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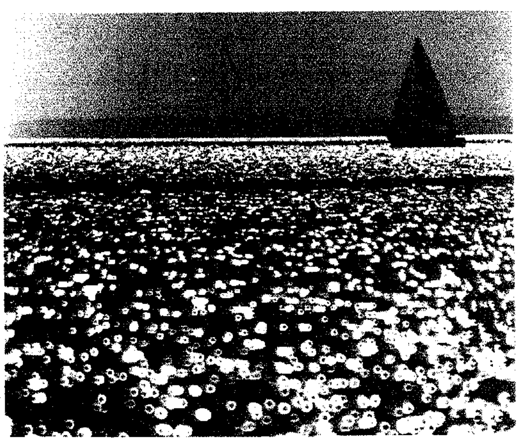
April 1984

THE ECOLOGY OF THE PAMLICO RIVER, NORTH CAROLINA: AN ESTUARINE PROFILE






Fish and Wildlife Service
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FRONT COVER PHOTOS:

Shrimping (photo courtesy North Carolina Division of Marine Fisheries), Blackbeard the pirate (artist unknown, courtesy of North Carolina Division of Archives and History), ducks (photo by Ken Taylor, North Carolina Wildlife Resources Commission), sailing (photo by Steve Murray).

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THE ECOLOGY OF THE PAMLICO RIVER, NORTH CAROLINA: AN ESTUARINE PROFILE

by

B. J. Copeland
Ronald G. Hodson
Department of Zoology
N.C. State University
Raleigh, NC 27650

and

Stanley R. Riggs
Department of Geology
East Carolina University
Greenville, NC 27834

Project Officer

Edward C. Pendleton
National Coastal Ecosystems Team
U.S. Fish and Wildlife Service
1010 Gause Boulevard
Slidell, LA 70458

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PREFACE

This estuarine profile is one of a series of publications concerning current issues facing the Nation's estuaries. Its purpose is to synthesize existing information to describe the structure and function of the Pamlico River Estuary, North Carolina. The Pamlico River Estuary and its associated tributaries constitute the most important tributary to Pamlico Sound, which is the heart of North Carolina's vast coastal system. Pamlico Sound yields the majority of the commercial and recreational fisheries catch taken in the State and serves as a base for a large and important recreation and tourism industry. It is also one of the most valuable coastal resources on the east coast of the United States.

The profile is a state-of-the-art synthesis, bringing together available information on the Pamlico River Estuary, especially that critical to managing the estuary. In many instances, critical gaps exist in information needed to effect management. Where this occurs we have identified the gaps, suggested comparisons with similar estuarine systems in other sections of the country or world, and described ways that the missing information may be accommodated.

Because the estuary is an intact integrated unit, we are approaching the profile from a systems viewpoint. No one function or any particular component operates in isolation from one another. Likewise, the integrated estuary does not function in isolation from the streams entering it, the land around it, the estuaries and sounds connected to it, or the ocean adjacent to it. We have attempted in this profile to describe the geological, biological, chemical, and physical characteristics of the Pamlico River Estuary and then to spatially and temporally relate the components to illustrate the integrated estuarine system. Finally, in Chapter 6, we suggest a multi-faceted management strategy tempered by socioeconomic realities and institutional constraints.

The Pamlico River Estuary has received considerable attention during recent years. During the past decade, the overall fisheries catch has fluctuated, shrimp catch has declined, and nuisance algal blooms have caused fish kills and have reduced aesthetic values. Changing land uses, increasing industrial and residential development, and freshwater diversions have been implicated. In response to some of these conflicts, the Governor appointed a multi-faceted Task Force in 1981 to examine water management problems in the area and to make recommendations for improvement. These recommendations were presented to the Governor in December 1982 and implementation has begun. This profile should be useful in assisting these important State efforts as well as assisting in the national perspective.

Any questions or comments about and/or requests for this publication should be directed to:

Information Transfer Specialist
National Coastal Ecosystems Team
U.S. Fish and Wildlife Service
NASA - Slidell Computer Complex
1010 Gause Boulevard
Slidell, Louisiana 70458

CONVERSION FACTORS

Metric to U.S. Customary

Multiply	By	To Obtain
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
kilometers (km)	0.6214	miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters (m^3)	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees	1.8(C°) + 32	Fahrenheit degrees

U.S. Customary to Metric

Multiply	By	To Obtain
inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
acres	0.4047	hectares
square miles (mi^2)	2.590	square kilometers
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	0.2520	kilocalories
Fahrenheit degrees	0.5556(F° - 32)	Celsius degrees

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ACKNOWLEDGMENTS

We are indebted to many colleagues' and former students who have provided much of the information reported here. Much of the research described in this profile was made possible by the extensive programs of the University of North Carolina's Sea Grant College Program and Water Resources Research Institute. Extensive contributions were made to the overall knowledge of the Pamlico River Estuary by the North Carolina Division of Environmental Management and Division of Marine Fisheries in the N.C. Department of Natural Resources and Community Development.

We appreciate all those who reviewed and helped improve the manuscript, especially Edward Pendleton and the NCET staff, Mike Gantt and the FWS field office at Raleigh, and Terry Sholar whose special knowledge of the estuary was particularly helpful.

Photographs were selected and prepared by Neil Caudle, who was also helpful with suggestions for improving the manuscript. Photographs were provided by Steve Murray (cover, Figure 63), Scott Taylor (Figures 58 and 62), Steve Wilson (Figure 55), Ken Taylor, N. C. Wildlife Resources (cover, Figure 53), Stanley Riggs (Figures 6, 7, 8, 9 and 10), N. C. Division of Marine Fisheries (cover) and Neil Caudle (Figure 32).

Gail Allen and, especially, Joan Messina labored tirelessly in making a readable script from our dictaphone tapes, typed the final manuscript, and manipulated the word processing machine to incorporate changes.

CHAPTER 1

INTRODUCTION—THE SETTING

1.1. PAMLICO RIVER ESTUARY AS A NATURAL UNIT

One of the most important estuarine systems in North Carolina, the Pamlico River Estuary, is a continuation of the Tar River and extends from Washington, North Carolina, for about 65 km to its confluence with Pamlico Sound (Figure 1). The estuary is oriented approximately WNW-ESE and gradually tapers from less than 0.5 km wide at its western limits eastward to over 8 km wide at its mouth, where it grades into the very broad and shallow Pamlico Sound (Lukin and Mauger 1983). The estuary extends to where the shoreline turns northward out in the sound.

The Tar River begins in the Piedmont and meanders across the North Carolina Coastal Plain. The coastal plain is generally a broad surface that slopes gently seaward and is moderately dissected by the drainage patterns of river systems (Brown et al. 1972). The incised streams with their associated floodplains and swamp forests, in combination with the upland interstream divides, produce the major topographic relief; the relief decreases seaward as the coastal plain approaches sea level. The Tar River flows into and becomes the Pamlico River Estuary just west of Washington, N.C. The oblong basin drains about 14,000 km^2, falls approximately 180 m from its origin to sea level, and delivers relatively large volumes of fresh water. Large loads of suspended clay sediments are carried to the coastal system via the Tar River. The upper half of the Tar River basin lies in the hilly Piedmont with a narrow floodplain, while the lower half has developed a broad floodplain as it flows across the low, flat coastal plain. The Pamlico River Estuary, which is generally perpendicular to the ocean shoreline, is the flooded portion of the Tar River basin and its extensive floodplain.

