. 1989; Wells 1989). Standardized methods must be adopted for the primary monitoring program in order to intercompare results in different areas, in different years, and among different investigators. On the other hand, investigators should be supported, indeed encouraged, to ask new questions and to develop new approaches to study old problems. It is important, also, 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 to 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 building a total picture of functional characteristics of the trends in water quality. Several needs have been identified:

1. Determinations of nitrogen and phosphorus (dissolved and particulate, organic/inorganic forms) loadings into the Albemarle-Pamlico Estuarine System, and elucidating the processing (cycling characteristics) and ultimate fates of these loadings. Ultimate use of such information will be dictated by taking into consideration of existing and future freshwater nutrient input data, sediment input and sedimentation/resuspension information, as well as water input/circulation/retention data for the Albemarle-Pamlico Estuarine System. This effort should utilize a "grid approach" so as to obtain data on spatial/temporal integrity.

2. Investigations into the relative importance of nitrogen vs. phosphorus as potential regulatory and limiting factors governing primary production. This need links 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 (i.e., Neuse, Pamlico, Chowan) as well as several locations in the mid-Sound region.

3. A comparative study aimed at delineating physical from chemical limitations on primary production in the Albemarle-Pamlico Estuarine System. Turbidity (sediment resuspension and water color) as well as temperature exert independent limitations on quantitative and qualitative aspects of primary production; whereas, it is well known that nutrient (most likely nitrogen) limitation operates simultaneously. This program must address the relative importance of each type of limiting factor on a seasonal and temporal basis in all parts of the 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 framed in such a manner as to be useful for both water quality management and flux/mass balance modeling efforts which are to be undertaken.

4. Determine the presence and potential (future) for proliferation of nuisance (considered undesirable from trophic, recreational and aesthetic perspectives) phytoplankton in response to nutrient (and sediment) enrichment in the Albemarle-Pamlico Estuarine System. Specifically, blue-green algae, toxic dinoflagellates (red tides) and bloom potentials should be investigated with the goal of establishing nutrient input and concentration "thresholds", above which periodic dominance and blooms might be anticipated. Ancillary (other relevant) environmental factors known to play regulatory roles in nuisance bloom development (including salinity, turbidity, thermohaline stratification and humic substances) should receive parallel consideration in spatial/temporal evaluations of bloom development within the estuarine system.

5. Investigations relating the incidences and impacts of enhanced hypolimnetic and sediment deoxygenation. The interaction and impact of stratification, water movement, temperature and wind, in particular, on the intensity and stability of deoxygenation needs to be

characterized. In addition, the role of enhanced nutrient loading (from both "internal" recycling processes and loading) and resultant eutrophication (including bloom potentials) needs to be identified as to their relationship to hypoxia.

6. Examination and evaluation of 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 as well as field evaluations of the utilization of primary producers (emphasizing potential nuisance species) by herbivorous zooplankton, larval and mature invertebrates (including shrimp for example) and commercially important fish.

7. Development of 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 flux that dominates cycling in certain places at certain times. 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.

D. CONCLUSIONS

1. The United States Geological Survey has gathered abundant data on stream discharges in North Carolina over several decades. Groundwater discharge directly into the estuaries and exchange through the tidal 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, accompany accelerated eutrophication. To varying degrees, symptoms as well as 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 are composed of municipal and private wastewater treatment facilities. These facilities must obtain a permit from the North Carolina Division of Environmental Management which limits the amount of pollution that may be discharged to a give 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, 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 1990.

5. There have been 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 N. C. 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" (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 un-impacted 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 un-impacted by nonpoint sources.

7. Despite the scarcity of open-water nutrient and productivity data, a reasonable 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.

8. 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 (for the Pamlico River estuary the concentration is higher than in most 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 parallel 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.

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, data to verify such simply do not exist prior to the mid-1960's. Trend analysis for the Neuse River estuary indicate 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 both upstream and downstream sections. Nitrogen concentrations are very similar to that 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.

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 bottom water 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 hypoxia. Hypoxia can become established in a short period of time during summer; and, conversely, can be dissipated 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, nor is there evidence that they are functionally different. Anoxic and other adverse water quality episodes have probably been 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 impacts simply 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 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, and modification of riverine flow raise serious concerns about the future of the area's important fishery stocks and fisheries.

The fishery stocks of the estuary consist of the finfish, crustaceans, and shellfish inhabiting the system. The fisheries include the stocks, fishermen, and harvesting gear and methods utilized to capture and convey the catch. This report concentrates on economically important species; those that are important commercially and/or recreationally. This emphasis is not meant to ignore the vast majority of species (and biomass) which provides the basis for production of the economically important species. However, far more is generally known about the harvested species than most forage species, and management efforts concentrate on the economically important species.

The system's habitats include one of the largest coastal freshwater sounds in the country (Albemarle), 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 exhibit three predominant life history strategies. First, anadromous fishes are those which spend the bulk of their lives in salt water, but return to freshwater streams to spawn. The river herrings and shads (*Alosa* sp.), striped bass (*Morone saxatilis*), and sturgeons (*Acipenser* sp.) are typical of these types of fishes. Resident species, which spend their entire life in the estuary exemplify a second strategy. These species are confined to a given geographical area, apparently by factors such as salinity, bottom type, depth, and currents. This group includes finfish, such as white perch (*Morone americana*) and catfish (*Ictalurus* sp.), as well as molluscan species such as hard clams (*Mercenaria mercenaria*) and oysters (*Crassostrea virginica*). The third strategy, and most important in terms of economically important fishery resources, are the estuarine migratory species. These species principally spawn in the open ocean, around inlets, or near shore. 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* sp.), 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 near-shore 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 also a major fishing area. Recreational and commercial fishermen in the area use as wide a variety of gears and methods as the species they seek. The area contains numerous fishing ports for the state's "highly migratory" fishing fleet. Fishing, both commercial and recreational, with their associated industries, has a major economic impact on the region (Street and McClees 1981).

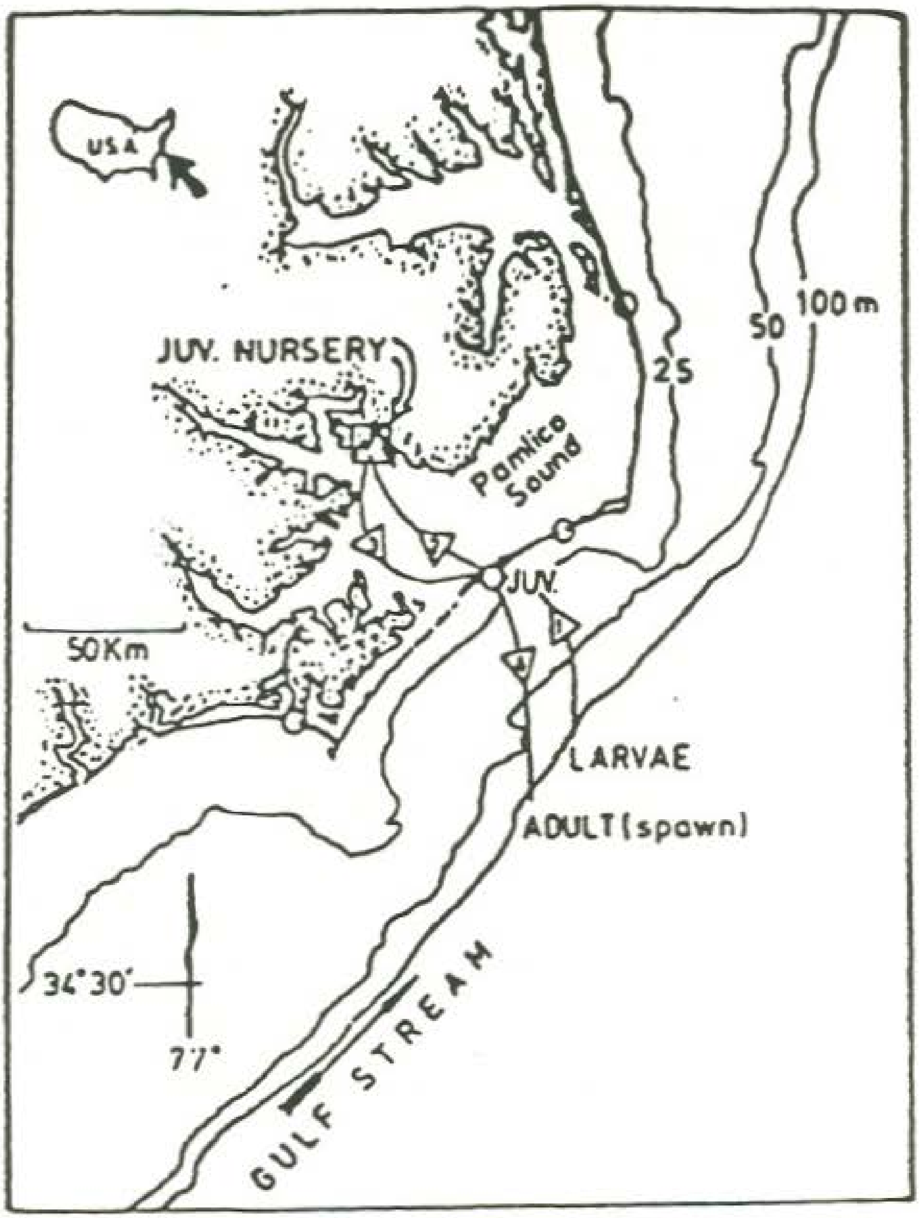

Figure IV-1. Migration Patterns of Typical Fish Species in the Albemarle-Pamlico Estuarine System. From Miller et al. 1984.

Table IV-1. Commercial Landings of Estuarine Dependent Finfish, Crustaceans, and Shellfish in North Carolina, 1986-1988, in Thousands of Pounds. (DMF Data)

Species	1986	1987	1988
Finfish			
River herring	6,814	3,195	4,191
Atlantic croaker	9,425	7,289	8,434
Flounder	8,845	7,984	10,265
Menhaden	66,378	55,499	73,715
Mullet	1,932	2,590	3,060
Grey & spotted seatrout	14,501	12,198	15,388
Spot	3,354	2,806	3,080
Striped bass	189	262	116
Others	9,888	9,151	10,660
Subtotal	121,326	100,974	28,909
Crustaceans			
Blue crab	23,755	32,424	34,634
Shrimp (heads on)	6,162	4,416	8,139
Subtotal	29,917	36,870	42,773
Shellfish (meats)			
Clams	1,356	1,207	940
Oysters	745	1,426	913
Bay scallops	306	155	39
Others	99	94	106
Subtotal	2,506	2,882	1,998
Total	153,749	140,726	173,680
Total state landings	168,882	157,324	191,701
Percent estuarine dependent	91.0	89.4	90.6

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 as well as other fish and shellfish year-round.

Fisheries

The area's 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 growth, feeding, and spawning. Regulatory controls also impose seasons on some species, such as striped bass and oysters. Commercial fishermen utilize both fixed and moveable gears. Otter trawls, oyster dredges, and long haul seines are the most important moveable gears. Major fixed gears include pound nets, gill nets, and crab pots. Recreational fishermen are generally assumed to use hook-and-line gear. In North Carolina, however, they use commercial gear, as well, though in 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. Especially in estuarine areas, anglers frequently set a small anchor gill net (about 50 yd), fish for several hours with hook-and-line, and then pick up their gill net on the way in. In some coastal areas, cottages rented to tourists come equipped with a gill net.

A. 1. Available Data

A variety of data are available to evaluate trends in the fishery resources and fisheries. The DMF samples the catches of the major commercial fisheries for species composition, size (and age for selected species), and effort. Division personnel sample juvenile finfish, shrimp, and crabs in estuarine nursery areas to determine relative abundance and growth. Environmental parameters are also sampled. Similar sampling is conducted for oysters and bay scallops. A quarterly survey of the open waters of Pamlico and eastern Albemarle sounds is conducted to gather data on relative abundance, distribution, and growth of species present. Sampling of adults began in 1972 for anadromous fishes in the Albemarle Sound area, as did sampling for juvenile anadromous fishes. Commercial catch sampling in the Pamlico Sound area began in the late 1970's. General juvenile sampling began in some areas in the early 1970's, and became standardized in the late 1970's. Bay scallop sampling started in the mid-1970's. Sampling of planted oysters began in the mid-1970's, while sampling of wild oysters began in 1987 in the Pamlico Sound area. The quarterly sounds survey was also initiated in 1987. Because of their long-term importance to fishermen, commercial and/or recreational, the DMF considers certain species as "target species". Biological sampling and analysis emphasize these species, which include shrimp (three species), oysters, bay scallops, Atlantic croaker, spot, weakfish, red drum, summer flounder, southern flounder, bluefish, blueback herring, alewife, American shad, hickory shad, striped bass, Spanish mackerel, and king mackerel. All except king mackerel are principally estuarine or near-shore ocean species.

The longest fisheries database is the commercial landings statistics, which extend back to 1880 in North Carolina. Commercial landings data are too 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, and data collection procedures, as well as stock abundance. As a result, they should be viewed primarily as a very general indicator of the fisheries themselves, but not of the fish stocks. As such, they can characterize the various fisheries and provide insight into the fishing trends relative to all of the various factors which influence the statistics. The current 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 during 1979-1986 were collected by the NMFS to characterize regional and national sport fisheries and have very limited applicability to North Carolina alone, with no confidence limits about the estimate for North Carolina. In 1987, DMF began a cooperative program 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 confidence limits, but only two years of data are available. Data are now being gathered on the sport catch from the different water bodies, but because of the design and intensity of the survey, the data cannot be expanded to total estimates nor can confidence limits be calculated.

In addition to the monitoring programs noted above, numerous short term projects have been conducted, directed at certain species or specific areas or habitats. The long term monitoring programs generally utilize standard methods so that, within limits, data may be compared over time and area. 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 relative 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.

Lack of effort data is frequently cited as a weakness in fisheries databases. 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, is very rare. To utilize this measure, 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 fisheries: Chowan River pound nets, winter trawl fishery, shrimp fishery, Pamlico Sound summer pound net fishery, and the long haul seine fishery.

A. 2. General Trends

Since most of the DMF monitoring programs are of relatively recent origin (most since the late 1970's), long term trends cannot be determined from data collected by those programs. One hears widely that current fishing cannot compare with the "good old days." An examination of total commercial landings data for North Carolina indicates that the five-year period with the greatest recorded landings was 1978-1982, hardly the "old days," 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 sounds area also rose during this period, reaching their highest level in 1980 (DMF Unpublished Data). During the late 1970's-early 1980's, commercial landings of a number of species (or species groups) taken in the Albemarle-Pamlico area established all-time records or

Table IV-2. Commercial Fisheries Landings in Albemarle Sound Area, Pamlico Sound Area, and Core Sound Area, North Carolina, 1972-1988 (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
Mean	14,981	34,713	9,304	58,997	54.2
Percent state total	13.8	31.9	8.6		

reached levels not seen for many years (Table IV-2). Such species included menhaden, blue crabs, flounder, weakfish, croaker, white perch, hard clams, and shrimp. Biological data, such as size and age composition, and anecdotal information from fishermen strongly indicate that the elevated harvests during this period reflected actual increased abundance relative to previous years. Why 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 complex 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 impacted fisheries productivity. A few 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) hypoxia, 5) loss of critical habitats, 6) freshwater discharge, 7) fecal contamination resulting in shellfishing closures, and 8) toxics.

Fish and shellfish diseases are a significant problem in the Albemarle-Pamlico Estuarine System. During the 1970's, large numbers of freshwater finfish species were affected by red sore disease in the western portions of Albemarle Sound (North Carolina 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 has subsided in Albemarle Sound in the 1980's, a multitude of ulcer-diseases has occurred principally in the Pamlico River but also in other areas (Noga and Dykstra 1986; Noga et al. Submitted). Most of the commercially important estuarine fish species utilizing the Pamlico have been observed with lesions, including Atlantic croaker (*Micropogonias undulatus*), spot (*Leiostomus xanthurus*), weakfish (*Cynoscion regalis*), southern flounder (*Paralichthys lethostigma*), red drum (*Sciaenops ocellatus*), spotted seatrout (*Cynoscion nebulosus*), and Atlantic menhaden (*Brevoortia tyrannus*). The worst disease in terms of prevalence is ulcerative mycosis, a fungal infection primarily affecting Atlantic menhaden (Noga and Dykstra 1986; Dykstra et al. 1986). As much as 80-90% of the Atlantic menhaden in random pound net samples have had ulcerative mycosis (LeVine et al. Submitted). Recently, an aggressive shell disease has been noted on blue crabs (*Callinectes sapidus*) in the Pamlico River (McKenna et al. 1989; Engel and Noga 1989).

Diseases can impact fisheries productivity by several means. The stocks of affected species can possibly be depleted by acute mortalities due to disease; however, the 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 due to the chronic recurrence of disease which induces continual mortalities (Merriner and Vaughan 1987). Diseases also impact commercial fisheries production indirectly by making affected 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 impact recreational production by decreasing the attractiveness of fishery areas where fish disease prevalence is relatively high.

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 sublethally impact vital life history characteristics of fish in the estuary, such as reproduction and growth. If the multitude of 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 fish and shellfish estuarine utilization in several ways. Extremely dense algae can deplete dissolved oxygen from estuarine waters during periods when photosynthesis is reduced, such as nightfall. Also, some species of algae release toxins which 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 75 in 1988 (North Carolina Division of Environmental Management 1989). The number of documented algae blooms in the Albemarle-Pamlico Estuarine System has increased since 1984, especially in the estuarine waters of the Tar-Pamlico River, where 55 blooms were recorded from 1986 to 1988. No blooms were reported in the Tar-Pamlico during 1984 and approximately five were noted in 1985. Stanley (1988) found that levels of chlorophyll a, an indicator of algae abundance, increased in the middle and upper Pamlico River from 1967 to 1986. Nutrient enrichment of North Carolina's waters are thought to be responsible for the increasing number of algae blooms (Rader In Press).

Algae blooms in the Tar-Pamlico River are frequently associated with fish kills (North Carolina Division of Environmental Management 1989). Toxins produced from algae blooms have contributed to fish kills in the Tar-Pamlico River (North Carolina Division of Environmental Management 1981). The effects of such kills on the fishery resources are usually acute and very difficult to discern due to the natural variability of fish and shellfish populations. Besides initiating acute events such as fish kills, algae populations 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 (*Morone saxatilis*) in Albemarle Sound (Rulifson 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 impacting the larval feeding ecology of fish in the Neuse River (Paerl 1987).

One of the most significant examples of how an algae 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 (*Argopecten irradians*) were killed in Core and Bogue sounds and hundreds of square miles of estuarine waters were closed to shellfishing due to a 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/crab kills were documented by the Division of Environmental Management (DEM) in the Tar-Pamlico. In 1988, DEM and DMF received 39 reports of fish/crab kills in the Tar-Pamlico. Most of the documented kills have been attributed to hypoxia due to algal blooms or salinity stratification and occur during warmer months in localized areas. However, in 1988 and 1989 the DEM and DMF documented extensive continuous Atlantic menhaden kills occurring over 10 to 15 miles of the Tar-Pamlico River during June 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 impact 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). Hypoxia is caused by a variety of environmental factors such as freshwater runoff (with its accompanying organic matter), water column stratification, biological processes which produce organic matter, 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 oxygen depletion/eutrophication status. Six of the 23 areas were found to experience substantial hypoxia/anoxia (no oxygen); 3 of the 6 were in the Albemarle-Pamlico Estuarine System (Chowan, Neuse, and Pamlico rivers).

Hypoxia is of concern to fishery managers and to commercial fishermen because it is frequently responsible for fish and crab kills in the estuaries. Low oxygen conditions often impact commercial fishermen who harvest blue crabs with pots, sometimes killing substantial numbers of individuals captured in the devices. 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 is usually higher; another is fishing the pots more frequently. Hypoxia also sometimes causes substantial mortalities of benthos, some of which are commercially valuable, such as oysters (*Crassostrea virginica*). Hypoxia can contribute to changes in fisheries ecology, such as in the Neuse River, where low oxygen conditions appeared 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 may possibly contribute to 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 through changing their temporal and spatial trends, such as noted in Chesapeake Bay by Officer et al. (1984). A major hypoxia 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 habitats of fish and shellfish through water quality changes has also impacted 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 rates into primary nursery areas. The increased freshwater discharges are a result of large scale land clearing 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 impacted utilization of these areas by economically important juvenile finfish and crustaceans (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 may also have impacted striped bass spawning success and critical nursery areas in the Roanoke River (H. Johnson, DMF, personal communication).

Fisheries

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 virtual disappearance of these valuable grass beds in the Albemarle-Pamlico Estuarine System are thought to be due to changes in water quality (Rader In Press), as has been noted for grass beds in Chesapeake Bay (Orth and Moore 1984).

Closures of productive shellfishing waters due to contamination with fecal organisms 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, those areas provide oysters and clams for consumption as raw products, a very valuable product. While the total amount of estuarine acreage closed to shellfishing in North Carolina has generally remained constant since 1980 (approximately 320,000 acres), the reasons for closures have varied. Since 1980 shellfish closures due to runoff from agriculture and urban/residential development have increased (Rader In Press). Closures due to fecal contamination from marinas have also increased (G. Gilbert, Shellfish Sanitation, personal communication). As development expands and the Coastal Plain becomes more populous, the amount of shellfishing areas closed to fecal contamination will likely increase under present management guidelines. The present acreage of closed shellfishing waters in the counties surrounding the Albemarle-Pamlico Estuarine System that have historically supported oyster fisheries include (as of July 1989): 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. Toxics 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 agriculture and silviculture.

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, ECU, Unpublished Data). 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. Significant levels of pesticides have been found in both the Tar-Pamlico and Neuse rivers (North Carolina Division of Environmental Management 1986). Significant quantities of dioxin have been found in fish near industrial discharges located along one tributary of Albemarle Sound and along the Neuse River (DEM Unpublished Data).

Toxics may affect fisheries production both directly by impacting fish stocks and indirectly through impacts to the aquatic environment. Toxics can kill fish acutely and also chronically through deleterious effects on basic life history functions such as reproduction and feeding. High levels of toxics in fish can make them unmarketable. Toxics are thought to lead to environmental stress in fish which may result in tumors and ulcer diseases (Malins et al. 1984). Toxics also can have sublethal effects on fish such as affecting 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

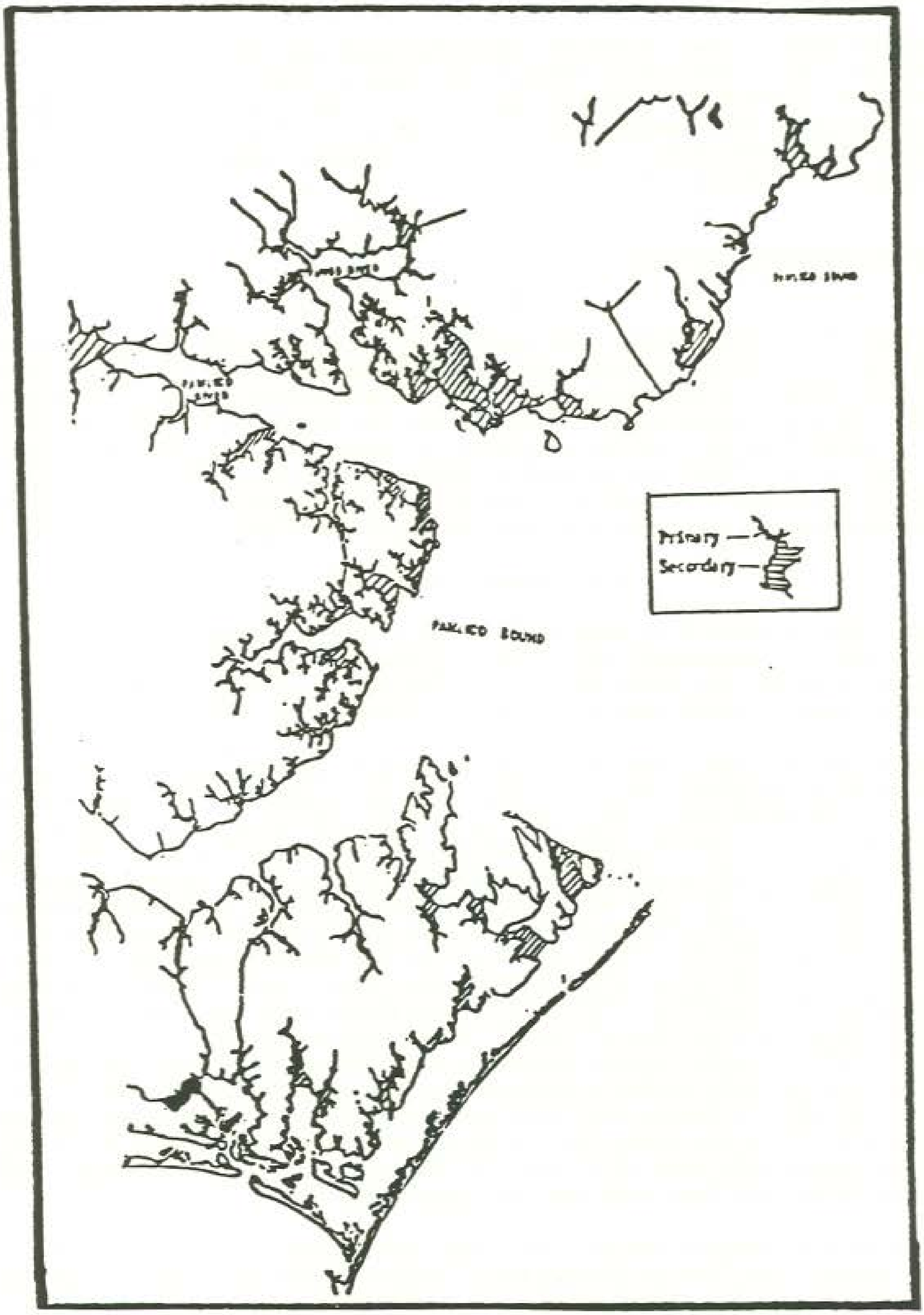

Figure IV-2. Designated Primary and Secondary Nursery Areas, Albemarle-Pamlico Estuarine System. (DMF) several finfish resources along the Atlantic coast (Schaaf et al. 1987; Summers et al. 1987; Polgar et al. 1985). The ability to distinguish the effects of anthropogenic impacts from other factors, such as overfishing, 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 also for other areas of North Carolina and the Atlantic Coast. Although all areas in the estuarine system are extremely 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 the 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 where postlarval and 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 embayments around the sounds and rivers. These creeks are usually shallow in depth, and the bottom type is soft detrital matter. These areas are generally bordered by marsh. Larvae arrive in these areas from oceanic spawning grounds throughout the year, depending on individual species life histories. However, most species enter nursery areas during the winter and spring. Larval transport mechanisms for 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 organisms are large enough to emigrate to the secondary nursery areas. Primary nursery areas in North Carolina were first defined and identified by MFC regulations in 1977. Approximately 19,000 acres of primary areas are defined and officially designated in the Albemarle-Pamlico Estuarine System. 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. Numerous fisheries surveys have been conducted in the estuarine system, many aimed specifically at characterizing the organisms utilizing 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).

Those areas immediately downstream from primary nursery areas are considered to be Secondary Nursery Areas. They are generally larger, deeper bodies of water which contain high numbers of mixed sizes of organisms. Most juvenile organisms leave the primaries during the summer, occupying the secondaries until they migrate offshore with declining temperatures in the fall. As seen in Table IV-4, the species composition in the secondary nursery areas is similar to the

Table IV-3. Species Composition of Primary Nursery Area Trawl Survey, Albemarle-Pamlico Estuaries, 1988 (N.C. Division of Marine Fisheries).

Common name	Species	Total Number
Spot	*Leiostomus xanthurus*	118,891
Bay anchovy	*Anchoa mitchilli*	58,364
Arrow shrimp	*Tozeuma carolinense*	46,233
Atlantic croaker	*Micropogonias undulatus*	11,680
Pinfish	*Lagodon rhomboides*	10,547
Trachypenaeus shrimp	*Trachypenaeus constrictus*	9,057
Brown shrimp	*Penaeus aztecus*	6,922
Blue crab	*Callinectes sapidus*	6,401
Atlantic menhaden	*Brevoortia tyrannus*	6,280
Marsh/bayou killifish	*Fundulus confluentus/pulvereus*	5,022
Pink shrimp	*Penaeus duorarum*	3,009
Pigfish	*Orthopristis chrysoptera*	2,748
Silver perch	*Bairdiella chrysoura*	2,708
Rainwater killifish	*Lucania parva*	1,697
Flathead shrimp	*Crangon septimosa*	1,362
Southern flounder	*Paralichthys lethostigma*	1,361
Mysid shrimp	*Peracarida mysidacea mysidae*	1,237
Snapping shrimp	*Alpheus heterochaelis*	1,071
Naked goby	*Gobiosoma bosci*	775
Others		6,726

primary nursery areas. In addition, larger adult fish may be found feeding in the secondary areas. Secondary nursery areas are legally designated in a manner similar to primary nursery areas and are also shown in Figure IV-2.

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 utilizing the area include blueback herring (*Alosa aestivalis*), alewife (*Alosa pseudoharengus*), hickory shad (*Alosa mediocris*), American shad (*Alosa sapidissima*), striped bass (*Morone saxatilis*), and Atlantic sturgeon (*Acipenser oxyrhynchus*). These species utilize the major drainages around the estuarine system and especially the major rivers, including the Chowan, Roanoke, Tar, 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. 1981; 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 a major river such

Table IV-4. Species Composition of Secondary Nursery Area Trawl Survey, Albemarle-Pamlico Estuarine System, 1988 (N.C. Division of Marine Fisheries).

Common name	Species	Total number
Spot	*Leiostomus xanthurus*	248,533
Bay anchovy	*Anchoa mitchilli*	180,083
Atlantic croaker	*Micropogonias undulatus*	72,782
Blue crab	*Callinectes sapidus*	21,118
Shore shrimp	*Paleomonetes* spp.	12,963
Brown shrimp	*Penaeus aztecus*	11,214
Atlantic menhaden	*Brevoortia tyrannus*	6,819
Lesser blue crab	*Callinectes similis*	6,180
Silver perch	*Bairdiella chrysoura*	5,246
Southern flounder	*Paralichthys lethostigma*	2,422
Pinfish	*Lagodon rhomboides*	1,949
Weakfish	*Cynoscion regalis*	1,947
Mysid shrimp	*Peracarida mysidacea mysidae*	1,636
Pink shrimp	*Penaeus duorarum*	1,611
Hogchoker	*Trinectes maculatus*	1,417
Pigfish	*Orthopristis chrysoptera*	756
Flathead shrimp	*Crangon septimosa*	731
Mud crab	*Xanthidae*	719
Summer flounder	*Paralichthys dentatus*	320
Others		4,511

as the Roanoke, while blueback herring prefer flooded swamps adjacent to the river 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 (*Crassostrea virginica*) and hard clams (*Mercenaria mercenaria*) or are capable of producing oysters and clams. 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 culture in Pamlico Sound. The state worked to rehabilitate oyster areas after hurricane Ginger in 1971 (Munden 1975). These rehabilitation efforts continue as a major aspect of the state's oyster program by planting cultch material each year. Shellfish area criteria are currently being developed, and a shellfish mapping survey is being conducted by the DMF to locate specific resource areas.

Table IV-5. Landings of principal commercial species from the Albemarle Sound, Pamlico Sound, and Core Sound areas of North Carolina combined, 1972-1988 (in thousands of pounds). (DMF Data)

	SPECIES													
	River herring	Blue-fish	Cat-fish	Croaker	Flounder	Weak-fish	Amer. shad	Spot	Striped bass	White perch	Shrimp	Blue crab	Hard clam	Oys-ters
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

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 (*Argopecten irradians*) (Thayer et al. 1984; Fonseca et al. 1984; Thayer et al. 19791; 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 grass beds 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-1970's (Davis et al. 1985). SAV habitat is discussed in Chapter II.

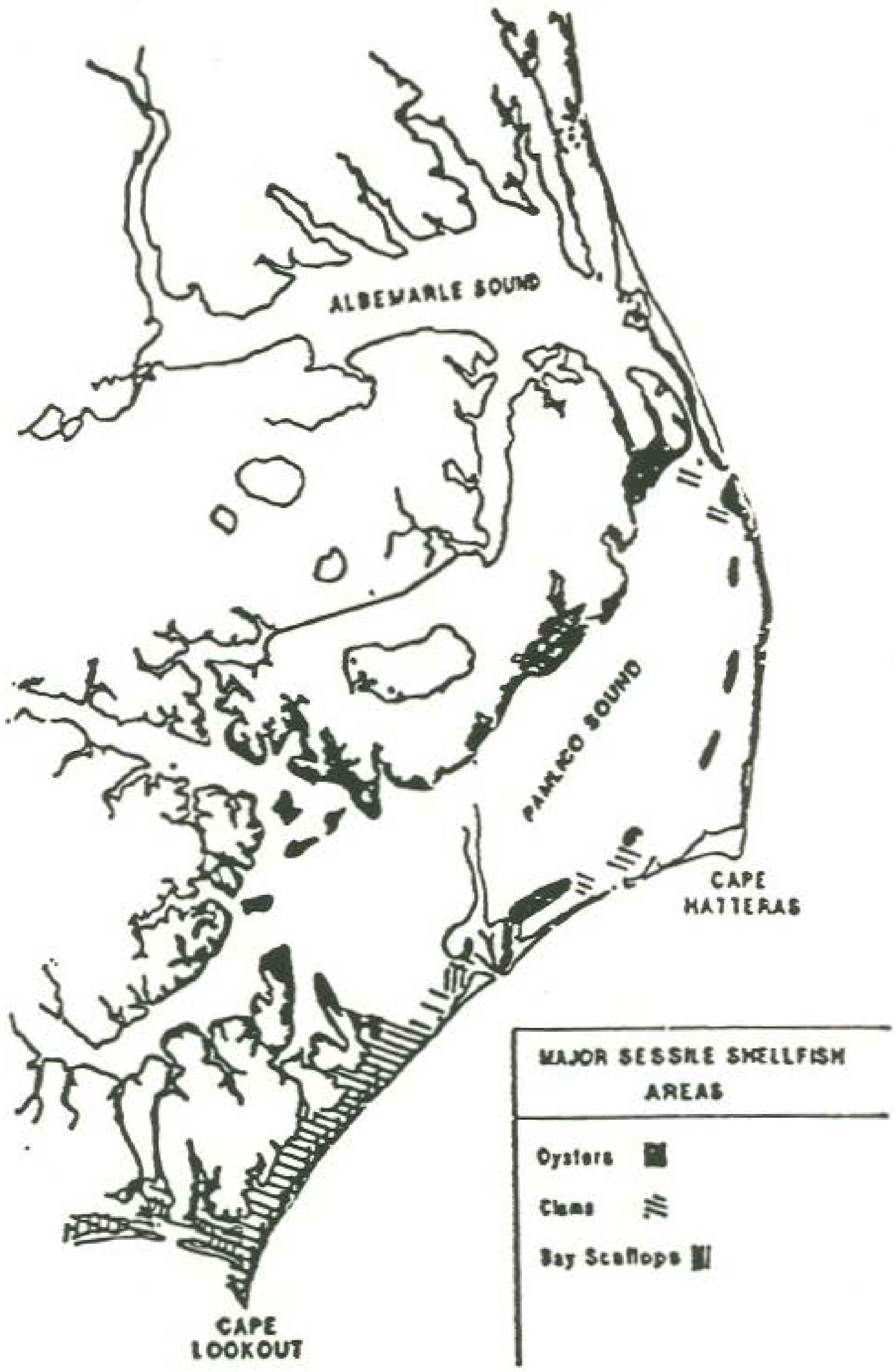

Figure IV-3. Major Shellfish Areas in the Albemarle-Pamlico Estuarine System. From Epperly and Ross (1986).

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. The value of such habitats is direct when occupied by estuarine organisms and indirect as they help maintain water quality and contribute nutrients and detritus basic to the 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*), and saltmeadow hay (*S. patens*). In addition, large areas of riverine bottomland hardwoods are found along the major rivers, especially the Chowan, Roanoke, Tar and Neuse rivers. Another important wetland type is nontidal freshwater swamps, especially in the Albemarle Sound area. Each wetland type contributes to maintaining the overall fisheries production of the estuarine system.

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, croaker, spotted seatrout, flounder, blue crabs, shrimp, and hard clams. A few species are of importance almost exclusively to commercial fishermen, including river herring, menhaden, harvestfish, and eels. Similarly, anglers have a predominant interest in a few estuarine species, including tarpon and red drum.

Commercial landings data are shown for 14 leading species for the Albemarle-Pamlico Estuarine System in Table IV-5. Data are from the DMF/NMFS cooperative statistics program. Comparable recreational data do not exist, as previously discussed. Each species is briefly discussed below.

C. 1. River Herring

Blueback herring and alewife (*Alosa aestivalis and A. pseudoharengus*), collectively known as river herring, ascend North Carolina's coastal rivers each spring to spawn in freshwater creeks and swamps. Millions of individual 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 1970's 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 (FCMA). However, landings remained depressed into the early 1980's. The fisheries in Virginia and Maryland declined along with North Carolina's and have remained severely depressed. Some recovery seemed to occur in North Carolina in 1985, but landings have declined since then to the lowest on record. 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 have combined to hinder fishing during 1986-88. The fishermen feel that adequate fish were available but were not entering the nets due to those condition (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 and 1988 was among the highest on record while catches and catch-per-unit-effort were the lowest on record. Data for 1989 indicate further decline (DMF Unpublished Data). 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 interfere with early juveniles by affecting the food chain, physically affecting individual fish with their filaments, or releasing toxins.

C. 2. 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. Most recreational catches are taken by trolling and surf casting. Abundance has been high all along the Atlantic coast since the mid-1970's, making bluefish one of the few species consistently available to all fishermen. Their wide distribution and abundance may indicate that bluefish can "co-exist" with civilization better than most other species. However, bluefish have been found to carry varying amounts of contaminants. A recent federal study of PCB's indicates that there is no general hazard to the public, although some large bluefish from various Atlantic coastal sites, including North Carolina, contained PCB concentrations exceeding the federal action level of 2 parts per million. Data from NMFS (NMFS 1987, 1988, 1989) indicate that the total recreational catch along the Atlantic coast in 1988 fell by half from the catches in 1986 and 1987. A coastwide management plan for bluefish has been prepared (Mid-Atlantic Fishery Management Council 1989) and will probably be implemented early in 1990.

C. 3. Catfish

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 1970's. Catfish are quite tolerant to degraded water quality, especially to low oxygen levels. However, they are susceptible to red sore disease, a bacterial infection prevalent in the Albemarle Sound area during the 1970's. 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. 4. 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 1970's which provided record landings during 1976-1980. 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. The ocean fisheries (gill net and fish trawls) have gradually come to dominate total croaker landings in recent years. Recent commercial landings (DMF Unpublished data) in the fisheries have come principally from long haul seines and pound nets, with few large fish. Reasons for the increase and decline in apparent croaker abundance are unknown but are probably environmental conditions in ocean spawning areas and estuarine nursery areas. Croaker spawn principally during fall-spring, and extreme winter conditions may cause mortality of eggs, larvae, or early juveniles.

C. 5. Flounder

Three species of flounder support North Carolina's most important commercial finfish fisheries, as well as very important recreational fisheries. All three species spawn in the ocean off North Carolina during the winter, and the young utilize nursery areas of the Albemarle-Pamlico complex. Summer flounder utilize the higher salinity open water shoals for nurseries, while southern flounder utilize the lower salinity creeks and bays. Summer flounder is the most important species and accounts for almost all of the oceanic catch. The harvest of southern flounder and Gulf flounder is restricted almost entirely to estuarine waters by the habits of these two species; they appear to be restricted to the estuaries and very near-shore ocean area, so they are not available to the ocean trawl fisheries. Landings of summer flounder have been nearly level along the Atlantic coast in recent years but have declined somewhat in North Carolina. Landings of southern flounder in North Carolina have not declined. A very controversial increase in the minimum size limit for flounder was implemented in North Carolina in 1988 in response to the heavy pressure on the stock and the need for conservation as well as to a federal management plan. The Albemarle-Pamlico Estuarine System is a major flounder nursery area, possibly the most important summer flounder nursery area for the entire Atlantic coast. Southern flounder has been one of the species exhibiting ulcerative mycosis infection in the Pamlico River (see section IV-G).

C. 6. Weakfish

Generally called "grey trout" in North Carolina, weakfish utilize estuarine waters for spawning and nursery areas. Commercial catches reached their peak during 1978-84, with most of the increased catch coming from the ocean. 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. Peak landings in New England have reflected increased landings further south, while weakfish virtually disappeared from New England during periods of reduced abundance further south. Landings from northern areas have fallen recently (Unpublished information, Atlantic States Marine Fisheries Commission, December 1988), while North Carolina landings have remained quite high. The historic centers of abundance appear to be Pamlico Sound and Chesapeake Bay. Reasons for the wide variations in abundance over time are unknown. Weakfish appear to be fairly delicate fish and are quite susceptible to disease; they have exhibited ulcerative mycosis infections in the Pamlico River during recent years.

C. 7. American Shad

During the early 1900's, American shad was the most important commercial 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 1930's. The lowest landings on record occurred during the mid-1970's, with some improvements during the early 1980's, and a decline since (Winslow 1989). An anadromous fish, American shad 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, as well as by industrial and municipal pollution of rivers, and overfishing of some stocks. Changed consumer habits have resulted in reduced market demand for shad, although seasonal demand remains high in some areas. Market demand has been largely replaced by recreational use in many 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, where the major commercial fisheries utilize gill nets in Pamlico and Albemarle sounds rather than in the coastal rivers. 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 worked extensively on American shad since the early 1970's but has been unable to pinpoint causes of apparent population changes.

C. 8. Spot

Spot are similar to croaker in spawning, nursery areas, distribution, and fisheries. Long haul seines in Pamlico and Core sounds constitute the principal harvest gear. Spot is usually one of the most abundant estuarine fishes of North Carolina, and is very important to recreational fishermen. Landings of spot vary widely from year to year, for unknown reasons, with a general decline in recent years. The fluctuations are probably related to environmental conditions.

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, Roanoke River-Albemarle Sound). In addition, the Atlantic coast migratory stock utilizes offshore wintering grounds which generally lie from Cape Hatteras north to the mouth of the Chesapeake Bay. The Roanoke-Albemarle population is the largest single North Carolina stock and currently supports the most important commercial and recreational fisheries. 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.

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 1970's, 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 under the guidance of the Atlantic States Marine Fisheries Commission (ASMFC), an interstate compact created by the U.S. Congress. Implementation of this plan required severe restrictions and moratoria on fishing in some areas for the past 5 years. These measures have helped the Atlantic coast migratory population to recover to the point that very restrictive fishing can begin 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 inside 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). The commercial and recreational fisheries have been supported, to some degree, by stocking of hatchery fish in 1981 and each winter since 1983. The North Carolina Division of Marine Fisheries' 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, remains extremely depressed.

An ad hoc multi-agency committee was formed to review the water flow situation and possible relationships with spawning success. This group recommended river flow changes in 1988, and juveniles were somewhat more abundant, with a juvenile abundance index (JAI) of 4.07, in contrast to the previous year's value of 0.08 (Manooch and Rulifson 1989). Unfortunately, full implementation of the committee's recommendations could not be accomplished in 1989 due to heavy rains and resulting high flows. However, the high flows were quite stable during the spawning and nursery seasons. The 1989 JAI was 4.25, the second consecutive year of improvement.

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 through Maine, under the ASMFC. The ASMFC interstate fishery management plan has recently been amended by Amendment #4, which will allow reopening of very limited fisheries, as noted above.

The U.S. 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 U.S. 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 and striped bass are sought by gill net fishermen in Albemarle Sound, leading to problems in taking striped bass as by-catch in the white perch fishery (Henry 1987, 1989). White perch spawn in the lower Roanoke River and throughout the Chowan River. 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 in recent years have been among the highest on record. 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 and pink shrimp all contribute to North Carolina's shrimp harvest, with brown shrimp supporting the major summer fishery, especially in Pamlico Sound. As an annual crop, shrimp abundance depends principally on annual environmental conditions, especially salinity and temperature in nursery areas (Hunt et al 1980; Jones and Sholar 1981). Thus, landings fluctuate widely from year to year. Especially critical for brown shrimp are nursery area conditions during April and May each year. Warm, dry weather during Spring, 1985, resulted in the largest shrimp harvest in North Carolina in 30 years. In contrast, wet conditions in the spring of 1984 produced a poor crop of brown shrimp, especially in Pamlico Sound. The contrasting situations in 1984 and 1985 demonstrate the importance of environmental conditions for commercial fishing. Recreational shrimpers probably take significant quantities of shrimp, but the amount is unknown (Pate 1977).