Numerous lateral tributaries drain off the low, flat, swampy coastal area into the main Pamlico River Estuary. These streams have considerably smaller drainage basins with low relief and small discharges of fairly acid blackwater. Consequently, the sediment load is low and dominated by organic matter derived from the broad floodplain swamp forests and upland pocosins. Lateral streams flowing directly into the westernmost portion of the estuary include Blounts, Tranters, and Broad Creeks. Farther downstream in the central and eastern portions of the Pamlico River Estuary, the lateral streams have been flooded to form small lateral sub-estuaries such as Pungo River, North Creek, Durham Creek, Goose Creek, South Creek, and Bath Creek.

The Pamlico River Estuary and the Neuse River Estuary to the south are the major freshwater tributaries to Pamlico Sound, which dominates the North Carolina coastal area (Figure 1). Thus, the estuary is bounded on the west by the Tar River, on the north by the Albemarle-Pamlico peninsula, on the east by Pamlico Sound, and on the south by the Pamlico-Neuse peninsula.

The Pamlico River Estuary is not directly connected to the ocean, but is a tributary to the expansive Pamlico Sound (Giese et al. 1979). Consequently, there is no direct exchange with the ocean and lunar tidal amplitude is very low. There is a large freshwater inflow relative to tidal volume, and biological communities are subject to drastic hydrographic fluctuations during weather extremes.

1.2. GEOLOGICAL ORIGIN AND EVOLUTION

Sediments and sedimentary rocks of marine origin underlie the entire Pamlico River Estuary 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

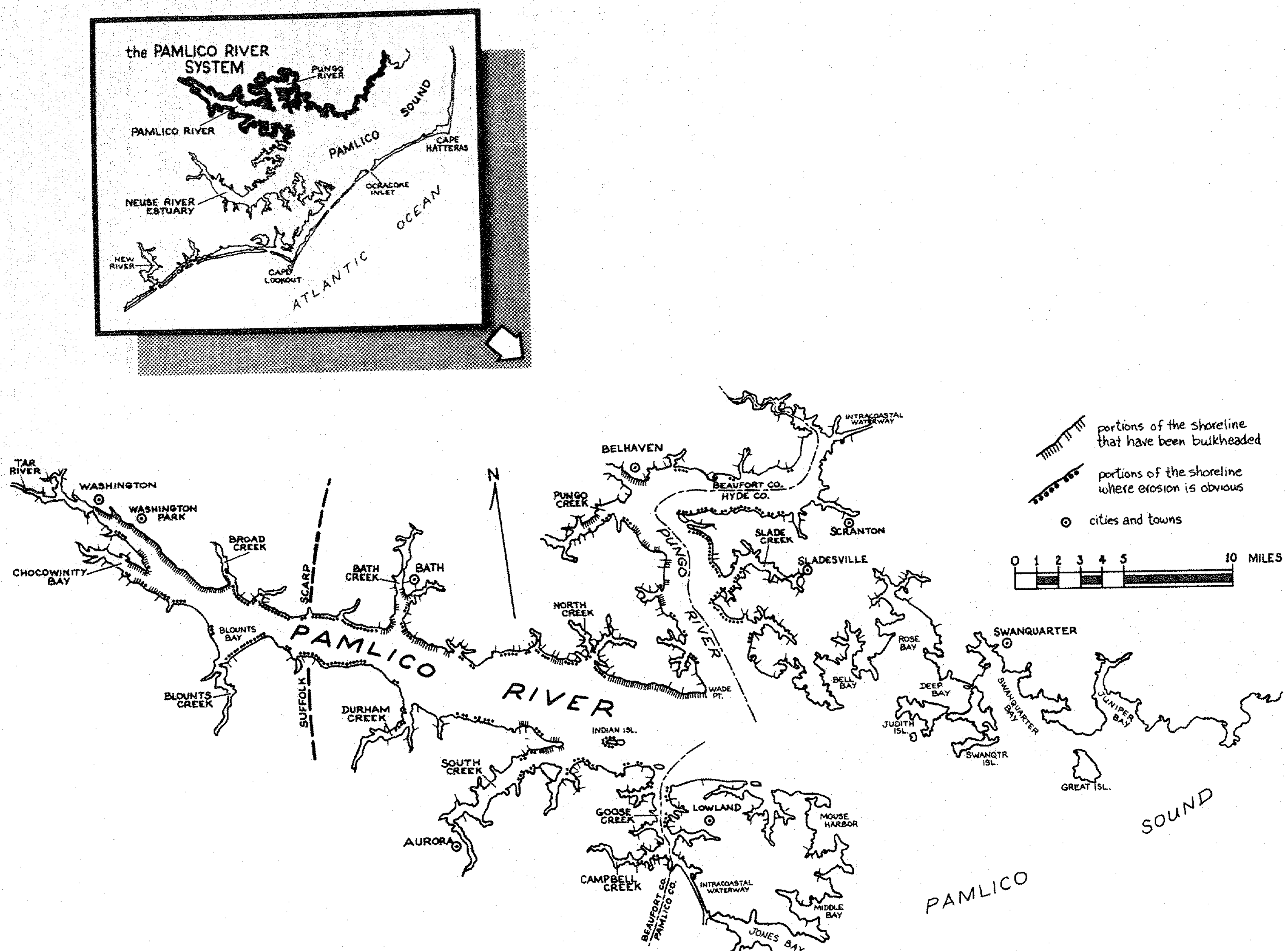

Figure 1. The Pamlico River Estuary.

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 (Brown et al. 1972). 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 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 Pamlico River Estuary. We have presented the names and ages of the formations in a cut-away cross-section of the North Carolina Coastal Plain Con-