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. Effort and landings increased steadily since the mid-1970's, reaching all time peaks during the early 1980's, before declining through 1986. Landings returned to former levels in 1987 and 1988 (DMF 1989). Pamlico Sound is the center of the fishery, although contributions from Albemarle and Core sounds have increased. Blue crabs may not have been fully exploited prior to the rapid increase in fishing effort during the 1970's, but they probably are today, 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. As with shrimp, there are large, but unquantifiable recreational landings.

C. 13. Hard Clams

Hard clams supported a minor fishery, principally in the southern coastal area, until the extremely severe winter of 1976-77 covered all of the northern production areas with ice. Abundant stocks in Core Sound were harvested by kicking (using propeller wash to dislodge clams from the bottom so that they can be captured in a small trawl towed behind the boat) in the winter. Harvest during warm weather with hand gears also developed rapidly to supply northern markets. The same pattern continues today. Landings during the last four years have been fairly stable, suggesting that clams are fully exploited under current fishing and regulatory conditions. Demand from northern markets has driven the price steadily upward, resulting in significant regulatory and enforcement problems, especially in controlling clam harvest in areas polluted by sewage and in grass beds and oyster rocks which are productive habitats for other species (crabs, shrimp, bay scallops, oysters) in their own right. The "red tide" algae bloom of 1987-88 resulted in closure of most clam harvest areas, causing 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.

C. 14. Oysters

North Carolina possesses thousands of acres of potentially productive oyster bottoms, especially around the perimeter of Pamlico Sound. Oysters can tolerate the wide variety of conditions found in the area as long as they have the proper bottom type. The DMF annually plants about 300,000 bushels of shells in the Pamlico Sound area to serve as substrate for oysters. While fluctuating widely, oyster landings from the Pamlico Sound have generally increased in recent years, due largely to this management program. Some environmental problems are becoming more important however, such as (possibly) decreasing general salinity–some oyster rocks in western areas are no longer productive–and oxygen depletion episodes. In 1985, several hundred square miles of Neuse River, Pamlico Sound and Pamlico River bottoms were virtually devoid of oxygen for several days, resulting in reported oyster mortalities in some areas. During 1988, additional oyster mortalities were noted in the Pamlico Sound area. Resulting analysis of samples collected showed the presence of two diseases, "MSX" and "Dermo," both fatal to oysters but harmless to people. 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. The Division's oyster management activities are being adjusted to avoid spreading the diseases through transplanting. Emphasis is being placed on locating disease-free areas and planting shell in such areas to provide resources for future harvest. The Division has also established a program to monitor MSX and Dermo.

D. STATUS OF MAJOR FISHERIES

D. 1. Commercial Fisheries

The Albemarle-Pamlico Estuarine System currently yields about 62 million pounds per year of commercial landings which represents about 54% of the total North Carolina catch of edible seafood. Table IV-2 shows the catch for the three sound areas (Albemarle, Pamlico, and Core) for the 17 year period of 1972-1988. Biologically, the area probably produces far more seafood, which is harvested all along the Atlantic Coast. Tagging studies on croaker, summer flounder, and Spanish mackerel (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 accounts 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 throughout the year 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 during the spring and fall and 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. The diversity of fishing gears also greatly complicates the task of relating harvest data to actual stock abundance.

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. Long haul seines harvest limited amounts of finfish in the eastern portion of the area. 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. However, while declining, long hauls are still the single most important finfish gear in the Pamlico-Core area. Crab pots, a fixed gear, account for the highest landings of any gear in the Albemarle-Pamlico Estuarine System, especially in the Pamlico Sound area, which is 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.

The use of various fishing methods is controlled by a variety of factors, principally natural conditions. Moveable gears require large, unobstructed areas. The best areas for crab pots vary from shallow to deep water, depending on the seasonal distribution of crabs. 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 work out use of areas among themselves, although conflicts do occur.

Commercial fishermen of the Albemarle-Pamlico Estuarine System rely predominantly on five gears:long haul seine, pound net, gill net, crab pot, and shrimp trawl. These gears produce, on the 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 each gear type from each area during 1974-1988. While certain species, such as blue crabs, are important throughout, 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. Fifty percent of the hard clams in the state are harvested from Core Sound. This variation in fisheries is due to the variation in habitat types. Generally, Albemarle Sound has low salinities, Core Sound is a shallow, high salinity area, while Pamlico Sound contains broad expanses of moderate salinity. The following is a brief description of the five major fisheries (Copeland et al. 1983; Copeland et al. 1984).

D. 1. a. 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 1930's, it did not become significant until the late 1940's - early 1950's (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). The fishery occurs from May through September-October and depends primarily on brown shrimp (*Penaeus aztecus*), although pink shrimp (*P. duorarum*) and white shrimp (*P. setiferus*) are also caught. Pamlico Sound is unique among southeastern estuaries in that it consistently produces large shrimp (16-20 tails per pound or greater). 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). 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 generally 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 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 (40 ft or less) vessels which fish the entire year in Pamlico Sound, converting to oyster dredging, crab trawling, or other fisheries when they are not shrimp trawling. 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. All trawling is now prohibited by regulation in Albemarle Sound.

D. 1. b. Long Haul Seine Fishery. The long haul fishery is somewhat unique to the Albemarle-Pamlico estuarine area. It began in the Neuse River and Albemarle Sound area in the early to mid 1800's (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 utilizing engine-powered boats had become almost identical to today's practices (Higgins and Pearson 1928). The 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 and the fishermen "foot" the net while overboard. Methods of footing the net in deep water (up to 18 feet) have been developed and are now used in northern Pamlico Sound and Croatan Sound by some fishing crews. Guthrie et al. (1973) described in detail the methods used. In addition to an early study by Higgins and Pearson (1928), on-going studies by the DMF have been conducted to characterize the fishery and monitor the catch composition of the long haul fishery since the late 1970's (Sholar 1979; DeVries 1980; DeVries 1981; DeVries and Ross 1983; Ross and Moye 1989; Ross et al. 1986). The fishery generally occurs from April through October and catches primarily croaker, spot, weakfish and menhaden. A shown in Table IV-7 these 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.

Table IV-6. Total Commercial Landings for Principal Fishing Gears by Sound Area for 1974 - 1988 (in thousands of pounds). (Division of Marine Fisheries, unpublished data).

	Long haul seines			Pound nets			Gill nets			Crab pots			Shrimp Trawl		
	Albemarle	Pamlico	Core	Albemarle	Pamlico	Core	Albemarle	Pamlico	Core	Albemarle	Pamlico	Core	Albemarle	Pamlico	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	1,232	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
Mean	743	9,430	3,190	6,815	3,239	535	2,583	1,384	692	4,062	15,455	2,024	24	3,884	1,789
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

Table IV-7. Species composition and percent frequency of occurrence for the long haul seine fishery, Albemarle and Pamlico Estuaries, North Carolina, 1987 (adapted from Ross and Moye 1989).

Common name	Species	Total number	% of total	% Freq. of occur
Atlantic croaker	*Micropogonias undulatus*	962,604	36.1	94.5
Spot	*Leiostomus xanthurus*	752,636	28.2	100.0
Weakfish	*Cynoscion regalis*	308,851	11.6	92.7
Atlantic menhaden	*Brevoortia tyrannus*	305,175	11.5	61.8
Pinfish	*Lagodon rhomboides*	168,401	6.3	72.7
Silver perch	*Bairdiella chrysouara*	44,872	1.7	57.3
Pigfish	*Orthopristis chrysoptera*	38,373	1.4	63.6
Bluefish	*Pomatomus saltatrix*	24,915	0.9	78.2
Southern kingfish	*Menticirrhus americanus*	12,084	0.5	50.9
Spotted seatrout	*Cynoscion nebulosus*	7,997	0.3	56.4
Lookdown	*Selene vomer*	4,791	0.2	17.3
Atlantic thread herring	*Opisthonema oglinum*	3,211	0.1	10.0
Blue crab	*Callinectes sapidus*	3,674	0.1	63.6
Crevalla jack	*Caranx hippos*	2,665	0.1	10.9
Founder	*Citharichthys spp.*	2,363	0.1	1.8
Harvestfish	*Peprilus alepidotus*	2,302	0.1	24.5
Southern flounder	*Paralichthys lethostigma*	2,241	0.1	35.5
Summer flounder	*Paralichthys dentatus*	2,018	0.1	28.2
Atlantic spadefish	*Chaetodipterus faber*	1,806	0.1	7.3
Butterfish	*Peprilus triacanthus*	1,574	0.1	10.9
Others		12,338	0.5	

D. 1. c. Pound Net Fisheries. Pound nets are large stationary devices which lead and trap fish. Modified forms of pound nets using 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 and during different seasons to catch different species of fish.

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 et al. 1989; Winslow et al. 1983, 1985). This fishery is directed toward adult river herring migrating to the 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 with about 11 million pounds landed in 1985 compared to 3 million pounds in 1988 (Table IV-6). In addition, 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. Relatively few summer flounder are caught in the pound net fishery, although they are the major species caught in North Carolina, primarily in the ocean during the winter.

The third pound net fishery occurs in the deeper waters of Pamlico Sound during the warmer months. This fishery primarily targets estuarine migratory species, including croaker, spot, and weakfish. Numerous other species are also taken, including menhaden, bluefish (*Pomatomus saltatrix*), harvestfish (*Peprilus alepidotus*), Spanish mackerel (*Scomberomorus maculatus*), and butterfish (*Peprilus triacanthus*) (Higgins and Pearson 1928; Ross and Moye 1989; Ross et al. 1986; Sholar 1979).

<u>D. 1. d. Gill Net Fisheries.</u> 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

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

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. Large numbers of gill nets are also used by recreational fishermen to catch fish for home consumption.

D. 1. 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, and total value. The Albemarle-Pamlico Estuarine System produces about 96% of the blue crabs caught in the state, averaging over 25 million pounds per year. Pots catch around 90% of the crabs landed. Current estimates indicate that about 535,000 pots are in use (DMF unpublished data).

Various studies have been conducted on the biology, fishery, 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.

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 (river herring salting and canning, flounder filleting, oyster shucking) are included in these figures, the majority of the value is attributable to blue crab processing.

D. 1. f. Other Commercial Fisheries. Many other commercial fisheries are also conducted in the area,including the oyster dredge fishery, bay scallop dredge fishery, and 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 clam kicking (Taylor et al. 1985). This fishery utilizes the wash from propellers and heavy trawls to catch buried hard clams, as described by Guthrie and Lewis (1982). In addition, clams are caught with a variety of other gears in the Core Sound area including rakes, tongs, bull rakes, and hydraulic dredges.

D. 2. 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, the recreational fishery harvest probably exceeds the commercial harvest. Some of these species are bluefish, spotted seatrout, red drum, and Spanish mackerel.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, summer flounder, pinfish, weakfish, spot, spotted seatrout and bluefish) comprised 81% of

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	*Micropogonias undulatus*	3578	814	1124	428	964	94	154
Pigfish	*Orthopristis chrysoptera*	1345	20	29	152	47	245	852
Flounder, summer	*Paralichthys dentatus*	925	119	44	312	423	1	26
Pinfish	*Lagodon rhomboides*	552			40	5	435	72
Weakfish	*Cynoscion regalis*	529	64	85	17	234	8	121
Spot	*Leiostomus xanthurus*	468	1	10	140	200	20	97
Seatrout, spotted	*Cynoscion nebulosus*	408	2	40	20	142	42	162
Bluefish	*Pomatomus saltatrix*	326		24	93	142	26	41
Lizardfish, inshore	*Synodus foetens*	273			211	4	57	1
Mullet, striped	*Mugil cephalus*	268			9	247	7	5
Sea Bass, black	*Centropristis striata*	190	5		80	25	68	12
Toadfish, oyster	*Opsanus tau*	133	20		67		42	4
Sheepshead	*Archosargus probatocephalus*	105		3			15	87
Drum, red	*Sciaenops ocellatus*	105			14	28	31	32
Killifish, striped	*Fundulus majalis*	98			30	68		
Puffer, northern	*Sphoeroides maculatus*	89			33	10	21	25
Kingfish, southern	*Menticirrhus americanus*	71	7	6	1	36		21
Kingfish, northern	*Menticirrhus saxatilis*	69				2		67
Skates	Rajidae	64	47		15		2	
Mackerel, Spanish	*Scomberomorous maculatus*	54			2	8	1	43
Flounder, southern	*Paralichthys lethostigma*	52		3	5	44		
Bass, striped	*Morone saxatilis*	43	32	11				
Searobins	*Triglidae*	43			8		32	3
Perch, silver	*Bairdiella chrysoura*	38		7	6	4	3	18
Flounder, lefteyed	Bothidae	38			5		21	12
Searobin, northern	*Prionotus carolinus*	25			22	1	2	
Sharks	Squaliformes	20	3		5		12	
Stargazer, southern	*Astroscopus y-graecum*	14	2		12			
Toadfishes	Batrachoididae	12					12	
Sunfishes	Centrarchidae	12	12					
Skate, clearnose	*Raja eglanteria*	11			11			
Puffers	Tetraodontidae	11			11			
Perch, white	*Morone americana*	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.

the total catch (Table IV-9). In addition to recreational hook-and-line fishing, pleasure fishermen also utilize commercial equipment to catch a variety of finfish and shellfish for personal consumption. These gears include gill nets, pots, and shrimp trawls as well as hand methods 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 is limited, they are thought to take substantial numbers of finfish, as well as blue crabs, oysters, clams, shrimp, and scallops utilizing 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.

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 1580's (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 1880's (Godwin et al. 1971). Long haul seines have been used in North Carolina since the early 1800's (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 1950's and became the dominant gear by 1959 (Chestnut and Davis 1975). Use of vessel propeller wash to dislodge hard clams so they can be caught by a heavily weighted trawl towed behind the boat is known as "clam-kicking" in North Carolina. The method began in the 1940's and changed little until the late 1960's-early 1970's (Guthrie and Lewis 1982) when a number of innovations were implemented. Hydraulic escalator dredges are also used to harvest clams. 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 impacts. Channel net anchors are similarly benign. Pound net stakes have a one-time impact during the setting procedure, with negligible habitat impact thereafter. Hand rakes and tongs used to harvest oysters and clams dig into the bottom, stirring surficial sediments. When 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.

Movable gears are generally assumed to have greater impact on the habitat than fixed gears. As a conservation practice, movable gears are banned from use by the MFC in designated primary nursery areas. For most of the gears, little or no information on impacts is available. Bay scallop dredges are toothless steel and netting devices dragged over seagrass beds to catch scallops. A leading bar prevents digging into the bottom, but considerable amounts of grass are broken loose.

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). Division of Marine Fisheries, 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

Fonseca et al. (1984) concluded that scallop dredges have a negative impact on eel grass meadows. Unfortunately, peak meat weight, peak juvenile attachment, and low seagrass biomass occur at the same time. Research is underway on the effects on juvenile bay scallops of use of scallop dredges for adult harvest.

Long haul seines herd their catch as they are pulled across the bottom. Depending on bottom type and weight of the bottom line (lead line) of the seine, this gear probably has a minor effect on the bottom. In grass beds, some damage undoubtedly occurs. To the degree that the seine digs

Table IV-11. Numbers of Licensed North Carolina Commercial Fishing Vessels by License Categories, 1980-1988. (DMF)

Year	Full-time vessels	Part-time vessels	Pleasure and hire vessels	Total 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

into the bottom and/or catches grass, additional energy must be expended to haul the net, costing the fishermen time and money. However, to retain the catch, the lead line must 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.

North Carolina is the only state which allows the use of clam kicking rigs. 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 in the bottom of varying depths and widths, so their use is strictly regulated by the MFC, with limited areas available during the winter (December-March). Physical effects on the bottom and its infauna are probably similar to that of kicking (Peterson et al. 1987) but may not 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-1970's. 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 been similar each season to that at the opening of earlier seasons. Thus, recruitment of hard clams does not seem to be hurt. This area is quite unique, with depths of 12-18 ft, which are beyond the harvest ability of all existing clam harvest gears in North Carolina other than the largest hydraulic dredges. No research has been conducted on the effects of the fishery on the habitat in this area.

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 in such an open area, use of hand gears, such as tongs or bull rakes (used in Chesapeake Bay and New England in depths much greater than those in Core Sound), is extremely difficult, if not impossible. Thus, if the clams are to be harvested in much of Core Sound, mechanical harvest gear is necessary. 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). However, illegal harvest occurs 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 impact 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 1970's, 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 with present conditions ("before and after") 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. The funnel-shaped net is held open by "doors" or "otter boards" on either side of the net. Water pressure spreads the doors which are attached to the leading edge of the 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 so they will 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 probable turbidity effect. Throughout the 1980's, North Carolina shrimp trawlers have converted their rigs from one or two large nets to multiple (up to six) small nets, which are believed to take less by-catch and trash, and use 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 1970's, 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 conducted during 1970-1976, trawling was prohibited in such 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 1970's. 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 closed to trawling in 1987 by the MFC. As a result of these regulations, trawling in the Albemarle-Pamlico Estuarine System is restricted to the open water areas, principally 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 that size are only rarely taken 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, richness).

F. TRENDS IN FISH STOCKS AND FISHERIES

As discussed previously, limitations in amount and quality of data greatly restrict the ability to determine actual trends in stock abundance. Trends in the fisheries can generally be determined, as long as the limits of the data are clearly understood. In addition to the limits noted in previous sections of this report, various institutional constraints exist. For various species, regulations of the North Carolina Marine Fisheries Commission directly control seasons, gear parameters, size limits, and quantity of daily harvest. Coastal Resources Commission regulations help maintain estuarine habitat and water quality. Similarly, rules promulgated by the North Carolina Environmental Management Commission 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 predominantly in the EEZ and the fisheries are subject to fishery management plans and regulations under 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 these species include menhaden, bluefish, striped bass, river herring and shads, weakfish, spotted seatrout, and red drum.

F. 1. Trends In Fish Stocks

Trends in abundance of stocks of a few species can be discussed but only in very general terms because of limitations in sampling data. The best data available are for juveniles (young-of-the-year).

F. 1. a. Trends in Juvenile Abundance. 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 various species' year class strength. Trend data are available only from the primary, anadromous, and striped bass nursery area surveys. The red drum and Pamlico/Albemarle sounds surveys have only recently been established (<3 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 m two-seam trawl, yearly since the survey's 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 10 years (1979-1988). 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 overfishing) 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 (DeVries 1985) and commercial catch-per-unit-effort data (DMF unpublished Data).

The anadromous nursery area survey provides an index on juvenile abundance of blueback herring extending back to 1972. This survey consists of 11 stations sampled monthly (June-October) using an 18.3 m 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 1986-1988 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. Currently the ASMFC, in cooperation with DMF and other states, is conducting 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. North Carolina State University (NCSU) personnel conducted the survey during 1955-1987. The DMF adapted the same methods in 1984 and conducted a comparative survey through 1987, when the NCSU survey ended. Starting in 1988, DMF has maintained the survey to continue the historic index of juvenile abundance. Sampling is conducted twice a month (July-October) at seven fixed stations in western Albemarle Sound using a 5.49 m 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 is also reflected in landings (Table IV-5). Some possible reasons for the low juvenile CPUE are (1) adult mortality became so high that recruitment was affected, (2) some factor(s) caused failure in reproduction and/or larval survival, or (3) a combination of both. The 1988 year class index was the highest in the last 12 years. Preliminary data indicate that the 1989 index may be similar to the 1988 value. It is unclear whether recovery is indicated for the future by these two years' trends in juvenile abundance.

<u>F. 1. b. Trends in Adult Abundance.</u> 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 cannot be determined with any degree of precision, except for striped bass and menhaden.

Because the database extends back to the 1950's for juveniles, 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 1950's and 1960's, 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 for 1956-1985. 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 of the 1960's through the mid-1970's.

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 come from by-catch (incidental catch) of the long

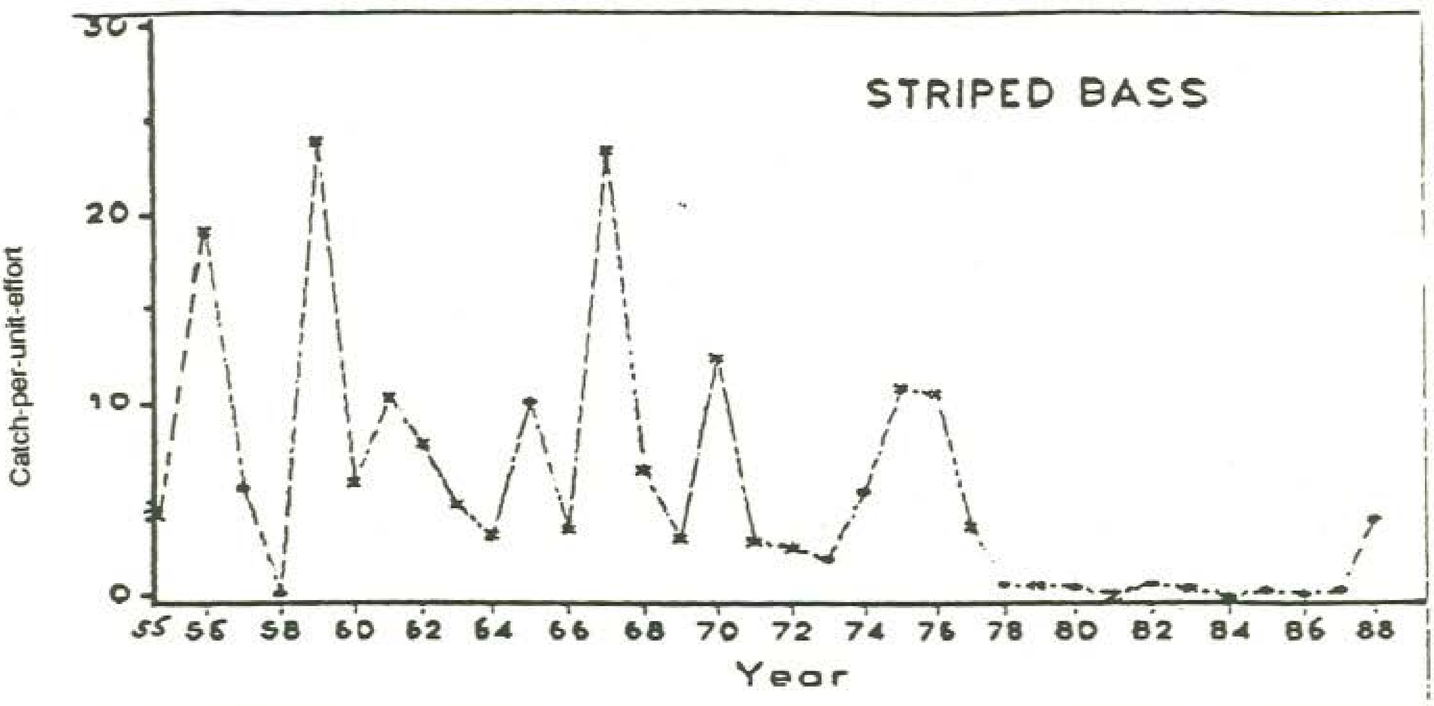

Figure IV-4. Catch-per-unit-effort for Young-of-the-year Striped Bass from Western Albemarle Sound, 1956-1988 (DMF).

haul seine and summer pound net fisheries, although some purse seine sets are made for bait. Vaughan and Smith (1987) 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 probably overfishing during the mid-1960's through the mid-1970's. Population sizes at present compare favorably with those estimated for the late 1950's.

F. 2. Fisheries Trends

Commercial landings data, when combined with biological data, can often provide general trends provided that certain assumptions are made and the limits of the data are understood.

A primary assumption is that landings data are collected in a consistent manner. Prior to 1950, the federal government collected annual landings data on a sporadic basis in North Carolina. Some state data are available, based on tax collections, a very unreliable source.Beginning in 1950, the federal government collected North Carolina landings data every year. Landings by waterbody are partially 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, contacting dealers by mail and personal visits. Coverage of certain species, areas, and seasons was obviously limited. Data for menhaden and shrimp were probably the most accurate due to their importance. Beginning in 1978, DMF and NMFS established a cooperative program with a total of six (now seven) port agents, along with support staff. Statutory authority (General Statute 113-163) exists to require all fisheries licenses to provide statistical data, but the program is conducted on a voluntary basis to foster support. Virtually all dealers are visited every month by a port agent. Interviews are conducted to collect effort data for several fisheries, either by the port agents or by DMF biologists. It is apparent that landings data have not been collected consistently in North Carolina since the 1880's, but data collected since 1978 are consistent for virtually all species and fisheries. For some species (menhaden, shrimp, probably a few others), data collected prior to 1978 may also be used with confidence. For most species, use of pre-1978 data for other than examining gross changes must be done cautiously.

Another assumption concerns species identification. The statistics category "flounder," as published, includes 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." Based on biological sampling of catches, which continues to the present, DMF persuaded NMFS to list flounder by "market species" starting in 1979. "Fluke" includes the three species discussed earlier in this report. Summer flounder is the predominant species, and when the DMF sampling data were accepted by NMFS, it was discovered that more summer flounder were landed commercially in North Carolina than in any other state. Similarly, 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.

Another assumption concerns the breadth of coverage, especially geographically, and for highly seasonal species such as anadromous fishes. Obviously, seven port agents can cover the coast more thoroughly than one or two. Some gaps probably still exist due to the myriad of isolated fishing and landing areas. In order to improve the quality of landings data (commercial and recreational) Street and Phalen (In Press) have recommended several changes in fisheries licensing and data collection.

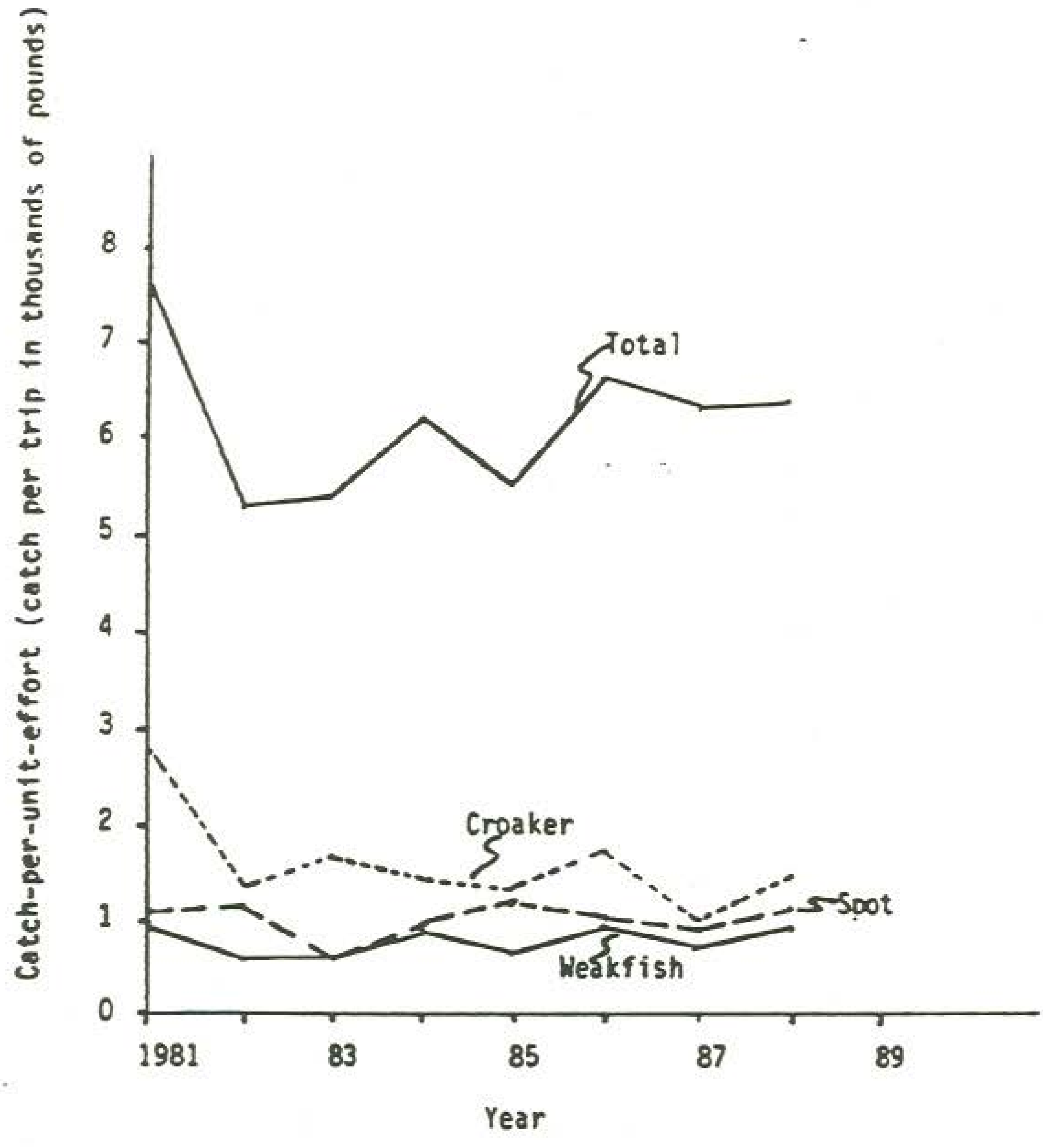

Figure IV-5. Catch-per-unit-effort (CPUE) for North Carolina's Long Haul Seine Fishery (DMF).

The vast majority of the Division'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. The existing approach requires that DMF do its sampling, to the maximum extent possible, before fishermen cull their catches. This approach is generally possible. 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 (prices,

F. 2. a. Trawl Fishery. Trawling is illegal in Albemarle Sound, and 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. The shrimp fleet was severely hurt in 1978 when a combination of the severe winter of 1977-78 and cool, wet weather in spring 1978 greatly reduced production of all three species of shrimp. Up to that time, larger vessels were entering the fleet. Since then, a number of fishermen have "traded down" to smaller vessels. Pamlico Sound landings in 1985 were the highest since the 1950's, but have fallen since that peak in response to annual variations in environmental conditions.

F. 2. b. Long Haul Seine Fishery This fishery peaked during the 1977-1983 period when about 50-60 different crews made landings. The harvest declined during the period from an average of 17 million pounds annually during 1977-1983 to about 9.5 million pounds annually during 1984-1988. The number of fishing crews was down to fewer than 30 by 1987-88 (West 1989). Probable reasons for the decline are complex but include competition with fixed gear (crab pots and pound nets) for space and apparent reduced availability of target species. As noted earlier, stocks of several important species probably peaked during the late 1970's-early 1980's, and several of these species (croaker, weakfish, spot) are important to the long haul fishery. Use of crab pots and pound nets during the spring-fall has grown in the Pamlico Sound area, eliminating some long haul areas. Occurrence of diseases in fish, especially croaker and weakfish, may have affected the fishery, as well. The Pamlico River is the area most impacted by fish diseases, and long haul fishing in the area has declined sharply.

Spot is a mainstay of the long haul fishery in southern Pamlico Sound and Core Sound. Total landings of this species have declined from about 7 million pounds annually during 1979 and 1980 to the 3 million pound range at present (Ross and Moye 1989). Juvenile abundance data show no trend corresponding to the greatly reduced commercial landings. The reason for the decline in landings of spot is not evident. Examination of CPUE data for the 1981-1988 period reveals no statistically significant trend for the fishery as a whole or for spot, croaker, or weakfish (Figure IV-5). The lower number of crews fishing at present are landing about as much as individual crews were landing in the early 1980's. Reduced landings may be due, at least in part, to reduced fishing effort.

F. 2. c. Pound Net Fisheries. The pound net fishery for river herring in the Chowan River has experienced greatly reduced catches since its peak in the late 1960's-early 1970's (Street 1988). Division of Marine Fisheries data (unpublished) indicate that landings in 1989 were the lowest on record. Area fishermen maintained that fish were available during 1986-88 but that weather and conditions hurt the fishery (Winslow 1989). Juvenile abundance data indicate considerable variability during 1972-1988, with poor year classes during 1986-1988. 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.

The flounder pound net fishery in the fall has experienced fairly stable to increased landings in recent years (DMF Unpublished Data). This fishery depends on southern flounder, a different species from that comprising the bulk of landings from the ocean during the winter. A monitoring program for this fishery will begin 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 which can release undersize flounder, reducing waste.

The summer pound net fishery in Pamlico Sound harvests many of the same species as the long haul seine fishery and has probably displaced that fishery to some degree, both physically and in landings, for its harvest has increased as pound net landings have fallen in recent years (Table IV-6).

F. 2. d. Gill Net Fisheries. Gill nets are set in much of the Albemarle-Pamlico Estuarine System without direction at a specific target species, especially during the summer when much of the effort is by recreational fishermen. The fishery is most directed in Albemarle Sound during the fall for white perch, winter for striped bass, and spring for American shad. Directed shad 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).

F. 2. e. Crab Pot Fishery. 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 1960's, reduced landings during 1971-1977, record landings each year for 1978-1982, decline through 1986, and during 1987-88 to levels of the record period. Effort data are poor, both in actual numbers of pots and effectiveness of individual pots. Estimates of the number of pots provided voluntarily by fishermen on their vessel license applications and through Division's statistics program's annual operating units survey vary widely. Frequency of lifting pots varies among fishermen. Many crabbers work on a part-time or seasonal basis. Regardless of the precise numbers of crab pots in use, there are probably more than enough to harvest the available stock. During 1980-82, DMF personnel tagged several thousand blue crabs in various tributaries of 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, with very few egg-bearing females. This situation is due to the biology of the species; males stay in low salinity areas, while females migrate to the inlets to spawn extending their 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. However, sponge crabs have negative impacts on crab processors since they purchase crabs by weight: the dealers get no return for the weight of the egg masses they purchase. In addition, the meat of egg-bearing females is of relatively poor quality compared 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 1970's, to the highest landings annually since 1986. This increase is probably attributable to two factors: 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 influenced some fishermen to change from fish 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. However, conflicts will likely increase, as the presence of crab pots interferes with moveable gears (long haul seines and trawls) and, increasingly, recreational boating (sailing and water skiing).

F. 3. 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 trends.

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 1970's-early 1980's and have since declined. Reasons for the peak and decline are unknown.

2. Landings of anadromous fishes (fish which spawn in freshwater but spend most of their life in salt water--striped bass, American shad, river herring) have declined since the early 1970's, or before. The American shad situation may be due to habitat degradation. River herring initially declined because of excessive catches by foreign vessels in the ocean, but recovery has probably been impacted 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 seems to have improved in 1988 and 1989 (preliminary data).

3. In particular, continued failure of Roanoke River striped bass to recover could necessitate drastic fisheries restrictions affecting other Albemarle Sound fisheries which take striped bass only incidentally to other target species.

4. Landings of blue crabs, North Carolina's most important commercial species, reached peak levels in the early 1980's, declined, and have again increased. Factors controlling abundance are unknown.

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. The red tide of 1987-88 may have affected stock size for the short term, but no information exists to clarify this point.

6. Oyster landings are highly dependent on state management efforts, and landings appear to gradually respond to such efforts. However, two serious diseases recently discovered in North Carolina oysters may affect resource abundance for a number of years to come. State management efforts must be adjusted to account for the presence of the diseases.

7. Continuation of downward trends in total commercial landings of edible finfish species at current levels of fishing intensity (assumed to be high) may indicate declining stocks. Current or increasing levels of fishing pressure on such stocks will lead to increased social conflicts among all fishermen (commercial and recreational) for access to the available resources, with resultant calls for the state to "solve" such problems. Such solutions generally have no biological basis, are usually reactions to perceived social issues, and have little or no effect on the resources.

8. Continuing stock declines, initially attributable to pollution, environmental conditions, or natural variations in abundance, will likely be magnified by fishing mortality from commercial and recreational fishermen. Such a situation will result in the need for restrictions on fishing to attempt to "solve" problems originally created by pollution or natural conditions, not by the fishermen. However, restrictions on harvesters, when biologically justified, are necessary and must be taken in concert with actions aimed at improving environmental conditions.

9. Lack of recreational fisheries data (hook and line and commercial gear) comparable to available commercial data will continue to hamper analysis and regulation of North Carolina's estuarine and marine fisheries.

G. DISEASE PROBLEMS

Very little is known of the actual consequence of disease to actual 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 is their potential impact upon the amount of biomass of the stock. 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 may be detectable, due to the wide degree of natural biological variation (Munro et al. 1983; Vaughan et al. 1986). However, it is the chronic deterioration in water quality that may affect fishery stocks most significantly; such chronic effects are 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, there may already be great harm to the population.

Second, disease is also 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 the fillet is affected, they may be totally rejected, thus excluding them from the commercial fishery, regardless of their potential human health risk. 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, which could potentially have considerable impact on a valuable recreational fishery. Such problems often become politicized. Political pressure placed on managers may be somewhat beneficial, because it focuses attention on these problems, but it can also be disadvantageous if it tends to emphasize short-term, stop-gap solutions that fail to recognize (or deal with) their 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. Neoplasia and other organ dysfunctions have been documented in fish exposed to environments contaminated with carcinogens and other toxins (Sindermann 1983). Toxin-producing phytoplankton can accumulate in the edible tissues of marine animals, especially bivalve molluscs, posing potential risk to humans if these toxins are present in edible tissues. Also, some pathogens that cause disease in fish (e.g., certain *Vibrio* bacteria) can also 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 suboptimal environmental conditions that allow a pathogen 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 are far from proven.

G. 1. Finfish Diseases

Epidemic disease was first reported in the Albemarle-Pamlico Estuarine System in the 1970's, when there were massive kills of largemouth bass (*Micropterus salmoides*), white perch (*Morone americanus*), and other species in Albemarle Sound area (Esch and Hazen 1980a). Dying fish frequently had extensive skin lesions, that at the time were referred to as "red-sore" (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 (DMF 1975).

Epidemics of red-sore disease were also reported in a number of freshwater lakes in North Carolina (Miller and Chapman 1976) and other parts of the southeastern U.S. (Esch and Hazen 1980b) during this time. 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 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* (= *Heteropolaria*). However, Huizinga et al. (1979) stated, based upon experimental infection studies, that the presence of a skin ulcer having only *Aeromonas hydrophila* should be considered as a diagnosis of "red-sore." However, the usefulness of such a criterion may be questionable, since *A. hydrophila* is probably the most common secondary invader of skin wounds in freshwater fishes. Thus, more often than not, it can be isolated from any skin wound, regardless of the true 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 *Aeromonas 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 Kjehldahl 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 South Carolina in Par Pond, a freshwater reservoir 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, a result of various stressors in the water, not only perturbs parameters of physiological stress in fish (thus increasing susceptibility to, and the occurrence of, red-sore disease), but also 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 *Aeromonas hydrophila* (Wedemeyer et al. 1976). However, their conclusions largely rested on inference rather than on definitive research. Esch and Hazen's (1980b) studies in the Albemarle drainage were 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 they 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 that they used for enumeration, Rimmler-Shotts, does not differentiate between *A. hydrophila* and Group F or EF6 vibrios (Kaper et al. 1981), 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 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). *Aeromonas 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. In Press). No other external clinical signs were present. Reports from fishermen suggested that as many as 90% of large (over 300 mm) bass 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. Stressful (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 Division of Marine Fisheries investigated lesions on southern flounder from the Pamlico and Pungo Rivers that had been captured by the estuarine winter trawl fishery. Affected individuals appeared to be predominantly in the tributaries between Blount's and Rose Bays. 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 (*Brevoortia tyrannus*). This disease was first reported in April 1984. First seen in the Pamlico River, it was soon reported from the Neuse River, New River, and Albemarle Sound, as well.

Since 1984, UM has continued to cause repeated outbreaks that in some instances has resulted in up to 100% infection rates in randomly sampled Atlantic menhaden schools in the Pamlico River (Levine et al. Submitted). In North Carolina, outbreaks are most common in the Pamlico River. The severity of epidemics in other estuaries in the state 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 infection are young-of-year (age 0) Atlantic menhaden. A similar disease has been observed on southern flounder (*Paralichthys lethostigma*), striped bass (*Morone saxatilis*), weakfish (*Cynoscion regalis*), Atlantic croaker (*Micropogonias undulatus*), spot (*Leiostomus xanthurus*), silver perch (*Bairdiella chrysurus*), gizzard shad (*Dorosoma cepedianum*), hickory shad (*Alosa mediocris*), hogchoker (*Trinectes maculatus*), pinfish (*Lagodon rhomboides*), and bluefish (*Pomatomus saltatrix*) (Noga et al. Submitted). The prevalence of skin lesions on these other species seems to be greatest during the peaks of the menhaden epidemics (Levine et al. In Prep.).

In the Pamlico River, where UM has been best studied, outbreaks exhibit a bimodal annual cycle, with peaks in disease prevalence usually occurring during April-June and again between September and November (Levine et al. Submitted). The highest prevalence rates occur in low to moderate (about 2-8 ppt) salinities. Both observations of lay observers, as well as empirical evidence from sampling surveys (Levine et al. Submitted) 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, Dykstra, Levine 1989).

Ulcerative mycosis 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, exposing 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, such lesions usually do not penetrate deeply into the body. The fish's inflammatory response to UM is also unusually severe, which 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 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 correlates with the highest prevalence of the disease in waters of low to moderate salinity. Salinity tolerance may also explain how these fungi can penetrate deep into fish tissue, which 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, Markwardt, Berkhoff 1989).

While UM is by far the most common disease affecting 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 eel (*Anguilla rostrata*) caused by the bacterium *Aeromonas salmonicida* (Noga, Dykstra, Levine 1989). 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 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). Toxic 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 juvenile trawl survey.

G. 2. Shellfish Diseases

While lesions on finfish have been most intensively studied in the Albemarle-Pamlico Estuarine System problems with shellfish have also recently been a concern. In the summer of 1987, fishermen in the Pamlico River began to report blue crabs (*Callinectes sapidus*) with shell disease (McKenna et al. 1989). 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 reported from the lesions. The most commonly isolated pathogens are chitinoclastic bacteria, belonging to the genera *Vibrio, Beneckea*, 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. 1989). However, other agents including myxobacteria, 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). This lesion is much more severe than that 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. 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. 1989).

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. (1989) 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 (*Crassostrea virginica*). During the annual DMF oyster shoal survey of fall 1988, high mortalities ("boxes") 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 also resulted in considerable mortalities of bay scallops (Summerson and Peterson In Press).

G. 3. 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 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 1970's. 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, salinities have been higher than previously in the Albemarle drainage during 1983-1988, due to the on average lesser amount of 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.

Conversely, 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, 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 have been in 1984, 1989, and possibly, 1988. Interestingly, 1984 and 1989 have been unusually wet years, resulting in depressed salinities in the Pamlico River.

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 ulcerative mycosis 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, Dykstra, Levine 1989). None of the water quality factors measured showed a correlation with UM. However, a more intensive cast net survey of UM prevalence focused on the high-risk (low salinity) area of the Pamlico River demonstrated that there was a positive correlation with both 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, Markwardt, Berkhoff 1989). 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 (DEM) were compared temporally 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. However, during or preceding three outbreaks of UM, 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, Dykstra, Levine 1989).

Fish disease does not appear to be a major problem in Core Sound, although the importance of bivalve pathogens such as MSX or *Perkinsus* 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.

G. 4. 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. However, there are several lines of evidence 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, UM overall prevalence in the Pamlico River from May 1985 to April 1987 was 15% (Levine et al. Submitted); during outbreaks, prevalence frequently exceeded 90% of sampled populations. In the Chowan River, some studies 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. 1989), 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). A 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, making 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. For example, skin ulcers 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 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. However, stressful environments increase the risk of disease.

Third, the tremendous number of affected species from diverse habitats and ecological niches indicates that some widespread environmental perturbation is present.

Fisheries

The overwhelming majority of diseases facing the fishery populations of the Albemarle-Pamlico Estuarine System have some infectious component to the disease process. 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") in polluted environments 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 (i.e., immune status) are met. The conditions responsible for this immunosuppression may not be easily determined.

If a toxin responsible for reducing immunity accumulates in host tissues, determining body burdens in affected individuals may provide clues to the cause of the problem. However, infectious diseases may also 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, it is their second and third order consequences (e.g., changes in dissolved oxygen or carbon dioxide due to eutrophication) that 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 an infectious agent to colonize a host. The need to identify those primary effects ultimately responsible makes the study very complicated.

G. 5. 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, about whether any anthropogenic factors 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 problems because distinct risk factors are associated with the development of different diseases. Once a putative pathogen(s) has (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.

Concurrently, it is 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 an unlikely scenario in the Albemarle-Pamlico Estuarine System fishery, since there are so many different agents causing lesions.

Field studies should include identification of zones of high and low risk for infection. The purpose of this step is to focus on those sites where 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.

At the same time, one must try to correlate specific water quality factors with high and low risk sites. The success of this stage 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 probable list of 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 above "normal" limits. With a myriad number 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 be dependent 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, Markwardt, Berkhoff 1989).

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. However, a direct causal relationship may not exist, and 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 and phytoplankton-produced toxins. Both have been shown to be responsible for acute mortalities of both finfish and shellfish in the Albemarle-Pamlico Estuarine System. The presence of such acute effects strongly suggests that sublethal 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. While not all the data that are desired will be acquired at once, new information should be incorporated into management plans.