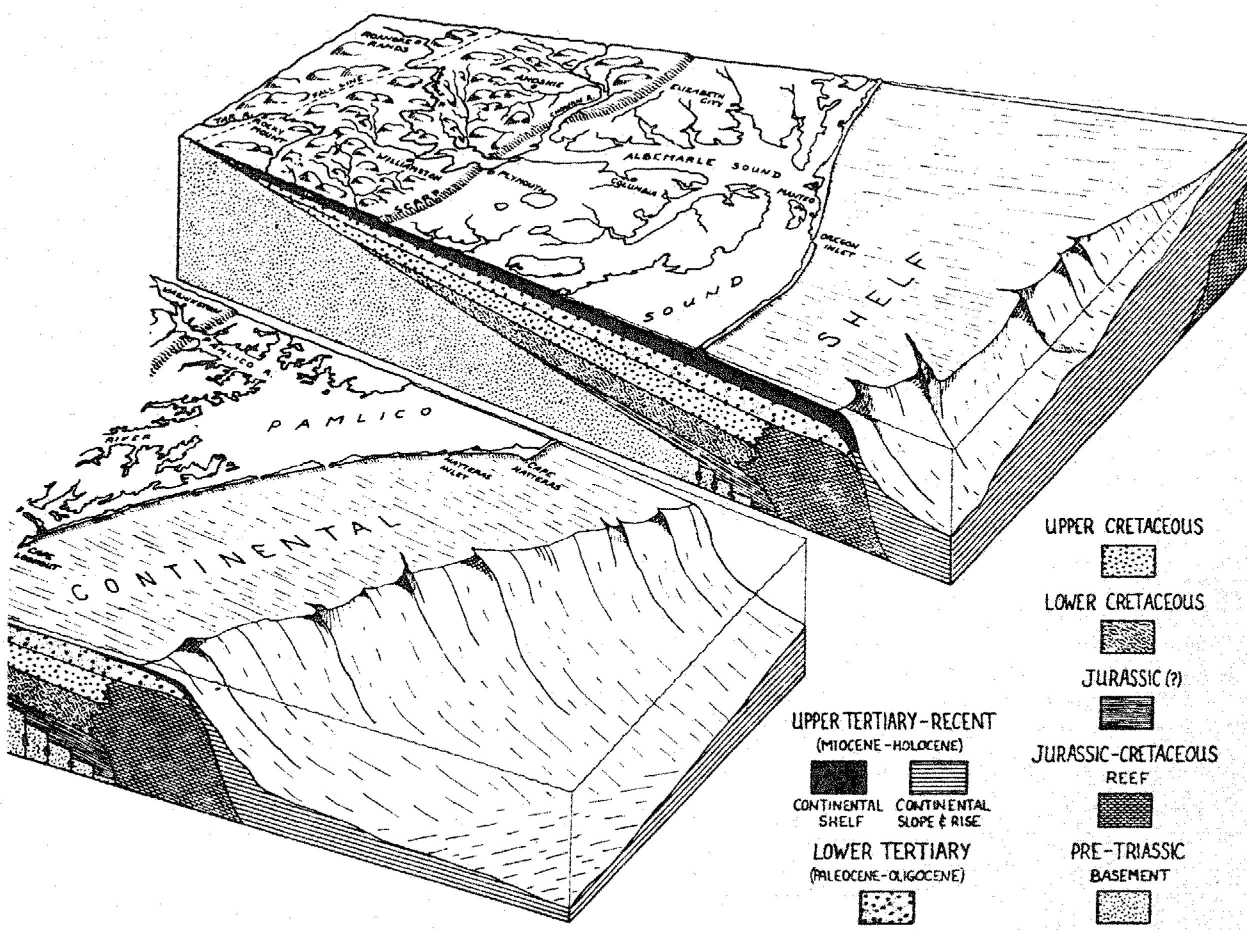

Figure 2. Cross-section of the stratigraphy of NE North Carolina (Fairbridge 1960).

tinental Shelf (Figure 2), to place the present-day estuary and its sediments in context. The uppermost veneer of unconsolidated sediments does have a direct bearing on the modern estuary. These sediments dictate the general characteristics of the estuarine system, including the general geometry and character of the estuarine margins and bottoms, as well as the topography, soil types, water drainage and use of the adjacent land areas.

The sediments of interest for the recent Pamlico River Estuary range from the Upper Miocene to the Pliocene (Table 1). The sediments deposited during this time of rapidly changing sequence in coastal environments (25 to 1 million years ago) are extremely varied and 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 groundwaters 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 industries along the Pamlico River are derived. The Pliocene and Pleistocene sediments range in thickness from a few meters up to twenty or more meters throughout the inner and middle estuarine areas (Table 1), increasing to 15 to 25 m in the Pamlico Sound area.

Table 1. Sedimentary deposits in the North Carolina coastal plain along a transect paralleling the Pamlico River Estuary.

Epoch	Formation	Thickness	Lithology
PLEISTOCENE	POST-CROATAN	3-15m	Quartz sands, quartz sandy clays; muds; & peats
	CROATAN	1-25m	Quartz, sandy & clayey shell beds; shelly quartz sands; & quartz sands
PLIOCENE	UPPER YORKTOWN	2-20m	Shelly & clayey quartz silts & sands
	LOWER YORKTOWN	2-4m	Clayey & shelly phosphorite quartz sands
MIOCENE	PUNGO RIVER	20-25m	Shelly dolomites; clayey & dolomitic phosphorite & quartz sands; phosphatic sandy dolomites and phosphatic quartz sandy moldic limestones

Recent sediments were formed during the Ice Ages of the Pleistocene, when the retreat and melting ice sheets brought about worldwide fluctuations in sea level (Figure 3). Development of ice sheets

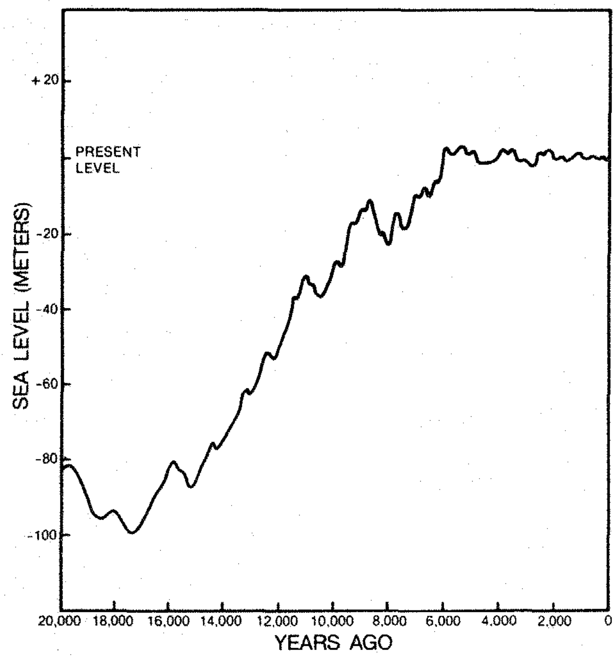

Figure 3. Fluctuations in sea level during recent times (Fairbridge 1960).

that covered vast areas of Europe, Asia, and North America required tremendous volumes of water. Consequently, the periods of ice advance were accompanied by a worldwide lowering of sea level by as much as 100 m (Fairbridge 1960). The last major glacial ice advance reached its maximum development approximately 15,000 to 17,000 years BP (before present). The shelf edge at that time was about 40 km east of Cape Hatteras. The land surface sloped gently seaward, and was dissected by the Tar River and associated tributaries with moderately deep channels and broad floodplains. The subarctic climate produced minimal vegetative cover (Whitehead 1965, 1981), resulting in maximum surface water discharge and sediment erosion.

The product of such an environment would have been coarse, sediment-choked, braided-stream systems, flowing across the coastal plain and discharging onto the continental shelf. The fact that coarse sands and gravels were deposited on the North Carolina Coastal Plain as cut and fill fluvial channel sediments during that period of time suggests that the climate was very wet.

The present rise of sea level began sometime after 17,000 years BP, when the climate began to warm again and glacial ice masses receded (Fairbridge 1960; Whitehead 1981). Thus, the sedimentary and physical character of the present Pamlico River Estuary system was defined. As the climate continued to warm, the vegetation slowly evolved into the hardwood and pine forests which characterize the Southeastern United States today. And, the estuarine system impinged landward across the continental shelf to its present position.