Thus, adaptive management, which allows managers to proceed on the best available information and to implement corrective actions as research produces new information, should be encouraged. 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.

G. 6. 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.

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. Submitted).

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 asymptomatically on healthy skin.

* *Numerous other bacteria that have been identified from lesions and which do not appear to be primary pathogens are not included.*

H. FISHERIES MANAGEMENT ISSUES

The responsibility for regulation of the fisheries in the estuary lies with the North Carolina Marine Fisheries Commission 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 Marine Fisheries Commission and the management agency, the Division of Marine Fisheries, deal directly with fishery conflicts (people problems), as well as 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.

Regulations affect the fishermen utilizing the resource by controlling gears, seasons, areas, size limits and quantities harvested. The fisheries resources cannot be directly controlled by regulations. In addition, some enhancement efforts, such as planting oyster cultch material for spat settlement and construction of artificial fishing reefs, occur within the estuary. Most efforts of DMF involve the collection of statistical information, monitoring the various stocks, conducting needed research, and enforcing fishing regulations.

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. However, it is unclear if 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, like shrimp trawls and long haul seines. Intense utilization of an area by crab pots precludes trawlers or seines from working the same area. Often, prime fishing for conflicting gears involves the same area, resulting in conflicts over the space available to each fishery. Towed gear has been displaced in some areas by fixed gear, while fixed gear is occasionally destroyed by towed gear, creating real conflicts. 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. As utilization of the estuary increases, these conflicts will probably intensify.

User conflicts sometimes occur among different commercial harvesting sectors. 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. User conflicts will probably 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 effort and still produce economically viable harvests and quality recreational experience? Clearly, limits on the amount of gear or effort, or possibly limited entry to commercial fisheries, must be considered for the future.

A growing conflict in the area involves recreational versus commercial use. As noted earlier, recreational fishermen and commercial fishermen generally fish for the same species. Recreational interests are becoming concerned over the use of fishing methods which may negatively affect the habitat as well as large harvests by commercial fishermen. 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. Again, 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 insure fair allocation of fishing opportunities.

North Carolina's estuarine system can continue to produce resources for sport and commercial fishermen alike, but quantities and access may have to be restricted in the future. 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. In recognition of policies which maintain commercial fishing and its way of life, commercial fishermen must adopt modern technology which harvests target species and releases non-target fish. Policy-makers must seriously consider limiting entry to the commercial fisheries in order to insure (1) availability of stocks for harvest by all fishermen, (2) economic viability of commercial fishermen, (3) continued supply of seafood for consumers and (4) allocation of fishing opportunities and resources for angler. 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.

Fisheries

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 impact the habitat and/or take significant by-catches. 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). The catch by such methods is largely non-selective and can produce large amounts of by-catch if care is not taken. 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 of mortality of juveniles from fishing on overall stock levels is unknown. Towed gear sweeps the bottom suspending sediments, potentially impacting benthic organisms. Methods, such as oyster and clam dredging and clam kicking, dig directly into bottom sediments with potential impacts, especially to such habitats as seagrass meadows. Regulations of the MFC prohibit use of dredges and kicking gear in grass beds, but enforcement is extremely difficult. 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, and fishing practices will, of necessity, need to become more selective in terms of reducing by-catch.

These are a few of the major fisheries issues facing managers of the Albemarle-Pamlico Estuarine System. There are many more specific issues. An important concern 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 problems are responsible for declines in the fisheries. On the other hand, eliminating sources of pollutants throughout the 30,000 square mile watershed is 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."

I. CONCLUSIONS AND RECOMMENDATIONS

I. 1. Habitat Protection

A healthy productive habitat is absolutely essential to provide fisheries resources for use by 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 insure 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 agencies which conduct the day-to-day work of the three commissions: Division of Marine Fisheries, Division of Coastal Management, and Division of Environmental Management.

I. 2. Data Collection

Analysis of the DMF data gathering programs by Street and Phalen (In Press) 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 sounds 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 weaker at lower levels (water body) where the data are needed for analysis. Availability of commercial data in a timely fashion varies widely, due largely to technical problems in the cooperative state-federal program. Collection of effort data is improving. Fairly reliable data for the recreational fishery, on a coast-wide basis, have been collected only since 1987. The statistical design of the survey (DMF 1987) precludes rapid availability of data for management use. In addition, species encountered only rarely or taken principally in highly seasonal or temporally geographically isolated fisheries (especially for anadromous fishes) are missed by the survey.

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 sales by commercial fishermen (with copies 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.

A recreational license would provide a reliable sampling frame for the general recreational survey, as well as 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.

I. 3. Stock Status

An important weakness of the DMF, noted in the report and by Street and Phalen (In Press), is the very limited ability to conduct the sophisticated assessments needed to determine stock status. Most of the requisite data 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 staff lacks the time needed to properly analyze the data it collects, as well as the expertise to conduct sophisticated analyses, such as virtual population analysis. Data collection must not be reduced; rather, analytical staff must be added. 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.

I. 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 confrontations 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 a reasonable expectation of a quality fishing experience. Anglers must recognize that commercial fishermen must make a reasonable economic return on their investment of time and equipment in order to support their families and that consumers who cannot come to the coast to fish demand a choice of fishery products in the marketplace.

Commercial fishermen need to emphasize product quality and efficiency, eliminating 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 near and far, 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 of resource a given stock can annually produce and still remain productive. Such over-capitalized fisheries potentially endanger 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 limited entry systems for 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.

I. 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 at larger sizes and/or 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, and pots.

I. 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. Recalling again the food-producing role of commercial fishing and farming, 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.

I. 7. Aquatic Resource Education

There is no coherent program in existence to educate the citizens of North Carolina in stewardship of their coastal resources. 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, and they conduct workshops for teachers and 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 publishes 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 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.

I. 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 Division and Commission 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 (i.e., 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 (N.C. 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 (N.C. 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 nonextractive 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. Nonextractive 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 nonextractive because they do not significantly affect the quality of the resource.

Both extractive and nonextractive 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 nonextractive 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 issue that cannot be addressed with existing information would be to model the reasons why 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 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.

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.

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 nonextractive, 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.

Equally important, government policy at both the local and state level influence 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 mandated in the North Carolina Coastal Area Management Act of 1974 (CAMA) (requiring 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's 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 compose 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 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 excluding 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 or 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 (Table V-1). The remaining 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 (Table V-1). 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, 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, however, can also have costs. 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 a overview of the A/P Study area growth, 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" and "Virginia Population Projections 2000".

Permanent population for the entire A/P Study area has increased steadily 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 in population format, further trends are evident. In the period 1970 to 1980, North Carolina counties within the study area grew at a rate below the state-wide average; however, the projected growth rates for 1980 to 1990 and the following decade are expected to slightly exceed the state's growth rate. The growth rates for Virginia's A/P counties, indicate that the counties within the study area are growing at a rate much greater than the state-wide growth rate. Growth during the 1970's exceeded state-wide rates, and the projected growth for this decade is expected to exceed that of the state by over 1.5 times. Population growth is projected to slow to a rate only slightly greater than the state-wide rate during the 1990's.

During 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. During 1980 to 1990, 15 of the A/P counties areprojected to exceed state-wide growth rates, 12 of which are located in North Carolina. Six counties are projected to lose population during the 1980's. During the period 1990 to 2000, 14 counties are expected to experience growth exceeding that of the respective states, and 8 counties should 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. North Carolina's "coastline" counties are experiencing tremendous growth in permanent populations. Currituck, Dare and Carteret Counties are among the fastest growing counties in North Carolina. During the 1970's, Dare County's growth rate exceeded the state-wide rate by almost 6 times, Currituck almost 4 times, and Carteret almost doubled the state's growth rate. These trends are projected to continue during the 1980's and 1990's, although, growth rates are expected to slow. Hyde County is a coastline county, but it has grown at a rate well below that of the state and is projected to lose population during this and the succeeding decade.

Of the "sound" counties, Beaufort County grew at a rate slightly below that of the state in the 1970's, and it is projected to continue that pattern during the 1980's and the 1990's. Craven County's growth rate was below that of the state during the 1970's, but the county is expected to surpass the state's growth rate for the next two census periods.

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 1970's; however, both are projected to exceed the state's growth rate during the 1980's and the 1990's. Wake County grew at twice the state's growth rate during the 1970's, and the county is projected to almost triple the state-wide rate during the next 2 census periods. Nash County presents a very different picture. The county grew at rate below that of the state during the 1970's, and it is projected to fall below state-wide rates during the next 2 census periods. Pitt County grew at double the State's growth rate during the 1970's and is projected to exceed state-wide rates during the 1980's and 1990's. Wayne County's growth equalled the state's growth during the 1970's, but it is projected to grow at a rate well below that of the state during the 1980's and lose population during the 1990's.

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. The city's growth rate was 3.5 times greater than the state-wide growth during the 1970's. While

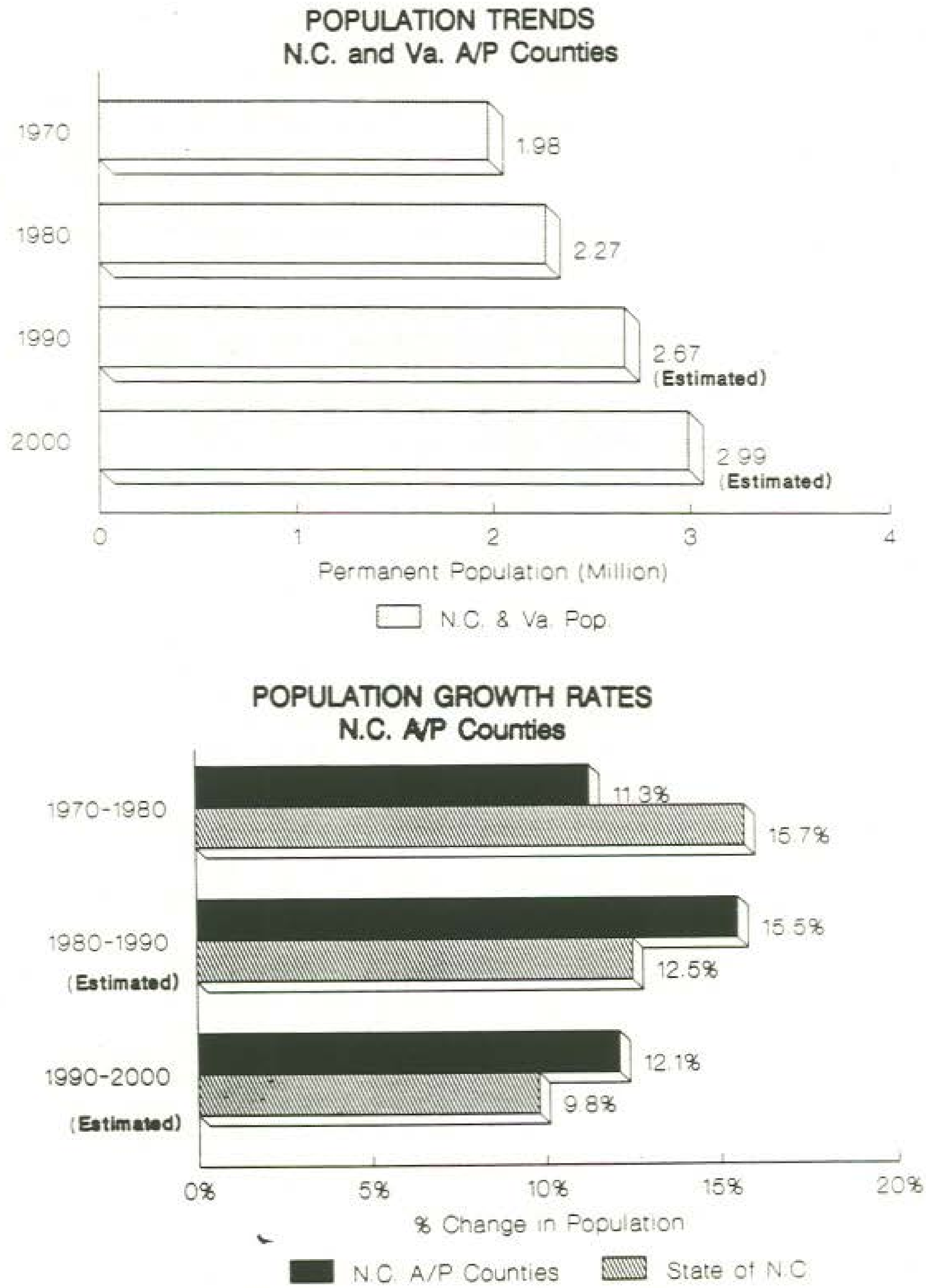

Figure V-1. Population Trends and Growth Rates: N.C. and Va. A/P Counties. From N.C. OSBM 1988; VA. DPM 1986

Virginia Beach's growth is projected to slow down, it will be double Virginia's projected growth. Southampton County lost population during the 1970's and is projected to experience little or no growth during the remainder of this century.

In summary, The A/P Study area is projected to have a population of approximately 3 million by 2000. When considering the North Carolina A/P counties as a single unit, growth rates are expected to slightly exceed state-wide levels until the year 2000. Growth rates tended to be the 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.

Both A/P counties in North Carolina and those in Virginia, are experiencing varying levels of population growth. Some of these counties are among the fastest growing counties in their respective states. North Carolina's Dare County and Virginia's Virginia Beach are experiencing growth rates that are exceeding state-wide levels by 5.5 and 3 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 and isolated, and depend heavily on 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. U.S. 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 North Carolina A/P counties' populations. 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 is the basis for the following graphical presentations. The 1987 seasonal data is 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 experience tremendous population fluctuations due to the influx of recreational residents. Dare County's population increased over 4 times that of the permanent

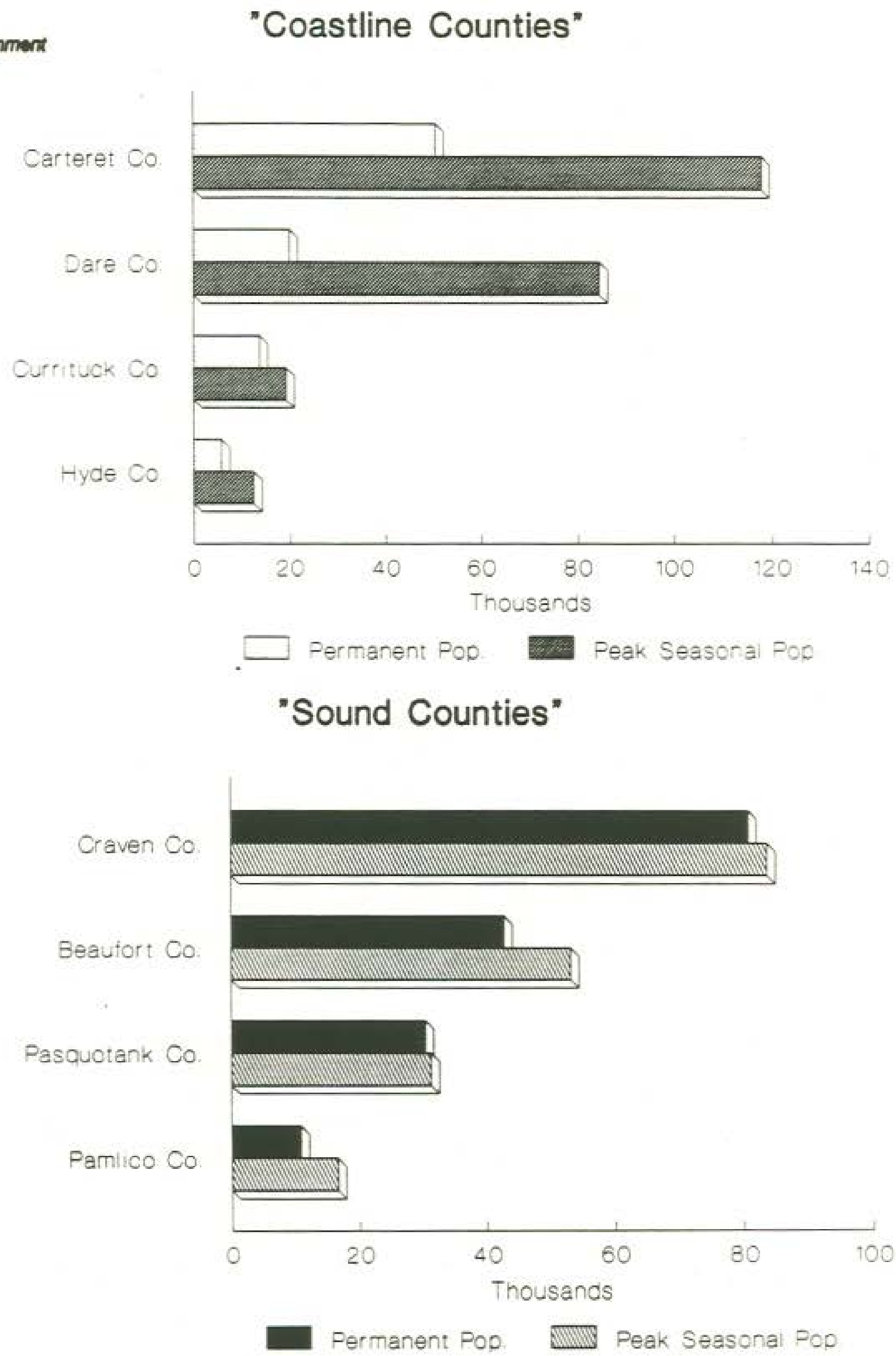

Figure V-2. Peak Seasonal vs. Permanent Population in A/P Counties. From Tschetter 1989.

population during the peak seasonal day in 1987. The other coastline counties experienced similar increases. Carteret County's population increased 2.30 times while Hyde and Currituck counties' populations increased 2.15 and 1.40 times, respectively. These estimates do not include day visitors, those recreationists who visit the area but do not stay overnight. According to a 1985 N.C. 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 a little over 3.5 times that of the permanent population. Pamlico County experienced an increase greater than 1.50 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 some of the A/P counties' populations; however, the effect varies from region to region. As one would expect, the counties that border the ocean and 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 from the onset 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 for the state for 1977-1987, excluding industrial landings (e.g., menhaden), increased from approximately $24 million to around $65 million over the 10 year period (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 1970's and early 1980's were periods of considerable inflation in the overall price level. 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.

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 estuary's 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

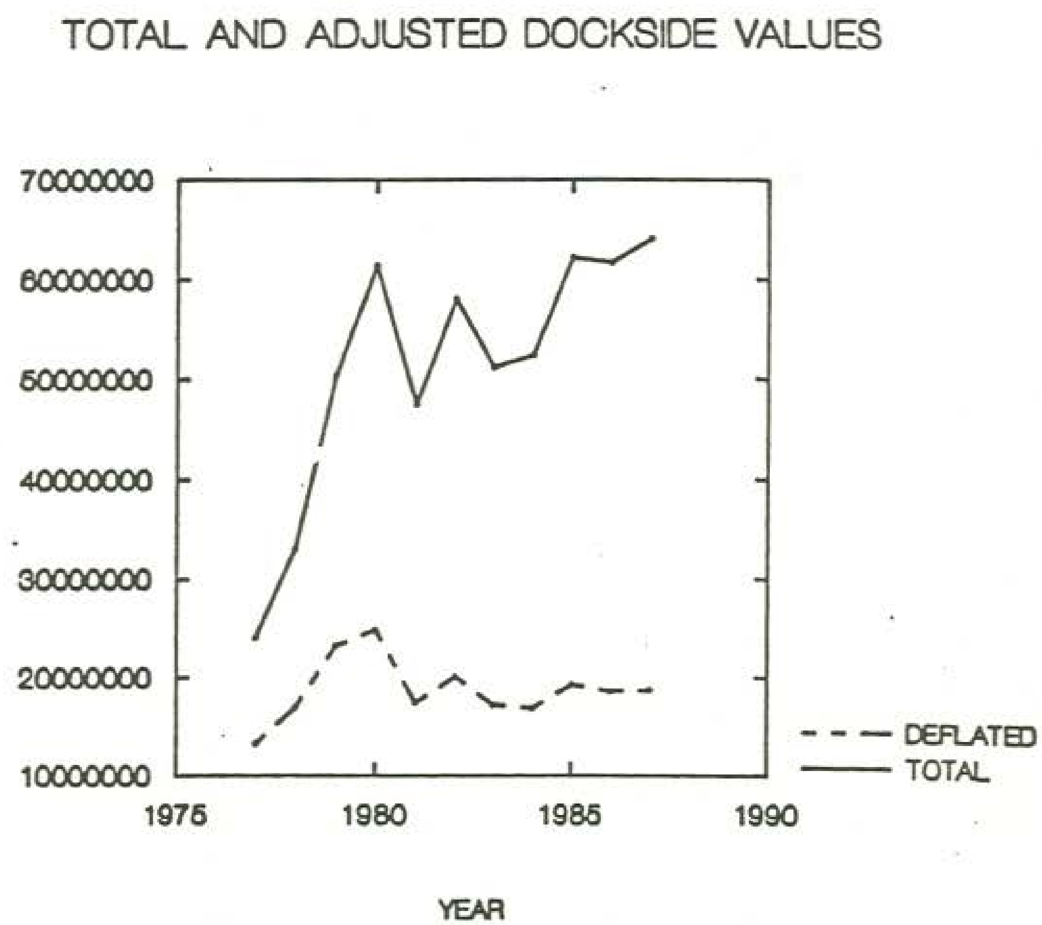

Figure V-3. Total and Adjusted (to 1977 Dollars) Annual Dockside Values for N.C. Commercial Fisheries. From Division of Marine Fisheries Data.

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.

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 are predominantly low-seasonality with low dependence on local sources of seafood, typical employer/employee relations, no direct ties between the processing and harvesting sectors, little control over processing, pay based on wages or piece work, low reliability of labor, and a primarily black work force. Such characteristics demonstrates that the bulk of the seafood processing workers in these counties are heavily reliant on processors and have few employment opportunities (e.g., family-centered commercial fishing operations, factory work).

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

Economic strategies for the households to which seafood workers belong often mix transfer payments with this low-wage labor in order to survive (Griffith 1988).

The Carteret County/Core Sound area is different from the other counties in terms of processing activities for two reasons. First, this area has the largest number of processors, particularly processors dealing in shrimp and scallops. Second, 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. Based on Griffith's categories of seafood processors, some of the dealers in the area can be characterized as having high-seasonality and dependence on local sources of seafood, with worker's relations to processors as familial or community-based, strong relations between harvesting and processing sectors, more worker control over the processed product, most being self-employed or involving unpaid family participation, and a highly reliable, primarily white, labor force.

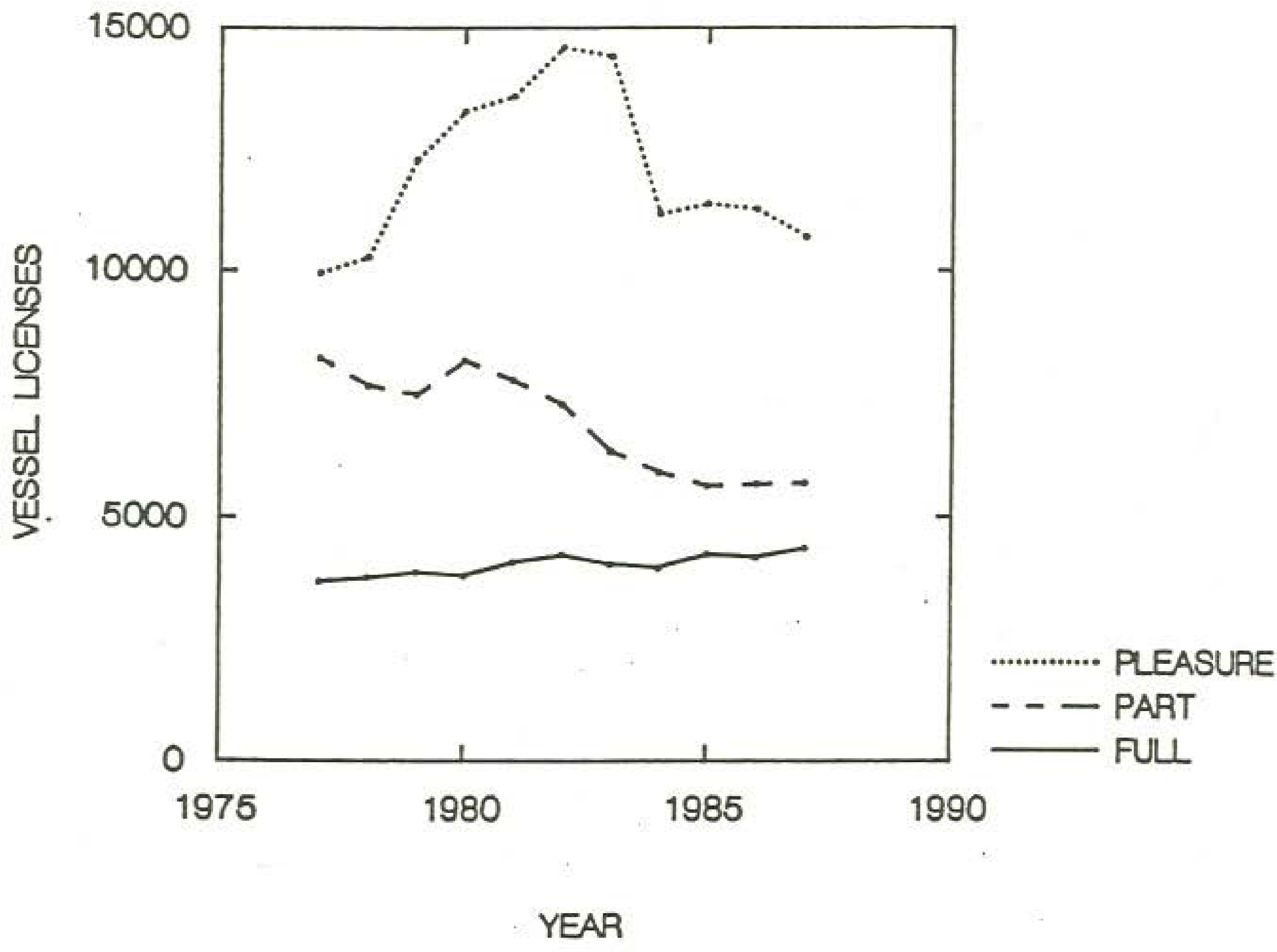

Figure V-4. Total Annual Vessel Licenses in the A/P Counties. From N.C. Division of Marine Fisheries.

Griffith (1988) also describes a third category of seafood processors found in this area that is exemplified by the menhaden processing industry. This form of processing can be characterized as moderately seasonal with some degree of local dependence on the source of seafood, conventional employer/employee relations, strong ties between harvesting and processing labor, no control over the processed products, remuneration based on wages or piece work, and 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 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 fish stock availability. They applied a modified version of the travel cost recreational demand for geographic areas within the Albemarle-Pamlico Estuarine System based on the entry points fishermen used to launch their boats into the sounds. These areas were treated as distinct recreation sites, and the demands for them were estimated using a 1981-82 intercept survey of sport fishermen sponsored by the N.C. Sea Grant Program (see Johnson et al. 1986) for a description of these data and the survey procedures. Smith and Palmquist (1989) developed estimates for the consumer surplus per fishing trip implied by the "final" models for two sites with fairly robust demand models, as well as the estimated increase in this value per trip that would be generated by a 25% improvement in the catch rate (Table V-2). Consumer surplus is the difference between what an individual would be willing to pay for using the site and what he (or she) actually pays in the form of the travel and time costs required to reach the site and the launch fee to gain access. It is the conventional measure economists use to gauge how much excess value or benefit consumers derive over what they have to pay, explicitly or implicitly, for using a good or service.

Smith and Palmquist (1989) use the estimates of the value of quality improvements to construct a benefit-quality elasticity estimate--the percentage increase in the benefits derived from a fishing trip to the Albemarle-Pamlico Estuarine System region with 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 sport fisherman derive from these experiences.

While this work offers one component of the information necessary to gauge the economic effects of nonextractive uses of the sounds, it is incomplete. It focuses on one type of fishermen does not consider other types of recreation supported by the estuary relates to a single time period

TABLE V-2: Benefit Estimates for Sport-Fishing Trips in the Albemarle-Pamlico Sounds[a]. From Smith and Palmquist (1989).

	Consumer Surplus Per Trip		Increment to Consumer Surplus Per Trip 25% Increase in Catch Rate	
Demand Model	(1982 Dollars)	(1967 Dollars)	(1982 Dollars)	(1967 Dollars)
Outer Banks Site	$163	$56	$24	$8
Pamlico Site	$103	$36	$9	$3

[a]Estimated are rounded to the nearest dollar.

and therefore offers no insight into trends fails to consider the gains (losses) nonusers experience from knowledge of improvements (deteriorations) in the quality or character of the estuary and does not provide insight into the indirect impacts of these activities on other sectors.

Some of these shortcomings can be partially remedied with information recently available from the U.S. Fish and Wildlife Service's "*1985 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation*". 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). Table V-3 highlights some of the aspects of the overall results for the 1985 saltwater fishing in North Carolina. Saltwater fishing is clearly an important recreational activity in North Carolina. Nearly 800,000 people are estimated to have participated in the activity, with over 60% of them state residents. The largest share of this activity takes place in and near coastal areas.

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. 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%, with the 22 coastal counties growing 155%. However, the bulk of this growth occurred inland (177%), or in southeastern counties. How many of these boats are used in recreational fishing, particularly in the area of Carteret County, is difficult to say. Based on the estimates of marina operators, however, Johnson and Perdue (1986) found that, on average, 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. Thus, a large percentage of the 45,926 boats registered in coastal counties in 1984 were probably used in some way for recreational fishing. When combined with the number of boats registered in inland counties near the study area (e.g, Wake County with 12,249 boats), this indicates that a large number of boats potentially have access to the study area.

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. Whereas, 28.4% of the boat fishermen interviewed were from the "sound" counties, 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

TABLE V-3. Saltwater Fishing in North Carolina in 1985[a]. From U.S. Fish and Wildlife Service.

Fishing Trips, Days of Fishing, Fishermen, Mode of Fishing	Residents	Nonresidents
Total		
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
Type of Water Used (Fishermen)		
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	---
Mode of Fishing (Fishermen)		
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

[a]Except where indicated, these statistics are in thousands of individuals.

fishermen would be estimated to come from outside this area. By contrast, bank or fixed structure fishermen came from "sound" counties (45.2%) or from the "drainage basin" counties (68.7%).

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 1970's and 1980's. 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 that support boating activities (gas, repair work, sewage pump-out stations, etc.). There have been two recent studies involving marinas, many of which are located within the A/P Study area. Taken together, these reports present a comprehensive overview of marina activities, and they are the basis of the following analysis.

There has been 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 there was a 36.6% increase in the number of boat slips. Most of this growth occurred in Carteret, Craven, Beaufort and Pamlico Counties. 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. Tschetter based this finding on two characteristics. First, all border the Albemarle and Pamlico Sounds and, second, the five counties are on the Atlantic Intracoastal Waterway (Tschetter 1989).

For the counties bordering the sounds, marinas are an important source of jobs and revenues. 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 nonresident 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 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.

C. 5. Travel and Tourism

Already one of the State's larger industries, 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 nonextractive activity. As noted 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 North Carolina's private employment, work in businesses that serve travelers directly. 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 will focus on the A/P counties' share of the total travel and tourism expenditures from 1971 to 1987. Next the 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).

The counties share of the state-wide revenues is growing. For 1982, the 36 A/P counties' share of revenues totaled over $1.1 billion (Figure V-6). The trend held for 1987 with revenues exceeding $1.8 billion (Figure V-6). Tourism provides substantial revenues to these counties; however, the financial impacts from tourism vary from county to county. Dare and Currituck Counties, both "coastline" counties, present a contrasting picture. Dare County's revenues have increased steadily since 1971, reaching $347 million in 1987. Currituck County's travel revenues have fluctuated and are well below that of its neighboring county.

The "sound" counties' tourism revenues 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. Pamlico County's revenues were well below those of other counties, although they appear to be increasing. If the recreational boating industry continues to increase, the "sound" counties' tourism revenues should also increase.

One would expect the "drainage basin" counties' tourism revenues to be well below those of the traditional recreational areas such as Dare and Currituck Counties. This analysis, however, does not support that assumption. Wake County's travel revenues have risen steadily, equalling $450 million during 1987. Although these revenues do not represent the substantial per capita share as

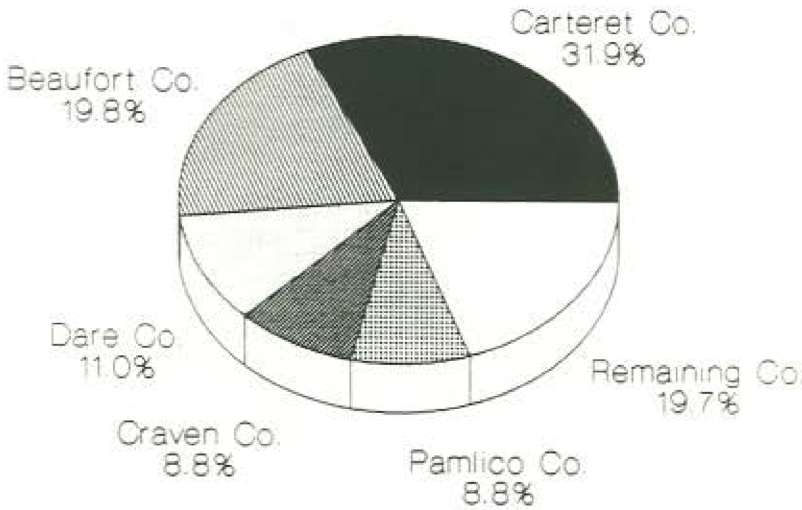

Figure V-5. Distribution by County (1987) of Marinas in the A/P Study Area. From Tschetter (1989).

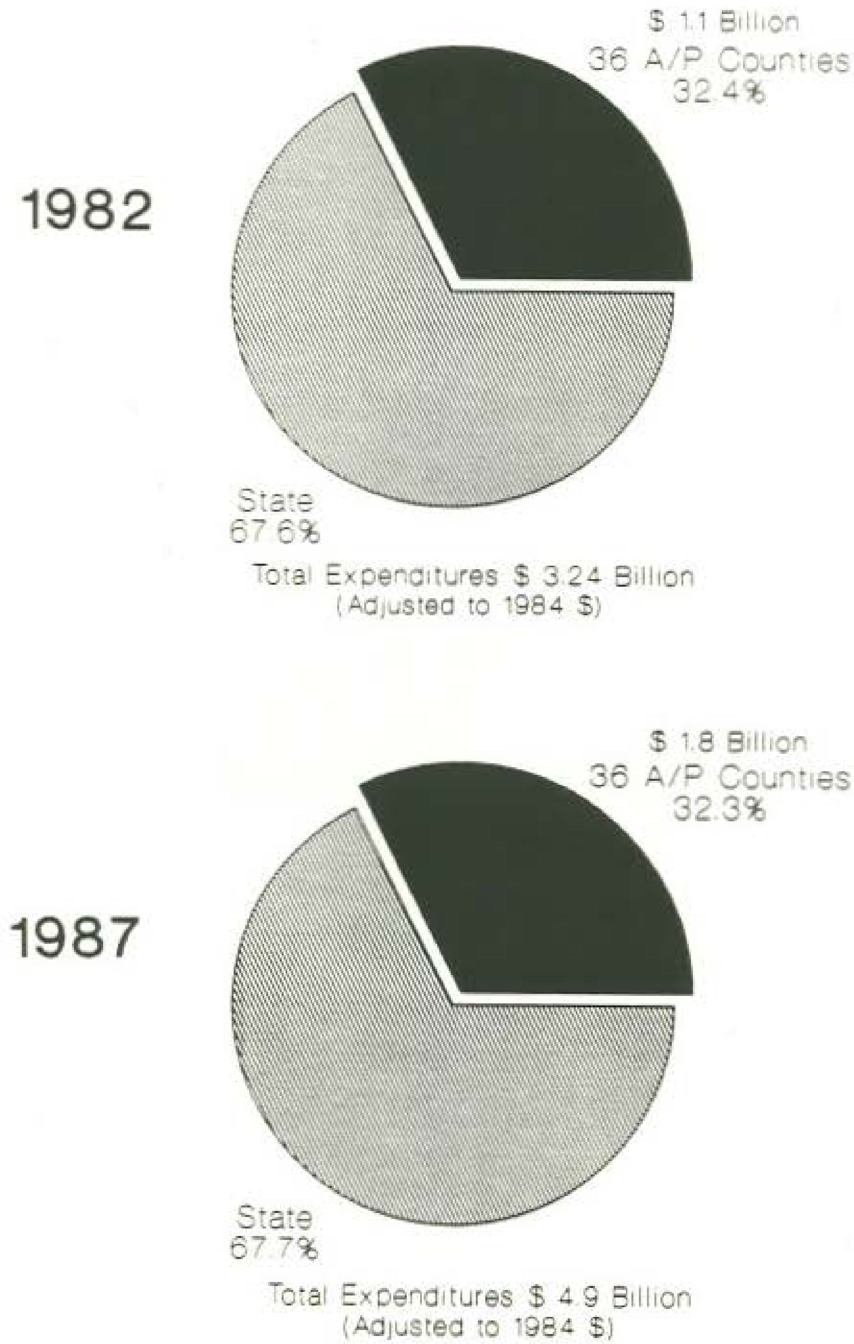

Figure V-6. Travel and Tourism Expenditures in N.C. A/P counties, 1982 vs. 1987. From N.C. Travel and Tourism (1983, 1988).

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 A/P counties' share of these revenues 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 usages. 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. This analysis will consist of two components.

The first is an attempt to develop measures 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.

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. For these uses, physical measures of trends in these activities were developed. 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 it deals with other factors besides 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

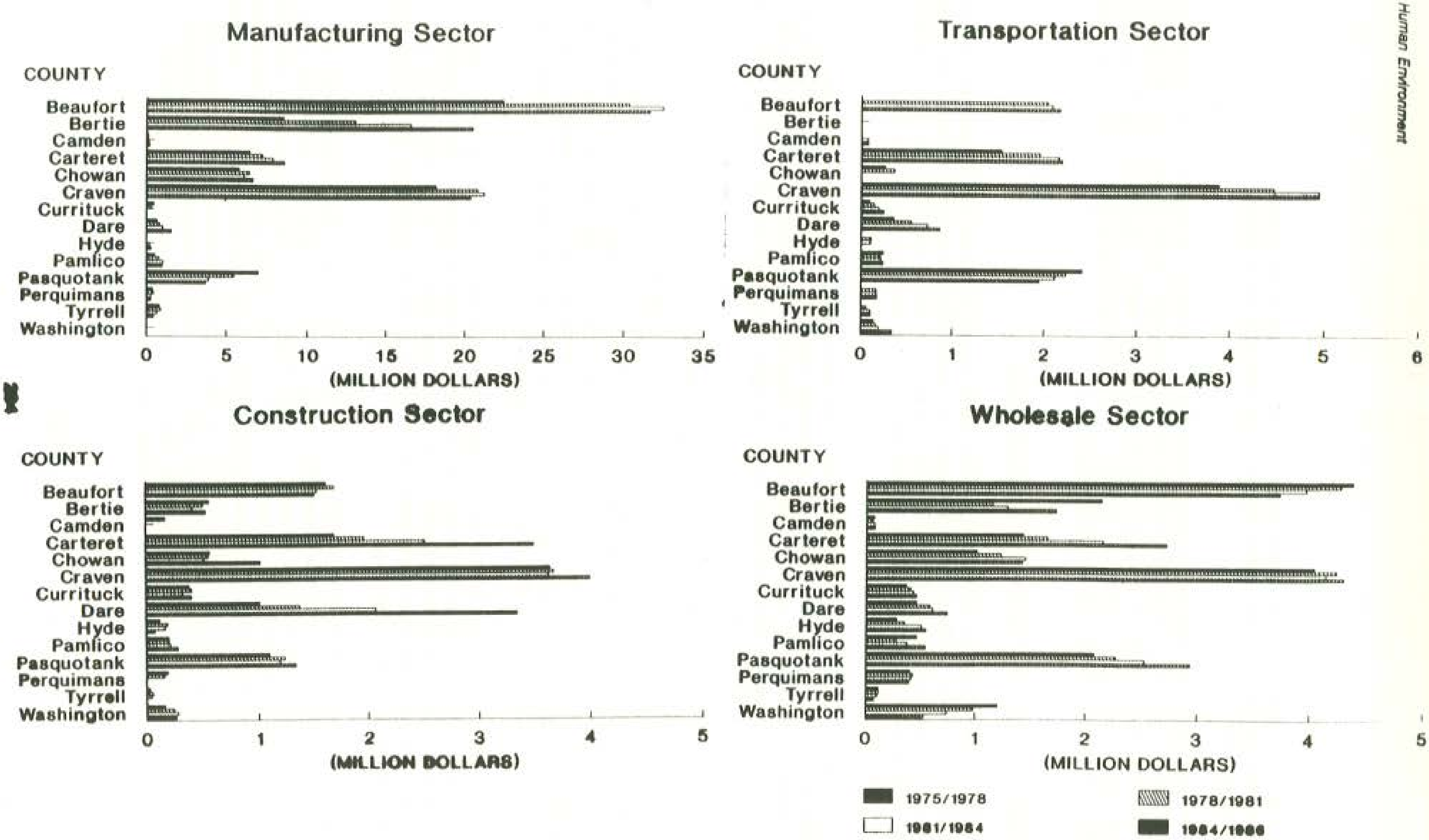

Figure V-7. **Average Value of Real Payroll for Manufacturing, Construction, Transportation, and Wholesale Sectors of the Economy in A/P Counties.**

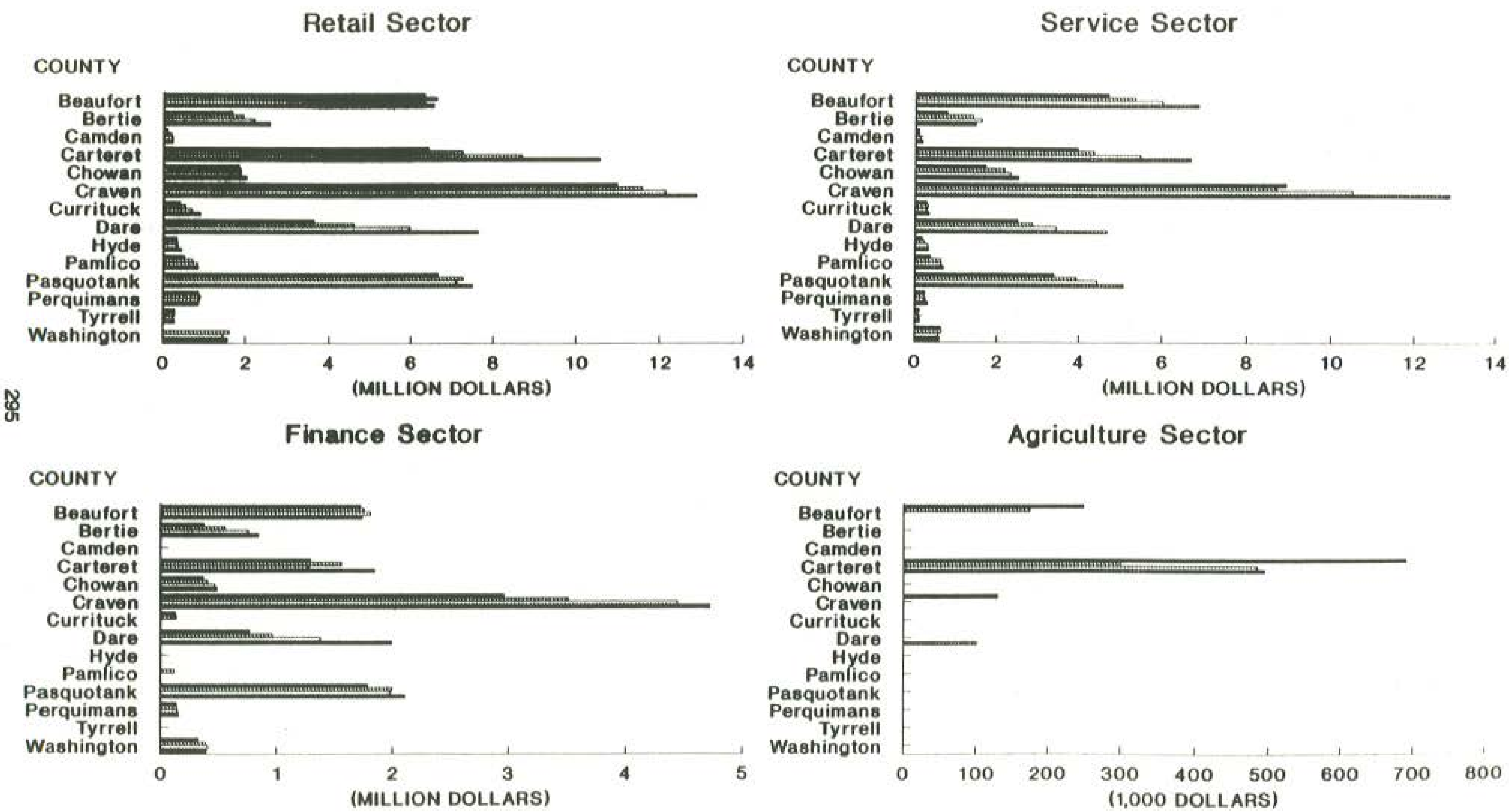

Figure V-8. Average Value of Real Payroll for Retail, Service, Finance and Agriculture Sectors of the Economy in A/P Counties.