A major geomorphic feature, known as the Suffolk Scarp, or the Arapahoe Ridge, trends north to south across the western portion of the Pamlico River estuarine 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 the sea level was higher than it is at present. West of the Arapahoe Ridge, the terrain gently rises to the Piedmont. To the east is the Pamlico Terrace, a low, flat surface sloping from 3- to 5-m elevations, at the base of the Suffolk Scarp gently 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.

1.3. SETTLEMENT HISTORY

Early settlement by colonists in the area around the Pamlico River Estuary was slowed because of the absence of adequate access to the sea (Mauldin et al. 1979). Just as the present ecology is dictated by the long-distance relationship to the sea, the wide, shallow Pamlico Sound and barrier islands influenced the rate of the area's human development in the early days. The settlement of Virginia, beginning with Jamestown in 1607, was the nucleus for the colonization of North Carolina, and early communities began north of Albemarle Sound (Stick 1982). Southern migration continued, leading to the establishment of Bath on the Pamlico shore in 1704. Bath was an early capital of colonial North Carolina, and is the oldest incorporated town in the State. The main activities of the early settlers included timbering, fishing, and farming (Mauldin et al. 1979), which continue to be prominent today. The Pamlico River was an important colonial highway for the transport of goods.

The current population, while still relatively sparse, is slowly increasing with the advent of large agricultural operations on the Albemarle-Pamlico peninsula. Phosphate mining has become a major industry on the southern side of the estuary, and continues to attract additional development. The Intracoastal Waterway is a modern-day route for the transport of products from mines, forests, and farms.

1.4. BIOLOGICAL ZONES

The Pamlico River Estuary is characterized by low- to mid-salinity, high turbidity, and shallow water. The deep, central portion of the estuary has a muddy bottom, and during summer, is frequently without oxygen near the bottom (Tenore 1970). The shallow nearshore has a sandy bottom and, occasionally, dense stands of widgeongrass (Ruppia) with attached periphytic algae and associated animals, such as rotifers, nematodes, arthropods, and grass shrimp. Salinity, on the average, is 10 parts per thousand (ppt) or less in the estuary west of the entrance of South Creek, and between 10-20 ppt in the lower portion of the estuary (Giese et al. 1979).

The biological zones of the estuary are characterized by certain assemblages of benthic animals (Tenore 1970), which clearly delineate biological zones (Sanders 1965). The upstream sector, or the oligohaline (0.5-5 ppt) regime (Sections C and D in Figure 4), is dominated by the clam Rangia cuneata, the polychaete worm Nereis succinea, and their attendant community (Tenore 1970). The mid-sector, the mesohaline (5-18 ppt) regime (Sections E, F and G in Figure 4), is dominated by Macoma balthica and its more salt-tolerant community. A polyhaline zone of 18+ ppt salinity further downstream (Section H in Figure 4) has greater diversity. The community is dominated by the snail Retusa canaliculata and a large variety of benthic animals (Tenore 1970). These zones move up- and downstream with the seasonal variation of freshwater inflow, and the

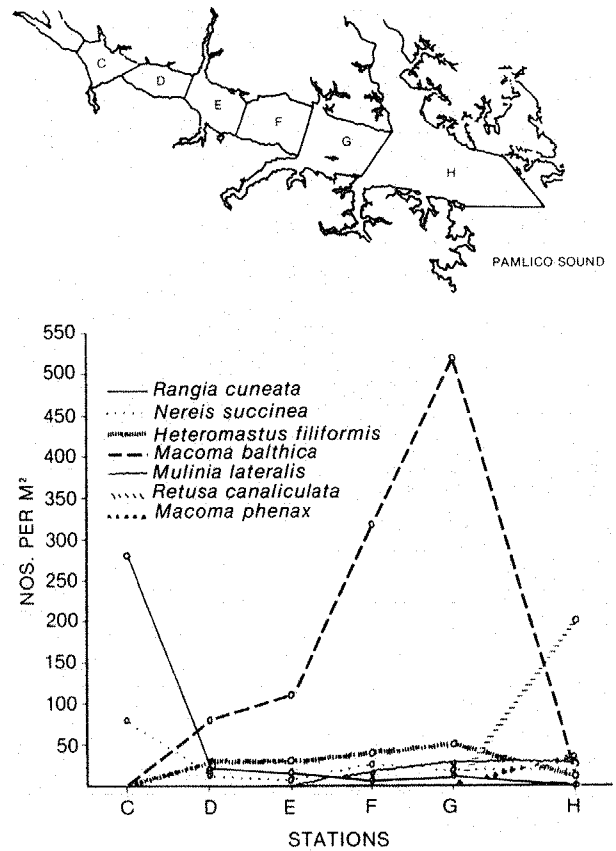

Figure 4. Biological zones of the Pamlico River Estuary, based on macrobenthic assemblages (Tenore 1970).

demarcations in biological communities become blurred (Copeland et al. 1974b). Benthic and water-column communities are detailed in Chapter 3.

1.5. POTENTIAL CONFLICTS AND IMPACTS

Since the estuary is so completely dominated by the flow of the Tar River, any activity on that river system is going to greatly influence what happens in the estuary. Land use patterns along the Tar River basin and municipalities along the river potentially conflict with other activities in the estuary and may adversely impact it. Major changes in the hydrologic regime have resulted from channelization, floodplain development, swamp drainage, and urbanization along the Tar River. Increased nutrients in the estuary (Hobbie 1974) may be a symptom of these changes (see Section 3.3). Exotic materials, such as pesticides, heavy metals, and organics, may also enter the estuary from upstream.

Downstream activites also create potential conflicts and impacts. The low-lying land around the estuary and the high water tables contribute to the potential for septic tank effluent contamination in the estuary. Commercially valuable shellfish beds in the lower estuary are threatened by bacterial and viral contamination from the developing watershed adjacent to the estuary. Drainage of the low-lying lands for agriculture and forestry represents a potential impact on the environment of shallow, localized estuarine areas. Discussion of the impact of localized land drainage on primary nursery areas will be the subject of Section 6.5 of this report. Effluent enters the estuary from phosphate mining operations on the southern shore. Additional phosphate inputs from recent effluents have not had serious impacts (Hobbie 1974), but additional mining volumes might create a problem in the future. Suggested management issues and possible management schemes are outlined in Chapter 6.

CHAPTER 2

DESCRIPTION OF THE ENVIRONMENT

2.1. ESTUARINE GEOLOGY

Suspended sediments carried by the Tar River are mixed with organic materials derived from the swamp forests and marshes, and settle out to produce the dominant bottom sediment of the Pamlico River Estuary. This brown-to-black, organic-rich mud, containing up to 15% organic matter (Giese et al. 1979), is deposited within the standing waters of the embayed estuaries. The level of sediment filling in the estuaries is controlled by the rising sea level and maintained by the physical dynamics of the coastal system. Periodic high energy floods and storms contribute new sediments, as well as recycling preexisting sediments, by eroding the estuarine shorelines and by scouring and resuspending the bottom muds. The muds become trapped and are deposited in the extensive salt marshes and in the adjacent embayed lateral estuaries.

The central portions of the Pamlico River Estuary and the adjacent embayed laterals are flat-bottomed with average water depths of between 2 and 5 m. These are generally muddy bottoms that grade laterally into a thin apron of very fine sand in the shallow waters around the estuarine perimeter (Folger 1972; Giese et al. 1979). The sand apron generally occurs landward of the main break in slope, at a depth of about one meter, and extends to the beach (Figure 5). Since the only major source of sand in the estuaries is from the erosion of the sediment bank shorelines, the distribution of sand is directly related to the sediment bank location, size, composition and rate of erosion (Bellis et al. 1975). The

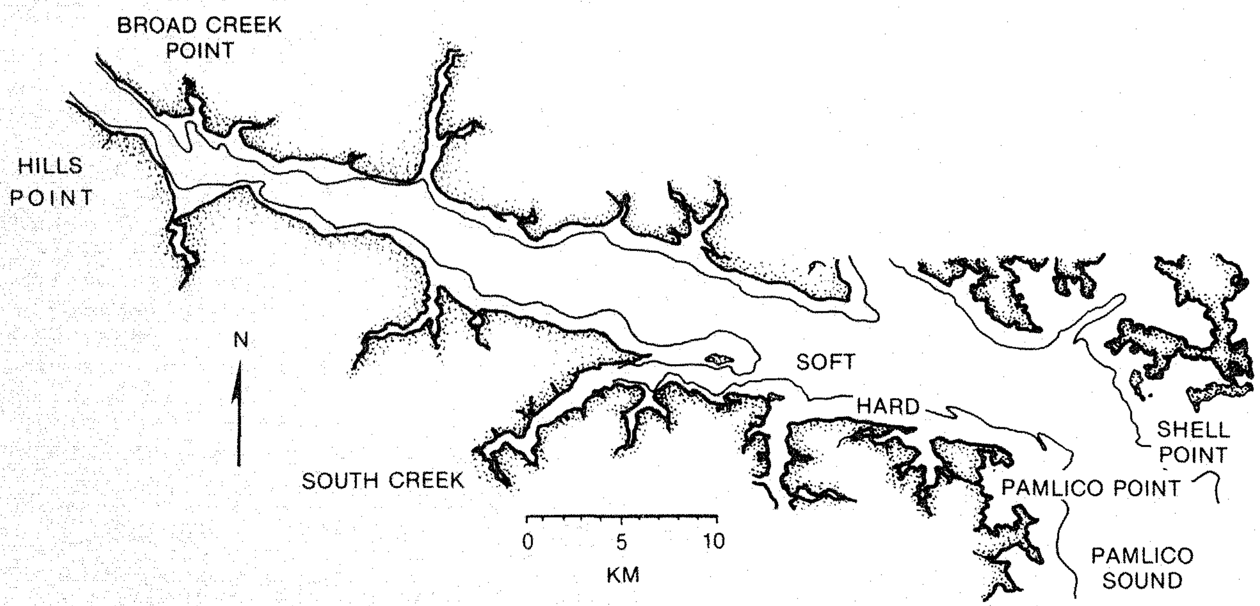

Figure 5. Distribution of bottom types in the Pamlico River Estuary (Reid 1970).

sediments in front of the marshes generally have very little sand, but contain more organic materials including abundant peat blocks, logs, and stumps.

2.2. SHORELINE CHARACTERISTICS

The Pamlico River Estuary is characterized by five different types of shorelines (Bellis et al. 1975). The entire Beaufort County shoreline, somewhat over half of the Hyde County shoreline, and the northern portion of the Pamlico County shoreline, from Goose Creek to Jones Bay, are all considered to be within the Pamlico River Estuary. The nature and distribution of the five different shoreline types for those counties are shown in Table 2.

Marshes

Marshes (Figure 6) constitute the most extensive type of estuarine shoreline (62%) in the Pamlico River Estuary system, occurring predominantly east of the Suffolk Scarp. Extensive marshes are most prevalent in the low-lying outer estuarine areas of Hyde and Pamlico Counties, where the slope of the land is low and the estuarine waters are moderately saline. The

Table 2. Composition and distribution (miles) of shoreline types of the Pamlico River Estuary (Bellis et al. 1975).

Type	Beaufort County	Hyde[a] County	Pamlico[a] County	Total (%)
Marsh	81	111	38	230(62)
Low bank	82	28	2	112(30)
High bank	19	0	0	19(5)
Bluff	5	0	0	5(1)
Swamp forest	7	0	0	7(2)
Total	194	139	40	373

[a]Only the portions of the county shoreline around the Pamlico River Estuary are included.

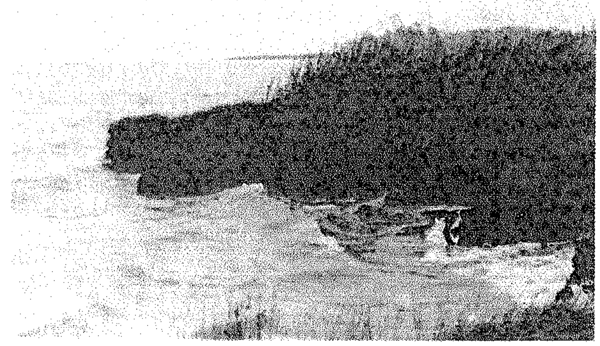

Figure 6. Marsh shoreline.

shorelines of the sub-estuaries along the middle of the Pamlico River (e.g., Pungo River, Bath Creek) contain less extensive marshes, but narrow fringing marshes along the shore. The extensive marshes of the outer estuary generally have the following characteristics:

1. The marsh grasses are primarily black needlerush (Juncus roemerianus) with lesser amounts of several species of cordgrass (Spartina);
2. The shorelines are irregular and consist of coves and headlands, ranging from a few meters to thousands of meters in width;
3. Marsh peats, thickest on the outer edge and thinnest on the landward edge, lap onto the upland forests;
4. The outer perimeter has vertical scarps that drop abruptly into 0.3 to 2 m of water; and
5. Shorelines are subjected to large etches in the outer estuarine areas, and erosion occurs at a rate of as much as 1 m/yr, depending upon the specific geographic location (Bellis et al. 1975).

These marshes grow on a peat substrate which consists of oxygen-deficient, water-saturated, black organic matter mixed with varying amounts of inorganic sediment trapped by the baffling effects of grass stems during storm tides. Below the surface is a live root zone, 30 to 60 cm thick. This tough mat of intertwined roots is underlain by a zone of soft, decayed, clayey peat, containing logs and stumps in the basal portion, on top of the old upland soil profile. As wave action and organisms attack the marsh's edge, the soft peat is undercut. Large blocks begin to slump, break off and sink to the bottom, where they are further broken down into fine organic detritus. This organic detritus is either redeposited with the estuarine sediments in front of the marsh, or is re-incorporated into the estuarine food chain (Benton 1979).

Rising sea level, which is about 10 to 25 cm per century in the Pamlico River Estuary, results in the gradual evolutionary succession of the marsh up onto the low slope. The landward extent of these marshes is limited by the height of flooding caused by regular astronomical tides, or by irregular wind tides and the topography of the land. Thus, as the marshes are being eroded along their outer perimeter, they are maintained by encroachment inland (Bellis et al. 1975).