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. As previously mentioned, 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 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.

TABLE V-4. Definition of Sectors. From 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

Table V-4	Continued
	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 U. S. 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: the establishment is usually a place of business and is engaged in activities to attract the general public to buy; the establishment buys or receives merchandise as well as sells; the establishment may process its products, but such processing is incidental or subordinate to selling; the establishment is considered as retail in the trade; and the establishment sells to customers for personal or household use. Not all of these characteristics need be present, and some are modified by trade practice.
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. Establishments primarily engaged in the construction of buildings for sale (operative builders) are classified in Industry 1531.
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.

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 activity are Beaufort, Craven and Bertie Counties. Beaufort has seen an uneven but progressive growth in the size of real payroll expenditures in that county, rising to over $30 million (in 1967 dollars) by 1984-86. This represented a slight decline over the period 1981-84, but still substantially above levels realized in earlier periods. Craven County demonstrated initial growth between 1975-78 to 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.

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 exceeds $1.5 million over the full period of our evaluation. Some growth was

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

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.

The level of real payroll in the transportation sector (Figure V-7) also is concentrated. We find it in four counties, with two of those experiencing growth over the period. 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 an approximate steady level of activity as measured by real payroll, and Pasquotank experienced some substantial decline -- from nearly $2.4 million in real terms to under $2 million by the close of the period. The data also suggest 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 and is concentrated in Beaufort and Craven Counties (Figure V-7). However, the level of this activity is steadily declining in Beaufort County from the high exceeding $4 million (in real dollar terms) in 1975 to levels that are below $2.8 million by the close of our period. Craven experienced some growth over the full period, with a slight downturn in 1981-84, and rebounded to close at the highest levels, nearly $4.5 million by the end of the period. In contrast, Carteret, Chowan and Pasquotank Counties experienced some growth over the period, with Carteret and Pasquotank rising to nearly $3 million (in real 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 to nearly $11 million. 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, where 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, where construction activity and the transport sector have remained stable or slightly declining, the retail sector is also approximately stable. Other counties have experienced much lower levels of activity, with only Bertie County experiencing some modest growth over the period that appears to correspond in pattern to the growth in the manufacturing sector. Again, this is another example of the interconnections between activities in the different sectors.

The service and finances sector 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 is nearly double that of Carteret and Beaufort Counties by the end of the 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). Here the real payroll data suggests 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 in the case of many of the 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, accounting for over 40% of North Carolina's gross farm receipts (N.C. 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. 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 when output levels 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 1970's and peaked in 1980 (Figure V-9). Since that time acreage in production fell. This decline is probably 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 N.C. 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.

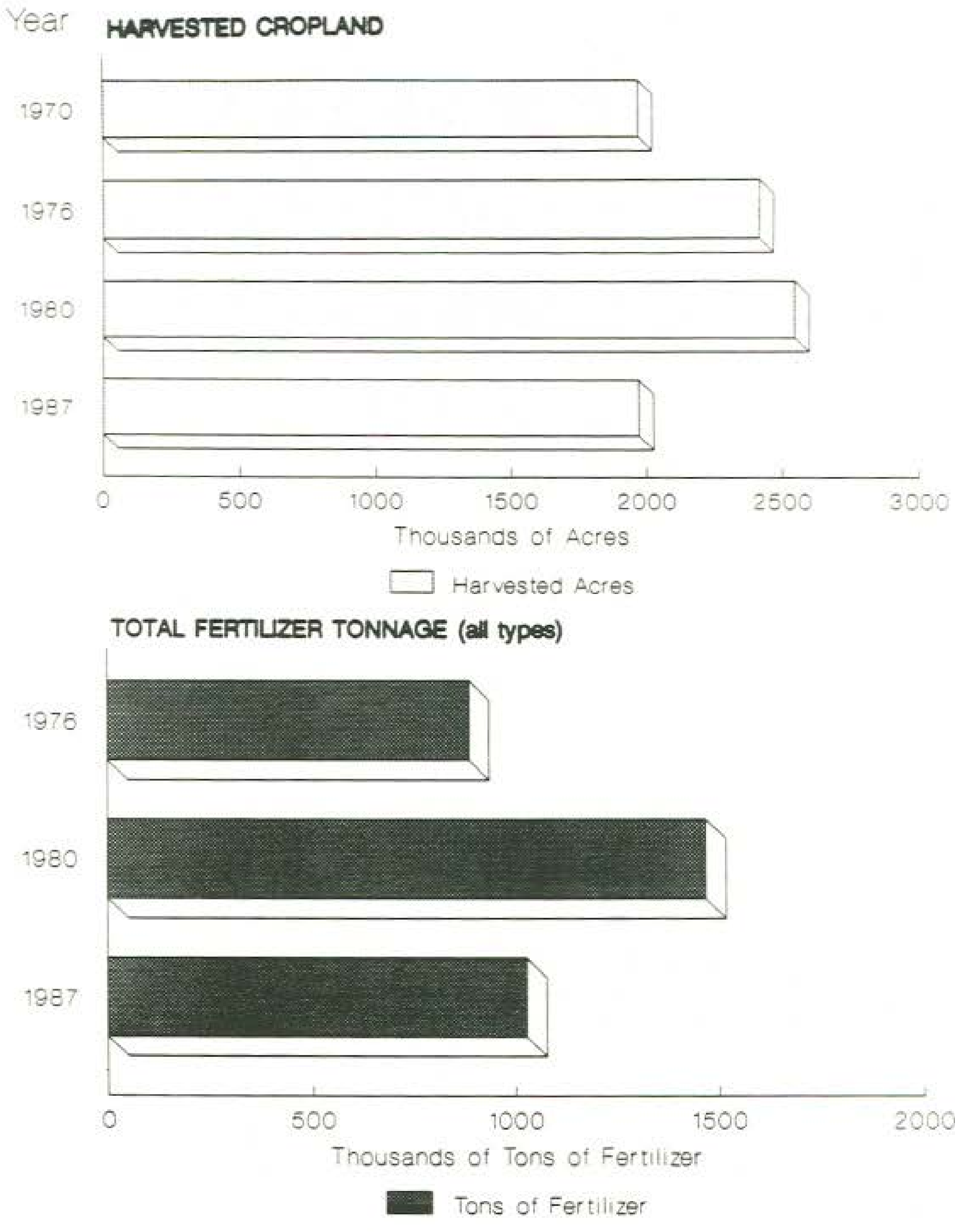

Figure V-9. Acres of Harvested Cropland and Total Fertilizer Tonnage Shipped to the 36 A/P Counties. From N.C. Department of Agriculture.

Of course, in interpreting these data it is important to recognize that acres planted will be responsive to economic policy and to 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, with each pool varying in qualifications for the program. At periodic intervals, the U.S. 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 nutrient loading of freshwater, particularly nitrogen and phosphorus (N.C. NRCD 1987). Much of this nitrogen and phosphorus originates from agricultural fertilizer. For this reason, 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 N.C. 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 (N.C. 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 N.C. Department of Agriculture.

Historical hog production trends for the A/P study area indicates 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 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.

Cattle production remained constant from 1975 to 1980, but experienced a 45% decline 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 equated to a 21.4% share of the state's total. The share remained constant through 1980 (22.1%), but 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, and there was a 33% increase in the period from 1980 to 1987 (Figure V-10). A similar pattern is evident when A/P chicken production is compared to state-wide production. In 1974, the A/P counties' share of the total chicken production was almost 23%. This share increased to 32% in 1980, and represented almost 40% in 1987.

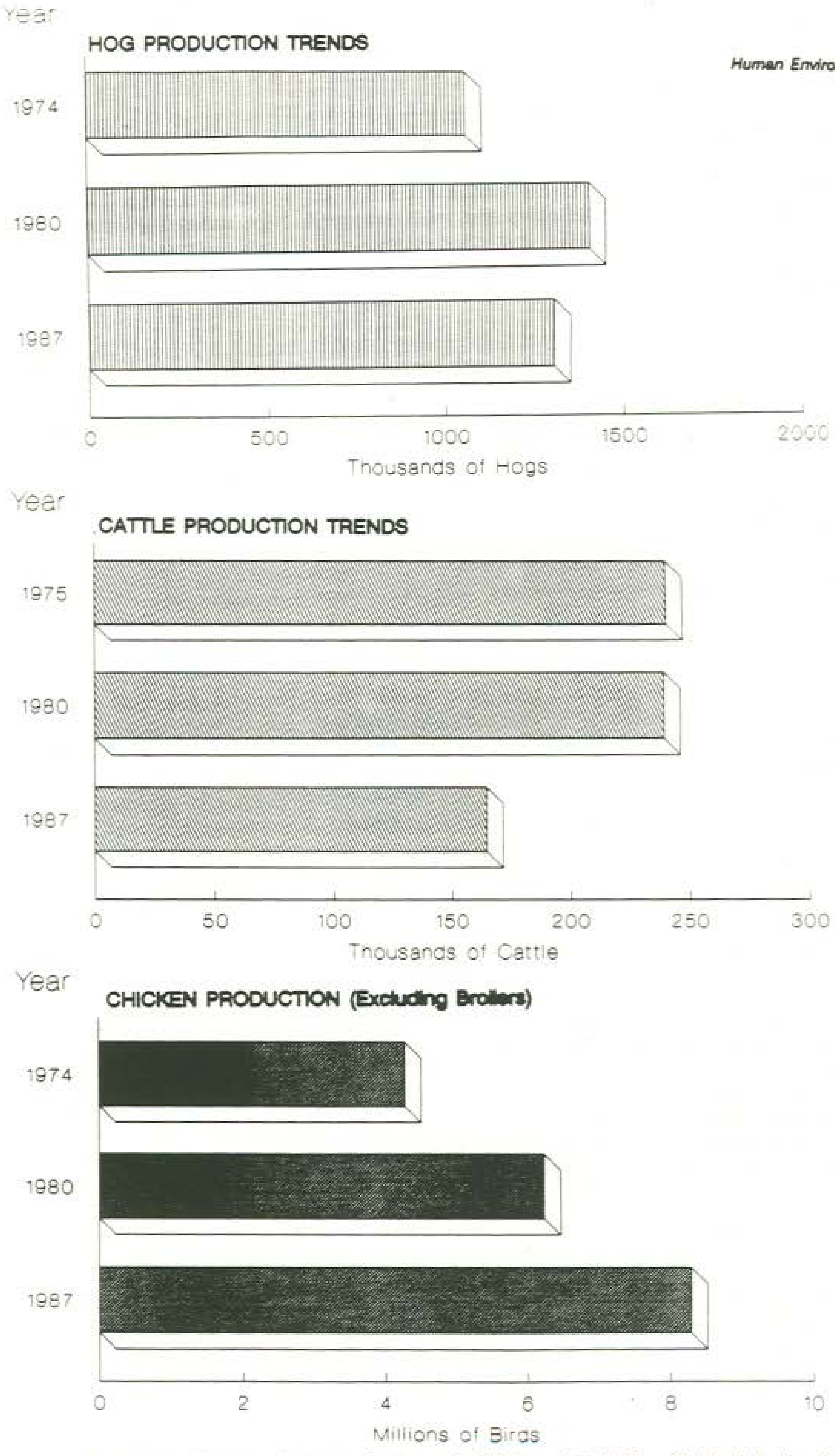

Figure V-10. **Production Trends of Hogs, Cattle, and Chickens (Excluding Broilers) in the 36 A/P Counties. From N.C. Department of Agriculture.**

In summary, the amount of harvested cropland within the study area has declined since 1980. Wheat acreage appears to be on the increase while corn and soybean production has remained constant. 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 increasing and 1987 production represented over half of the state's total. During the study period, cattle production fluctuated. Chicken production has increased steadily throughout the 1970's and 1980's. 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 U.S. Forest Service maintains an extensive inventory of the woodlands on North Carolina. These data were used for the majority of this trend 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 real payroll analyses of the forest industry. In this region, output levels could not be obtained for a comparable period, but the pattern implied by the period 1973-1984 appears quite mixed with most of the calculated rates of change in the outputs of softwood and hardwood arising in coastal counties indicating declines in output.

One other forest trend was analyzed for this sector, pine plantation acreage. To date, pine plantations in North Carolina have contributed only minor amounts to the supply of timber in the state. This trend, however, is shifting, and the U.S. Forest Service expects plantations to provide an increasing share of softwood timber supplies in the coming years (U.S.F.S. 1986). During the period 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 also wide-spread (N.C. NRCD 1987).

In summary, in the mid-1980's 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 are 252 permitted mines in the A/P Study area. The type of mine operation varies; however, the majority of them are sand and gravel mines followed next by crushed stone. Because of the nature of the permitting process, a mine may be permitted although it might 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. A new permit issued by the N.C. Division of Environmental Management will 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. 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, and there is no specific data showing trends in this activity.

In summary, of the 252 permitted mines in the A/P Study area, approximately 217 mines are operational. Construction materials mines account for over 90% of the mines in the study area. Texasgulf's phosphate operation discharges large amounts of phosphate and freshwater into the Pamlico Sound, however, by 1992, discharges are expected to be reduced by 90 percent.

D. 2. d. Department of Defense. Department of Defense activities have a profound affect upon the Albemarle-Pamlico Estuarine System (N.C. NRCD 1987). Defense activities are diverse and include the construction, usage and maintenance of the Atlantic Intracoastal Waterway, Cherry Point Marine Air Station, and the numerous and dispersed bombing ranges and target areas. A systematic assessment of the Department of Defense (DOD) activities, as with some of the other sectors, is beyond the capacity of this analysis. There are some readily available data 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 encompass over 96,000 acres within the study area. Much of this land is restricted to civilian use (Figure V-11). With the Marine Corps' proposed expansion in the Croatan National Forest, this acreage could increase.

The number of federal military employees in the A/P Study area declined slightly during 1970 and 1987. In 1970, there were almost 30,000 military employees. That number decreased by 1987, but it still represented employment for almost 28,000 North Carolinians. 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. For the same period, Craven County's share of the DOD expenditures was $476,835,136. 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.

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 encompass almost 100,000 acres. The DOD has employed well over 25,000 persons in the A/P area since the 1970's. The DOD has a substantial economic impact in the 36 county study area; however, the indirect effects of the DOD's activities on the estuarine systems are not clearly understood.

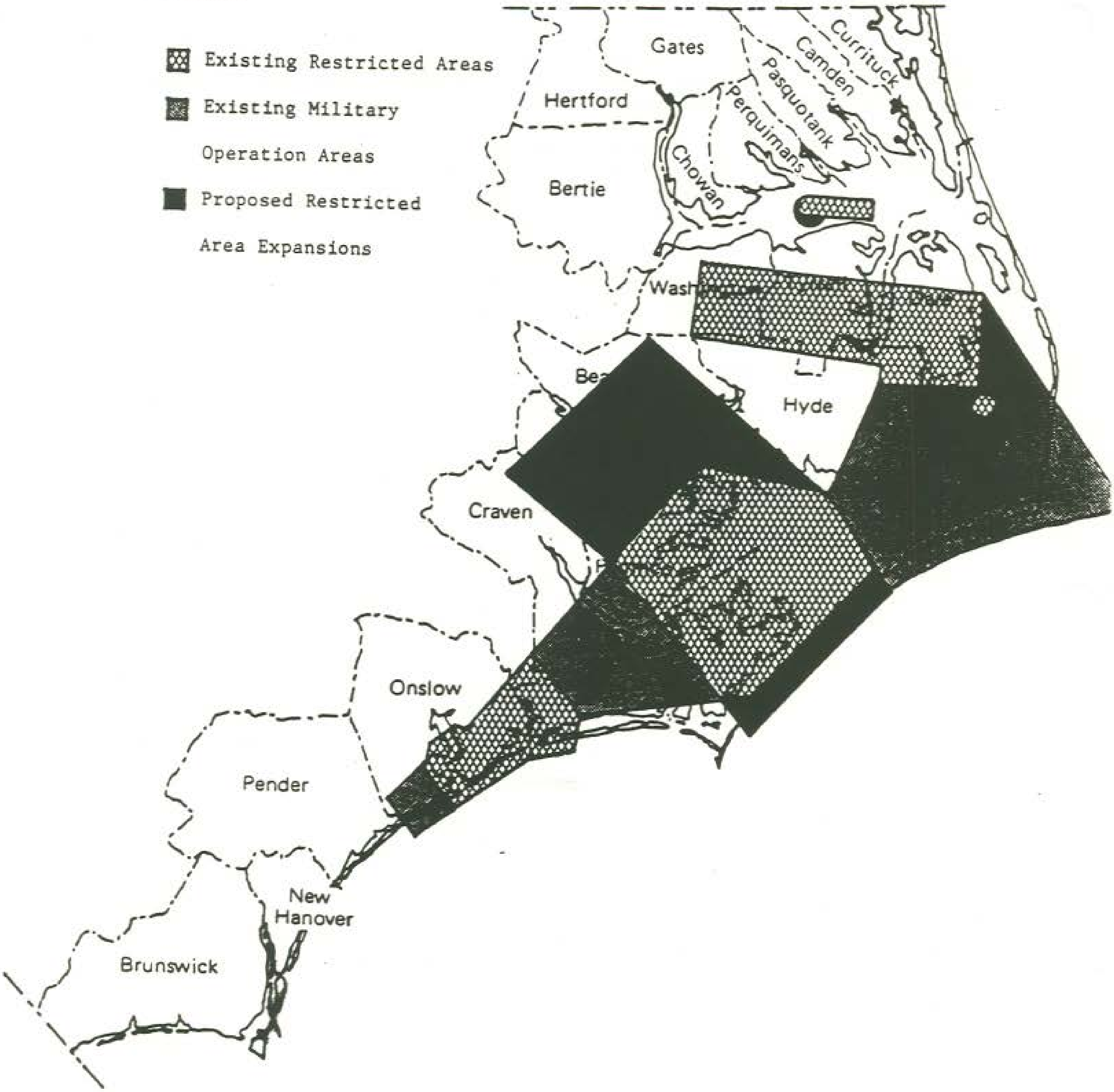

Figure V-11. Existing and Proposed Military Restricted Operation Areas in Eastern North Carolina.

D. 2. e. Waste Disposal. A major use of the Albemarle-Pamlico Estuarine System and its tributaries is the disposal of waste generated by domestic and industrial facilities as well as from other human activities on the surrounding land. For purposes of this discussion, "waste" is any material which enters waters of the State of North Carolina through human actions (N.C. NRCD 1987). Waste disposal within the A/P Study area is a complex topic and cannot be adequately addressed in this limited analysis. Also, the reader is reminded that waste disposal can be point source such as those permitted through the N.C. Division of Environmental Management, or nonpoint sources as runoff from roadways, agricultural areas or construction sites. There is little data documenting sources or amounts of nonpoint runoff, however, there are some data that can be presented to show trends in waste disposal and a discussion of that follows.

The discharge of waste by domestic and individual facilities is regulated in North Carolina by the Division of Environmental Management (DEM) under the 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. Nearly half of all permits represent small domestic dischargers such as schools, prisons and private residences. The vast majority of the waste volume is discharged by municipal wastewater treatment plants and industries. Figure V-12 shows the approximate location of the NPDES permits in the study area.

The NPDES temporal data for the 36-county study area were obtained from the 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. During that 8 year period, the number of NPDES permits has increased by 2.5 times. It should be noted that approximately one-half of the permits issued during the 1980's are inactive. Wastewater discharges from permitted activities can have a substantial impact on the receiving water bodies. In 1988, 14.9% of the Tar-Pamlico River's 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 Chowan River's nitrogen and phosphorus loads 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 1970's, 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 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.

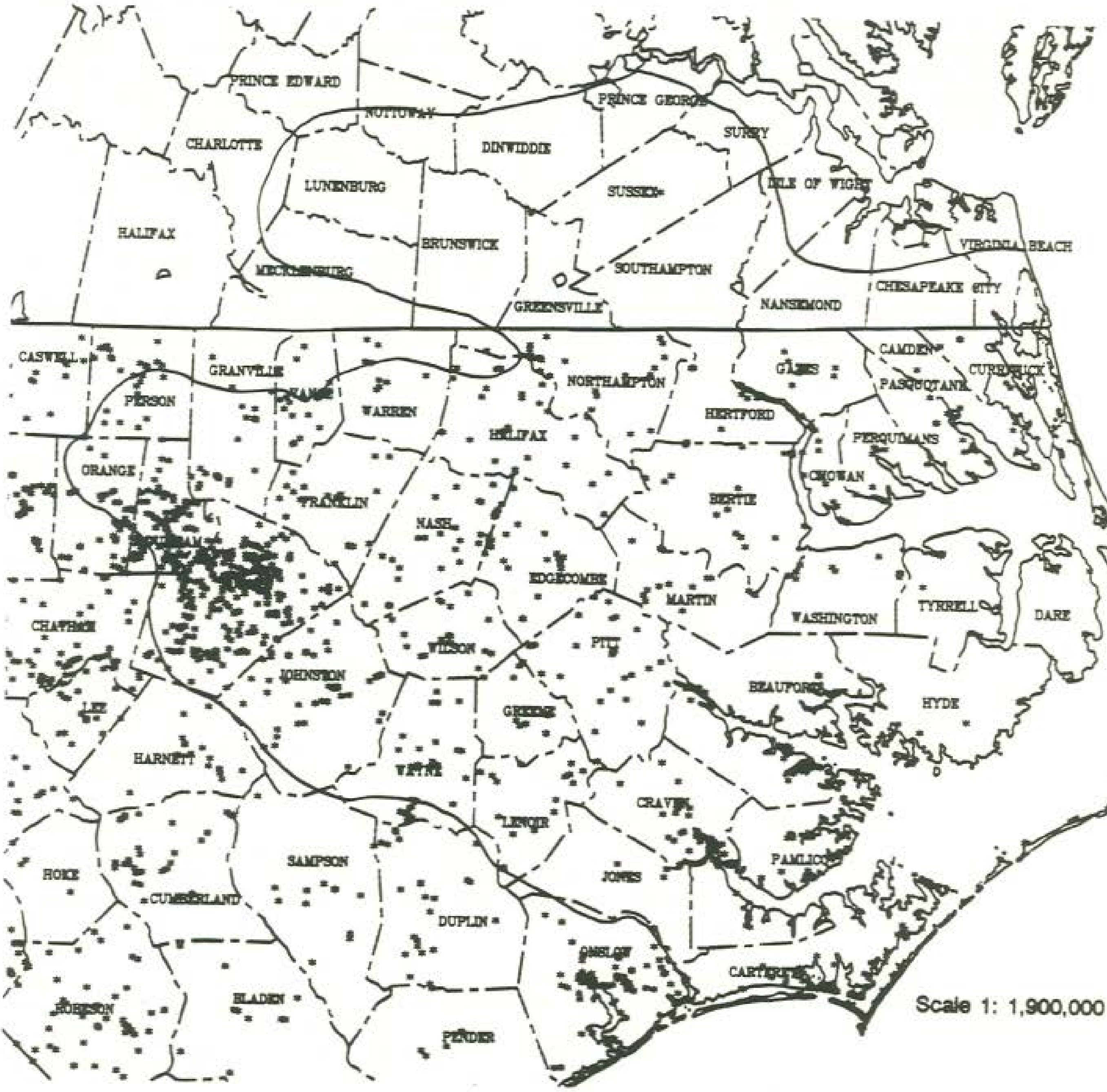

Figure V-12. NPDES Discharge Locations in the A/P Study Area, 1989. From N.C. Land Resources Information Service.