Low Banks

Low banks (Figure 7), which constitute 30% of the total shoreline miles, are scattered throughout the Pamlico River Estuary (Table 2). Low-bank shorelines are sediment banks, composed of sand and clay, that have a relief of 0.3 to 1.5 m above mean water level. The base of the eroded low bank usually has a thin beach consisting of a thin and sporadic sand, or clayey-sand, sediment layer on top of a clay bed at or slightly below the water level. This clay bed usually extends into the offshore area and controls the bottom slope and water depths. Low banks are

Figure 7. Low bank shoreline.

generally vulnerable to direct waves and erode at a rate of about 0.75 m/yr (Bellis et al. 1975). Sometimes bank-top vegetation falls into the water and traps patches of sediment where clumps of marsh grasses can grow. If the wave energy is not too severe, the marsh grasses may expand to produce a fringing marsh along the base of a low bank.

High Banks

High-bank shorelines (Figure 8) have a relief of 1.5 to 6 m above mean water level, and comprise about 5% of the total

Figure 8. High bank shoreline.

shoreline miles (Table 2). High banks generally occur only in Beaufort County, and recede at a rate of about 0.5 m/yr, due to erosion (Bellis et al. 1975). Tight clays and sands cemented by iron compounds usually compose the lower 1.5 to 2.5 m of the bank, and are overlain by a bed of clean quartz sand. High banks are generally eroded during severe storms, when onshore waves overtop the sand beach and break directly on the base of the bank. As the bank becomes more undercut, the unstable overhang eventually collapses onto the beach. These fresh sediments, reworked by waves, temporarily broaden and stabilize the beach with a new layer of sand. Fallen trees and brush act as natural groins and temporarily help stabilize the beach. If vegetation of any form can become established, either on the beach or on the bank, it will absorb much of the wave evergy and decrease the rate and extent of shoreline recession (Bellis et al. 1975).

Bluffs

Bluff shorelines (Figure 9) are sediment banks, composed of sand and clay, that have a relief greater than 6 m above mean water level. These spectacular shorelines constitute about 1% of the Pamlico River Estuary shore and only occur along the southwestern side of the estuary associated with the Suffolk Scarp, and along the Talbot Terrace west of the scarp. Bluffs generally consist of tight clay and moderately to tightly cemented sandstone at the base, with unconsolidated water-bearing sands and clayey sands on top. The bluffs are generally receding at the average rate of 0.6 m/yr (Bellis et al. 1975).

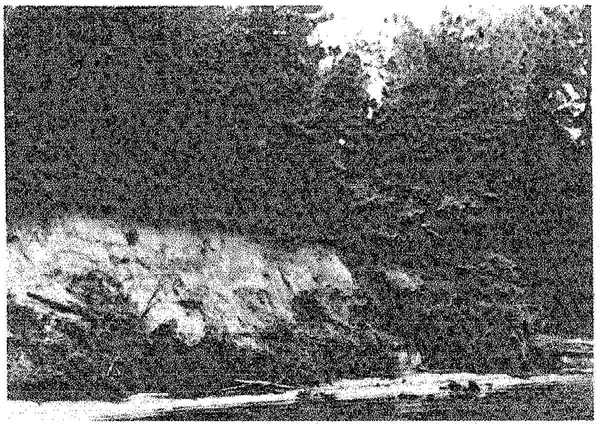

Figure 9. Bluff shoreline.

Swamp Forests

Swamp forests (Figure 10) constitute about 2% of the shorelines of the Pamlico River estuarine system. The cypress-gum swamp forests occur primarily along the river shore west of Washington, N. C. (where the swamp forests of the Tar River floodplain are being drowned out), the upper portions of Chocowinity Bay, and in the upper, freshwater regions of the lateral tributary creeks in Beaufort County. These old floodplains are characterized by an assemblage of cypress, gum, and maple trees. The average rate of shoreline recession is almost imperceptible, less than 2.5 cm/yr. As the gum and maple are drowned out by permanent flooding, the shoreline moves inland. It is often difficult to tell where the actual shoreline is, because the tree line does not neces-

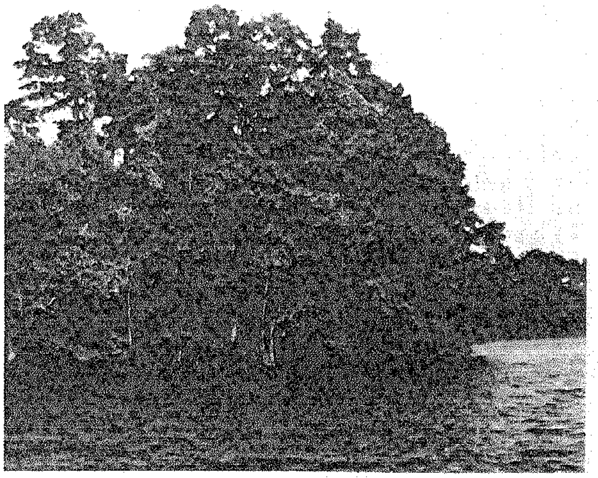

Figure 10. Swamp forest shoreline.

sarily follow the land-water interface (Bellis et al. 1975).

2.3. WATERSHED CHARACTERISTICS

Most (almost two-thirds) of the land around the Pamlico River Estuary is forested (Table 3). The amount of land taken up by urban areas and highways is small, amounting to about 5000 ha of the total 316,000 ha. All of the cities and towns on the Pamlico River Estuary, as well as those along the upstream sections of the Tar River, are small to medium size, with a total population of about 56,000 people living in the three counties adjacent to the estuary (1980 census). Land use on the watershed of the Pamlico River Estuary is rapidly changing (Heath 1975). Although cultivated land in the State as a whole is decreasing in area, the number of acres under cultivation in the lowlands between the Pamlico River Estuary and Albemarle Sound is increasing (Figures 11 and 12). For example, several thousand acres of forested land in Hyde County have been converted to agricultural uses in the past ten years (Lynch and Peacock 1982). Most of the mineralized soils (Figure 13) have traditionally been farmed, but agricultural activities are now increasing in the shallow organic soils and in some of the deep organic soils.

Due to low elevation and high water tables, land in the lower coastal plain must be drained for effective cultivation (Skaggs et al. 1980). With the increase in agriculture, there is now a network of canals carrying large amounts of fresh water to the estuary (Pate and Jones 1981). Drainage was first initiated in the late 1700's, but there are many more canals today (Lilly 1981). The latest period of increased drainage activity began in the early 1970's, when several large corporations became involved in clearing and developing thousands of acres of land in eastern North Carolina (Lilly 1981).

Another important land use in the watershed of the Pamlico River Estuary is mining for phosphate on the southern shore. One large company has been mining phosphate by strip-mining operations since the middle 1960's. More recently, another company has planned additional mining. Phosphorite ores are extracted from Miocene formations about 20 m in depth.

Table 3. Land use allocation (acres) around the Pamlico River Estuary (U.S. Soil Conservation Service 1977).