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 Tar-Pamlico River's nitrogen budget originated from atmospheric deposition. The same study estimated that 5.5% of the phosphorus in the basin came from the same source. Some of these atmospheric contaminants originate from automobile emissions. The environmental impacts of automobiles are not just limited 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 affect the water quality of the sounds. Because of this potential for environmental degradation, some trends involving automobiles and travel are analyzed.

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 1970 to 1980, the population in the region increased by slightly greater than 11% while vehicle registration (cars and trucks) increased 56.8 percent. In 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 is evident that multi-vehicle ownership is quite common throughout the A/P study area.

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, 11 sites were selected 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 North Carolina Department of Transportation.

During the period 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 U.S.13/64 near Williamston. Only two sites experienced decreases in traffic counts. For the period 1983 to 1985, all 11 sites experienced an increase in traffic. The increase ranged 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 indicating that multi-car households are the rule rather than the exception. Those 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.

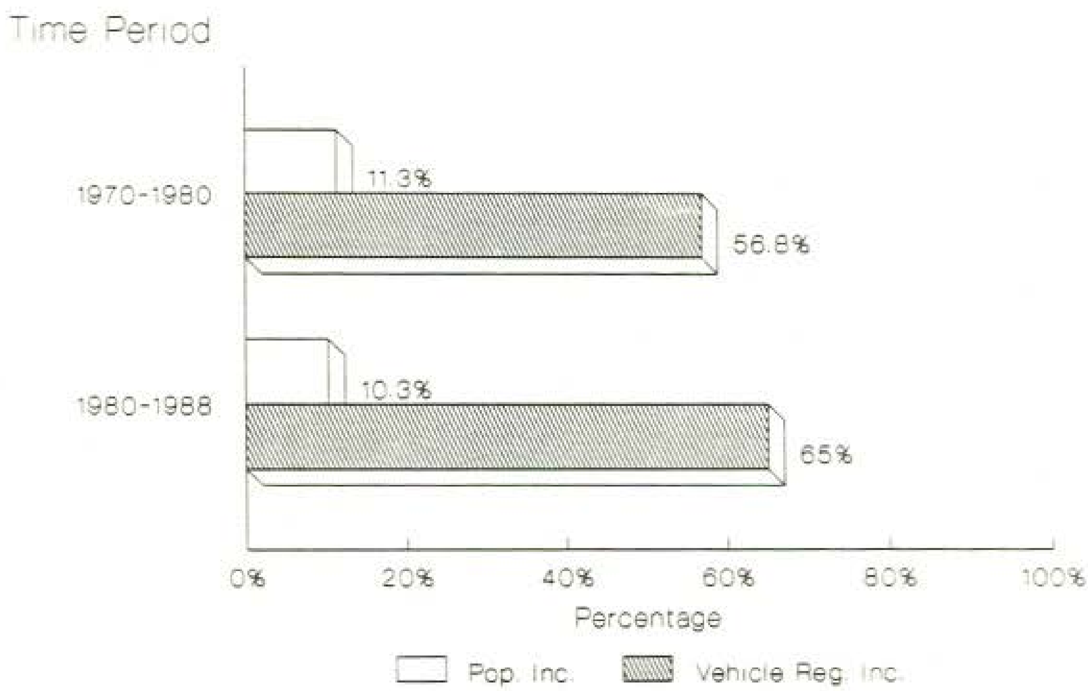

Figure V-13. **Population Change vs. Vehicle Registration in the 36 A/P counties. From N.C. Department of Transportation.**

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, with the education system. The value and beliefs taught in the school framework have the potential to affect a large number of the population, including both current and future generations. 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 in respect to the socio-economic forces that affect the study area. More importantly, 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 address 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; they are 1) the federal government, 2) state government and 3) local governments. Each level represents a separate jurisdiction, yet they interact with one another regularly. 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 that affect activities within the A/P region. A simple classification system is used 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. Eight regulations are classified as having a minor impact on the region and 25 federal legislative programs have marginal or extremely minor impacts on the area. Those programs are listed in Table V-6. Federal laws cover a variety of activities from water quality to soil conservation, and from endangered species to hazardous waste storage. Although specific laws are more inclusive than others, each has the potential to alter many of the previously discussed land and water uses.

As of the same date, there were at least 109 North Carolina regulatory programs that affect human activities in the study region. Forty-two of these regulations are classified as having a major impact on the sounds. There are 6 laws considered to have a minor impact on the A/P Study area, while 61 are judged to have only a marginal impact on the direct or indirect uses of the area's resources. 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 Zone Management Act (CAMA), are very selective and only apply to the counties that border the ocean or sounds.

Finally, local legislation, such as zoning, is addressed. 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 impact water quality within the A/P watershed, and there is some limited data available for this type of program. In 1987 the Division of

Community Assistance, within N.C. 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, and these data are the basis for this brief analysis. 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. In addition, 79% of the A/P counties had land use plans.

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).

E. 2. Education and Public Awareness

North Carolina citizens have more opportunity 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.

Statewide and regional newspaper and television stations devote larger sections to environmental issues perceived imminent. Reports on fish kills, declining fisheries, algae 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 student activity guide was developed through the N.C. 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 grade 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 northeast schools and to the eight statewide regional education centers. The new video format is now available through UNC Sea Grant. Cost: $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 N.C. National Estuarine Research Reserve System, written by Gail Jones and published by the N.C. 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" versus "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 nationwide 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 may be freshwater, such as rivers, lakes, ponds, and streams; or saltwater marshes. 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 water 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 N.C. Wildlife Resources Commission. Educational guides are provided to those teachers who participate in training workshops on the material. Representatives of the N.C. Wildlife Commission, the N.C. 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. <u>Examples of Sponsored Teacher Workshops</u>. "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 N.C. Center for Math-Science Education. Teachers were paid a $35-per-day stipend and received two graduate credits from UNC-CH.

E. 2. c. <u>Environmental Group Initiatives</u>. 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. <u>State Agency Support</u>. 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 N.C. Department of Environment, Health and Natural Resources, and the N.C. Wildlife Resources Commission.

E. 2. e. <u>N.C. Agricultural Extension Service</u>. 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 BMP's 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 linkages 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 youth 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 teens;

* 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 geared to the 10-year-old, which teaches the basics of soil and water quality;

* Plastics, lessons designed for the 9- to 12-year-old that focus on the perils of plastic in an aquatic environment; and

* 4-H Seafood Project, which is designed for the 4-H member 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 (WRRI) 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. WRRI 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 WRRI'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.

WRRI 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 N.C. 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 ability to take action on the problem. 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 N.C. Wildlife Resources Commission, 4-H, WRAL-TV, and private companies are part of the expansion strategy for a statewide aquatic program. The goal is public awareness and 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 and appreciation of 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 Administration, the Reserve now encompasses more than 12,000 acres of barrier beaches, marshes, 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 titled "It's a Beautiful Day: A Visit to the North Carolina National Estuarine Research Reserve" is also available. This video targeted to 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 to aid in disseminating to citizens relevant knowledge about the estuaries. These initiatives have 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 on both 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 provided. For example, the College of the Albemarle offers relevant specialized credit courses such as

Introduction to the Marine Environment, 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. l. 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;

* Providing alerts to citizens interested in participating in public hearings concerning coastal management 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 eight sites in the Albemarle. AEA has also undertaken, with support from the Albemarle-Pamlico Study, a program of public education. In this effort three groups are 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 and thereby stimulate the preservation of North Carolina's coastal environment.

With the documentary, "Troubled Waters," as the cornerstone, WRAL-TV launched a year-long campaign called "Save Our Sounds," which includes 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;

* PSA's and info-mercials (educational spots);

* Symposium--a free lecture, with keynote speaker Walter Cronkite, titled "Reflections on Our Coastal Environment." 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, and environmental groups, music and seafood. The event was attended by 10,000 people.

The station's half-hour documentary "Troubled Waters" was chosen winner of the National Edward R. Murrow Award in the news series/ documentary category. The documentary examined the sources of water pollution in the rivers and sounds of the state.

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. 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. Although there are numerous environmental factors that contribute to the health of this unique natural system, because of the tremendous water volume contained in the sounds, 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 analysis 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 analysis 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:

* There should be a concentrated effort by the Land Resources Information Service (LRIS) to map the major land uses within A/P Study area. This information would be useful for developing correlations between water quality and specific, and in many cases overlapping, land uses.

* Establish a central database (such as LRIS) to catalog and maintain all data involving the A/P area. A system such as this would simplify future projects such as this and also prevent much of the duplication in 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.

* There is a need to determine the **environmental cost** of the ever increasing travel and tourism industry. Tourism is one of the major industries in the area; however, little is known about its affects upon these environmentally limited coastal and sound systems.

* Develop comprehensive, consistent land use plans, similar to those required by CAMA, throughout the region. This effort should involve all the counties within the study area. Financial aid should be supplied to the smaller, rural counties who are unable to undertake such projects.

* Waste disposal, both solid and liquid, is potentially one of the most serious environmental problems within the A/P Study area. Waste disposal should be addressed from a regional viewpoint rather than from a county by county level.

* Establish a clearer identification for the A/P Project. Many people in the region do not have a clear idea concerning the mission or even the existence of the Albemarle-Pamlico Project. This was very evident in many of the state agencies interviewed for data requests.

IV.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've outlined some research needs that should be addressed if we are to adequately anticipate the likely factors influencing direct and indirect uses of the estuary and how those uses might respond to alternative management options incorporated in a Resource Conservation and Management Plan.

Consider first the direct uses of the estuary. For simplicity, we classify these into recreational and commercial fishing and other recreational activities (including tourism). Ideally, we would like to be able to model the demand for recreational fishing in the Albemarle-Pamlico area by considering both the decision to use this area for fishing and the amount of use each household makes in a typical season. In order for these demand functions to be capable of reflecting the influence of management policies, they need to incorporate a direct recognition of how the quality features of the estuary affect recreational fishing in this area. Thus, the site amenity features of locations within the estuary and measures of fish availability would be likely important determinants of both the decision to go to the estuary for fishing and the level of use in any particular season. These demand relationships probably would be distinguished according to local and non-local users, with the latter category including out-of-state residents. A similar framework might be envisioned for each of the principal other recreational uses of the coastal resources linked to the estuary, including facilities on the Outer Banks. Tourism might be defined to include bundles of recreational activities that usually occur together, such as a week's vacation on the coast involving swimming, fishing, boating, and the like. To the extent the package is regarded separately with each of the activities as individual day trips, we would need to describe how these decisions are made as well. Other quality dimensions of the estuary affected by management also influence these types of 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.

Commercial activities also respond to the character of the estuarine resource. In this case, the response is equally complex. Clearly it is related to the availability of fish, but it may also be affected by certain advantages that coastal locations provide. The response expected from alternative management policies might be more dramatic than anticipated if fishermen chose to relocate their operations. In the short term, commercial fishermen might respond to restrictions in fishing activities or the types of fishing that can take place in the estuary by traveling outside conventional fishing locations to avoid or adjust to the restrictions. However, when given the opportunity to relocate operations, they might have an incentive to move to a completely new location outside the regulated areas. Thus, we would expect short-term impacts from the reallocation of fishing effort to other areas along the coast to be modest. But over the longer term, a larger impact could occur with a complete loss of certain operations. As we described in Section II above, the actual patterns of these decisions likely will be different for the smaller, family-owned, commercial fishing operations than the larger firms. The former are more likely to delay moving operations because of family ties and to ultimately completely close down operations rather than relocate. Because these activities are directly tied to the quality and character of the estuarine resource and the complementary natural resources it supports, charting a path for anticipating future trends and their response to management policies is somewhat more direct than charting trends for the indirect uses of the estuary.

Predicting the trends in economic activities in any region and the role of government policy in influencing those patterns has proved to be an exceptionally difficult task within economics. The state of economic modeling for these tasks is rather limited. Two approaches have been proposed. The first approach examines regional productivity movements by sectoral categories, such as those identified in our trends analysis, and the influence of local conditions on productivity (see Aaberg [1973], Moomaw [1981a, 1981b], and Hazilla and Kopp [1988]). Here, the analysis tries to detect whether we observe more output produced per unit of input in certain locations as a result of characteristics of those location. Presumably, these factors would induce firms involved in productive sectors to relocate to regions where policies are productivity-enhancing from regions where they are less productive. However, the analysis offers no such direct predictions. It simply describes observed patterns. Thus, the information that can be provided is largely qualitative.

A second line of research -- one that we believe offers much more promise for addressing the types of issues required for an evaluation of the effects of a comprehensive conservation and resource management plan -- attempts to predict the likelihood that firms will locate plants in particular regions, as well as the size of those plants. This research is quite recent and is largely associated with Carlton [1979, 1983] and Bartik [1985, 1988].

The basic strategy underlying these analyses is straightforward. Firms are envisioned to evaluate the profitability of locating a plant in a particular area. That profitability is influenced not only by access to markets and the prices of local labor and other inputs to the production process, but also by what might be termed the public and private resource base of the region. This can include access to highways, the quality of the available labor pool, the overall infrastructures and support industries, as well as by policy considerations, including the tax and other regulatory mechanisms that affect firms' costs. The work by Carlton and Bartik demonstrates that the methodology is, in fact, feasible and has led to some important conclusions.

Labor costs are an important locational effect. Evidence is mixed on the effects of local taxes on location decisions, but we tend to accept Bartik's results indicating that they are a consideration. Carlton's analysis failed to find effects of local taxes, while Bartik's did. Bartik's analysis also suggested that unionization was a negative influence on locational decisions, but that environmental regulations did not influence the likelihood that a particular firm would locate in a region.

While these models are limited and structured for specific sets of conditions, they offer the most promising avenue for a prospective evaluation of coastal policies and their implications for plant location decisions and growth in coastal areas. At present, we do not have any models of this type that are capable of being applied to evaluate the likely effects of estuarine management policies. This does not suggest that they could not be developed. The Bureau of Census Longitudinal Establishment Database provides information that could be used to develop these types of models for coastal areas in North Carolina in comparison with other regions.

It is important to acknowledge that management policies do deliver improvements in estuarine resources and make them more valuable. These improvements are to be balanced against the costs of these policies. By understanding the demands for the resources supported directly and indirectly by estuaries and the costs of restricting how estuarine resources are used, 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 patterns of use.

H. 2. Recommendations for Public Education

Expanded educational programs on coastal water and estuarine issues are needed for a diverse audience of decision makers, educators, mass media representatives, adult citizens, youth, planners, engineers, policy makers, legislators, business and industry. To reach this diverse audience requires leadership, financial support, and a planned program. The leadership to coordinate and plan for an effective educational program should be a responsibility of the N.C. Department of Natural Resources and Community Development. The following are some recommendations that should be considered in the program.

The educational program should have a plan closely linked with the A/P Study that

1. describes the estuarine concepts and information that needs to be taught,
2. identifies the target audiences,
3. outlines strategies to be used to reach the specific audiences,
4. identifies those organizations that have the responsibility to do the work and the groups which should be asked to assist.

Other recommendations for education and public awareness include the following:

* A need for an organized assessment or study by A/PS regarding the extent to which teachers incorporate coastal and environmental concepts and educational materials in the

classroom. This study would help determine whether there are strategies that could be implemented to provide a mechanism for continued teacher education and monitoring of effects of this training on students.

* A complete cataloging and description of existing education programs, an assessment of their effectiveness and what, if any, are the multiplier effects of these programs.

* An assessment of youth and adult current understanding of environmental issues and concepts is needed as a basis for designing new programs.

* While there has been an increase in educational activity, there is a need to encourage and support teachers with in-service training, travel support, and study materials for estuarine related topics and the associated concepts. These efforts need to be supported, strengthened and systematically evaluated to see that teachers and youth are provided with knowledge on estuarine issues. There is a need for strong leadership in the public school system to build upon current programs which are heavily dependent upon a few enthusiastic individuals and one-time funding efforts from sources such as the A/P Study. Follow-up studies are needed to determine the effectiveness of teacher workshops and educational materials.

* 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 relevant to the A/P Study. The Community Colleges should also consider the development of relevant courses, such as marine operations, fishing, and wastewater disposal, for those living and working in the estuarine/coastal area.

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VI SUMMARY

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A. THE STUDY

During the last decade, the U. S. 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 perception that some of the nation's prominent estuaries are in serious decline in spite of a plethora of laws and regulations enacted in the 1970's 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 and was scheduled to culminate in 1992 with a comprehensive management plan to more effectively manage the system to reverse the perceived trend of degradation. This technical report is a preliminary analysis of status and trends that will serve as the precursor for development of the comprehensive management plan.

This report attempts 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 technical study has been summarized in a general interest document suitable for public use. Specific objectives of the preliminary 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 Dynamics (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;

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 the current information in a technical document that can later be used to develop a final "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 the content of this report is a "preliminary technical analysis" of the status and trends. It will serve as the base from which a concentrated and extensive analysis of status and trends will be developed during the fourth year of the study. Subsequently, a comprehensive management plan will be developed from the status and trends analysis.

B. THE SETTING

The Albemarle-Pamlico Estuarine System (A/P 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 extends upstream in tributary basins to the seaward-most impoundment, or if there is no impoundment, to the upstream boundary of the drainage basin, or if the basin extends into Virginia, to the North Carolina-Virginia state line. 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 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 impacted habitats--all of which negatively impact fisheries yields. 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. 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.

The longest fisheries data base is are 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. Unfortunately, very little long-term data exists for recreational fisheries catch.

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 1980's), it is unclear if 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 diversity of species and use a large variety of gear. As expected, this intense utilization results in highly volatile management issues. Arguments over the allocation of species and fish to commercial versus recreational interests has intensified in recent years. In addition to commercial versus recreational conflicts, user conflicts often occur between different commercial harvesting sectors.

Impacts on fishery habitats, including fishing practices as well as 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 1970's, 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 sore". 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 seem 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 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 (anoxia) 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.

There is little or no evidence to support the notion that the Albemarle-Pamlico estuarine sediments are quantitatively much different today than they were in past decades and centuries, nor is there evidence that they are functionally different. Anoxic and other adverse water quality episodes have probably been 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 impacts simply are not available. In any case, the precise relationship between pollutant loading and pollutant concentrations in sediments is unknown since the role of 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 to fresh areas, wild celery, Eurasian watermilfoil, or a mixture of pondweeds and related species may occur. Currituck Sound once contained dense growths of native SAV's, which were largely replaced by Eurasian watermilfoil during the 1960's and 1970's. The milfoil decreased dramatically during the latter 1970's and was replaced in turn by widgeongrass (a native plant). Similarly, SAV was common in the Pamlico River until the mid-1970's, 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 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 algae growth in response to nutrient additions and increases in 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 restricted to eastern Pamlico Sound and Core Sound. Hard clam abundance is strongly impacted by harvesting pressures and techniques that harm the bottom habitat, both of which have apparently decreased the abundance. 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 1988 summer. 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).

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, occupying 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 impacted 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 N. C. 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 or percolation through the soils–primarily from what has been disturbed by man's activities. Nonpoint source pollution is addressed through a combination of regulatory, cost incentive and voluntary programs. Point sources contribute about 15% of the North Carolina nutrient inputs to the Chowan, about 505 to the Neuse, and about 18% of the nitrogen and 7% of the phosphorus (TexasGulf, Inc.) to the Tar-Pamlico.

In 1988, the N. C. 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 nonparametric 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 (comparable 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 parallel 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-1960's 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 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 both upstream and downstream sections. Nitrogen concentrations are very similar to that 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 acreages 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 community. By contrast, the marine submerged aquatic vegetation community appears relatively stable, at least since the recovery of eelgrass from the "wasting disease" of the 1930's. 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 continue 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, geomorphical 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 stability 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 acreages 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 water line in tidal waters or the ordinary high water line in nontidal areas and including contiguous wetlands, is regulated by the U. S. 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 N. C. 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 N. C. 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 potential for pathogenic infections in humans from consuming shellfish increase to a certain level, the N. C. Division of Shellfish Sanitation requires that the waters affected be closed to public harvesting of clams and oysters. This level is based on the estimated concentration of "fecal coliforms", which are used as indicators of real pathogens. There are over 300,000 acres of coastal waters closed to shellfishing on either permanent or temporary basis. Only about 50,000 to 90,000 acres of this total are considered to be productive shellfish bottom. The area closed has remained relatively constant over the past few years, down from a high of about 500,000 acres in the 1960's.

The source of pathogenic contamination is the waste from warm-blooded animals. Pathogens 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, several thousands of acres of shellfish production area may be contaminated (therefore, closed) for a period of time. Regulations exist to help prevent land activities that would contribute to pathogenic contamination during runoff events. Most of the closure areas are outside the A/P Study area, but Core and Bogue Sounds, and several small embayments, are affected.

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 toxins in the Albemarle-Pamlico Estuarine System is underway. The first phase, heavy metal pollutants in the Pamlico River estuary, has been completed. The Neuse River estuary and Albemarle Sound will be completed by the end of 1990. 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" 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 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 the 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 impact in some areas. And, as the population continues to increase, these trends are expected to continue.