County	% of County	Total	Federal non-crop	Urban	Cropland	Pasture	Forest	Other
Pamlico	11	24,006	55	314	3,508	182	17,337	2,610
Beaufort	83	441,427	1,909	9,946	114,082	6,770	282,613	26,107
Hyde	78	316,493	39,000	2,051	51,333	780	184,612	38,717
Total		781,926	40,964	12,311	168,923	7,732	484,562	67,434
% of total			5	2	22	1	62	9

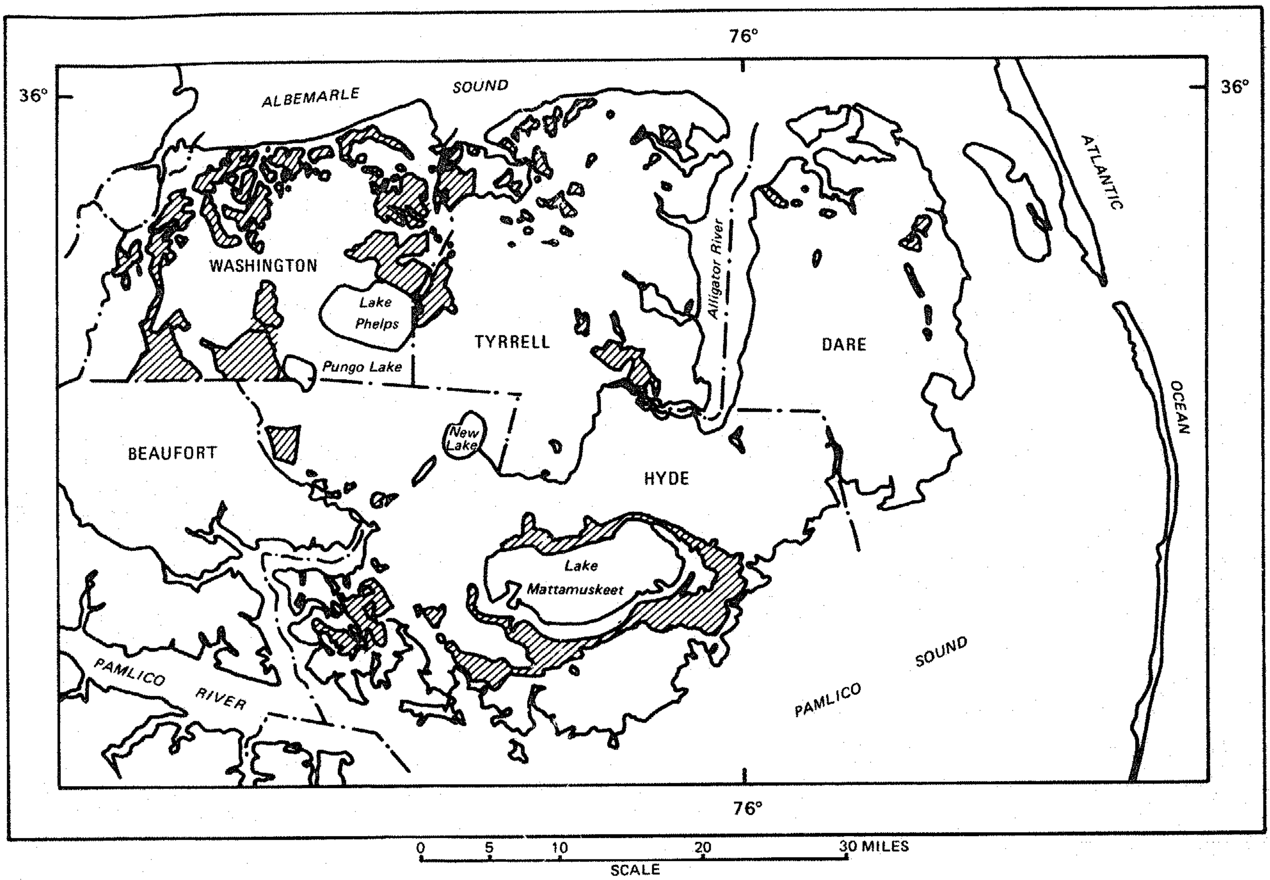

Figure 11. Cultivated land on the Albemarle-Pamlico peninsula, 1956 (Heath 1975).

Overburden (overlying sediments) is removed and groundwater pumped from the upper aquifer, so that the ore can be "stripped" from the formation. The pumped fresh water is discharged as surface water into the estuary, adjacent to the mining site. As areas are mined, the accumulated overburden is restored into the pits, leveled and planted to grasses for re-stabilization.

Unconsolidated sedimentary deposits (Figure 14), in which the ground water occurs, range in thickness from a few meters along the fall line to about 3,000 m at Cape Hatteras (Heath 1980). The ground water available in the coastal plain is mainly from the upper aquifer and the limestone aquifer (Wilder et al. 1978; Heath 1980). The upper aquifer yields the most water (Figure 15). It is a source of input to the streams and the estuary and is also the one most likely to be contaminated by land use activities. The water table from this aquifer lies very close to the surface in many of the low-lying areas around the Pamlico River Estuary.

2.4. CLIMATE

The climate in the Pamlico region is moderately mild and moist, creating a good environment for agriculture, forestry and

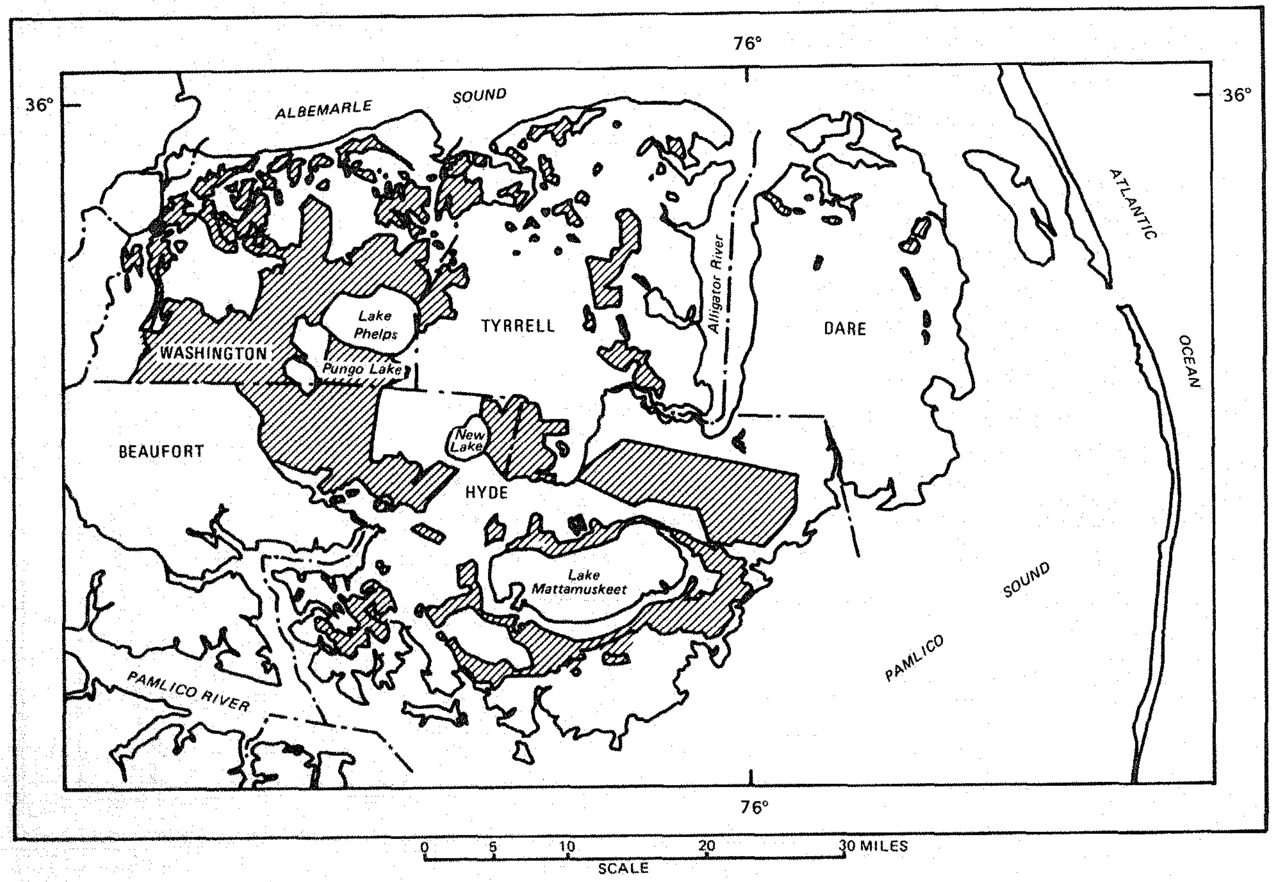

Figure 12. Cleared land on the Albemarle-Pamlico peninsula, 1973 (Heath 1975).

fisheries. Rainfall averages about 125-130 cm/yr along the coast (Clay et al. 1975). There are occasional years, however, of low rainfall that create shortages of surface waters (Figure 16). For example, significantly less than average rainfall was recorded near the estuary during the exceedingly dry years of 1919 and 1927 (Figure 16).

Distribution of rainfall throughout the year is reasonably uniform, with the highest precipitation associated with the summer months (Figure 17). The lowest amounts of rainfall occur during the fall, with a secondary low in the spring. Evapotranspiration exceeds rainfall only during April and May (Heath 1975).

The Pamlico River Estuary lies in a belt where the mean monthly temperature ranges between 6-8^{o}C in January and 28-30^{o}C in August (Clay et al. 1975). Winters are mild and summers are characterized by hot, humid days. Prevailing winds are in the S-SW quadrant, with an average wind speed of 15-16 km/h (Clay et al. 1975). Thunderstorms, hurricanes and tornadoes may occasionally create considerable winds, however. The highest wind velocities (N-NW during frontal movements) generally occur in winter, and the lowest

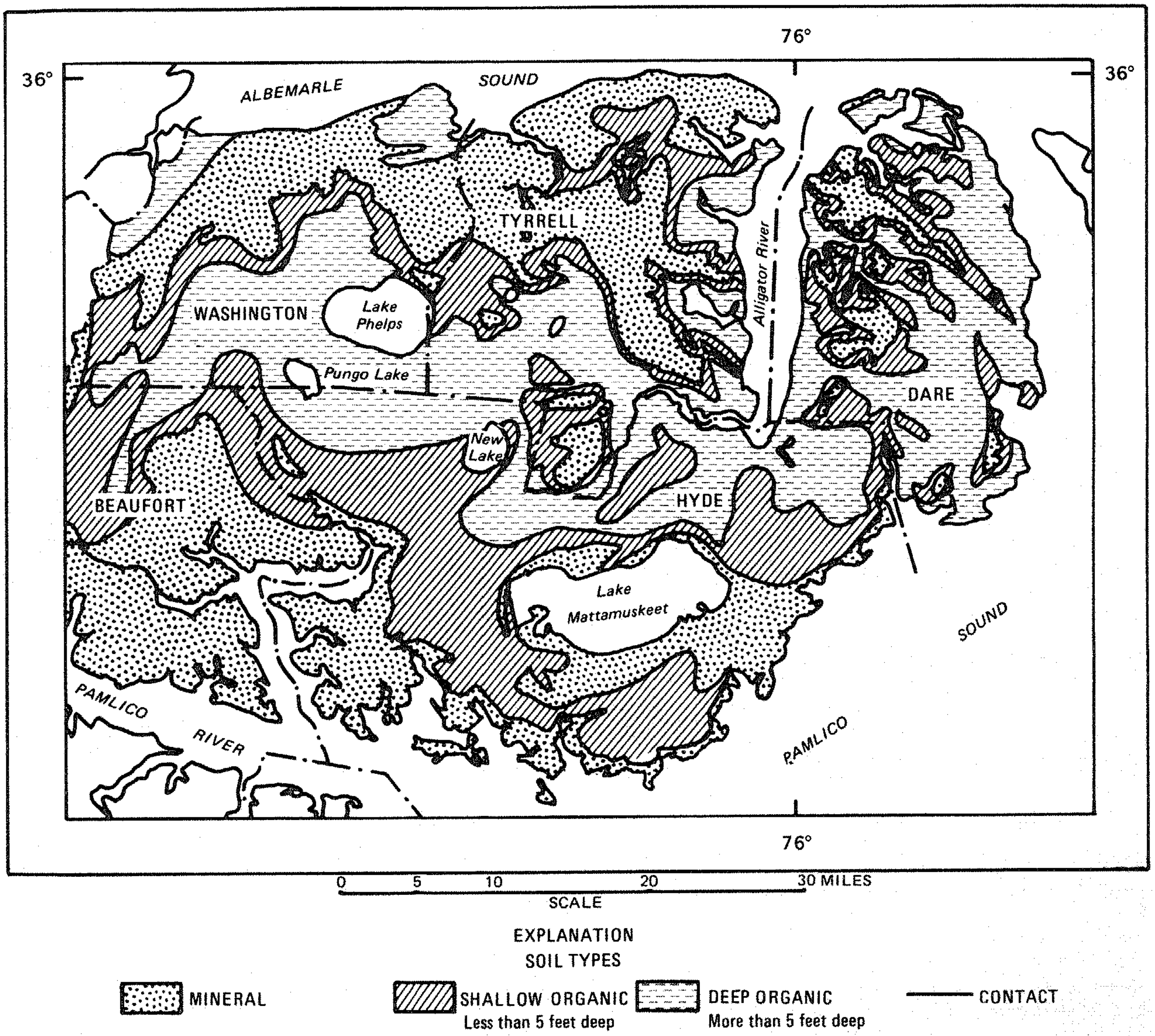

Figure 13. Generalized soils map for the Albemarle-Pamlico peninsula (Heath 1975).

wind velocities occur during the summer. Hurricanes occur infrequently, but when they do, most of the estuary can be filled with ocean water due to wind tides. The last major hurricanes occurred during the mid-fifties (e.g., Hazel in 1954).

2.5. HYDROLOGY

The major source of fresh water into the Pamlico River Estuary is the Tar River, which arises in the Piedmont and flows southeasterly across the State to

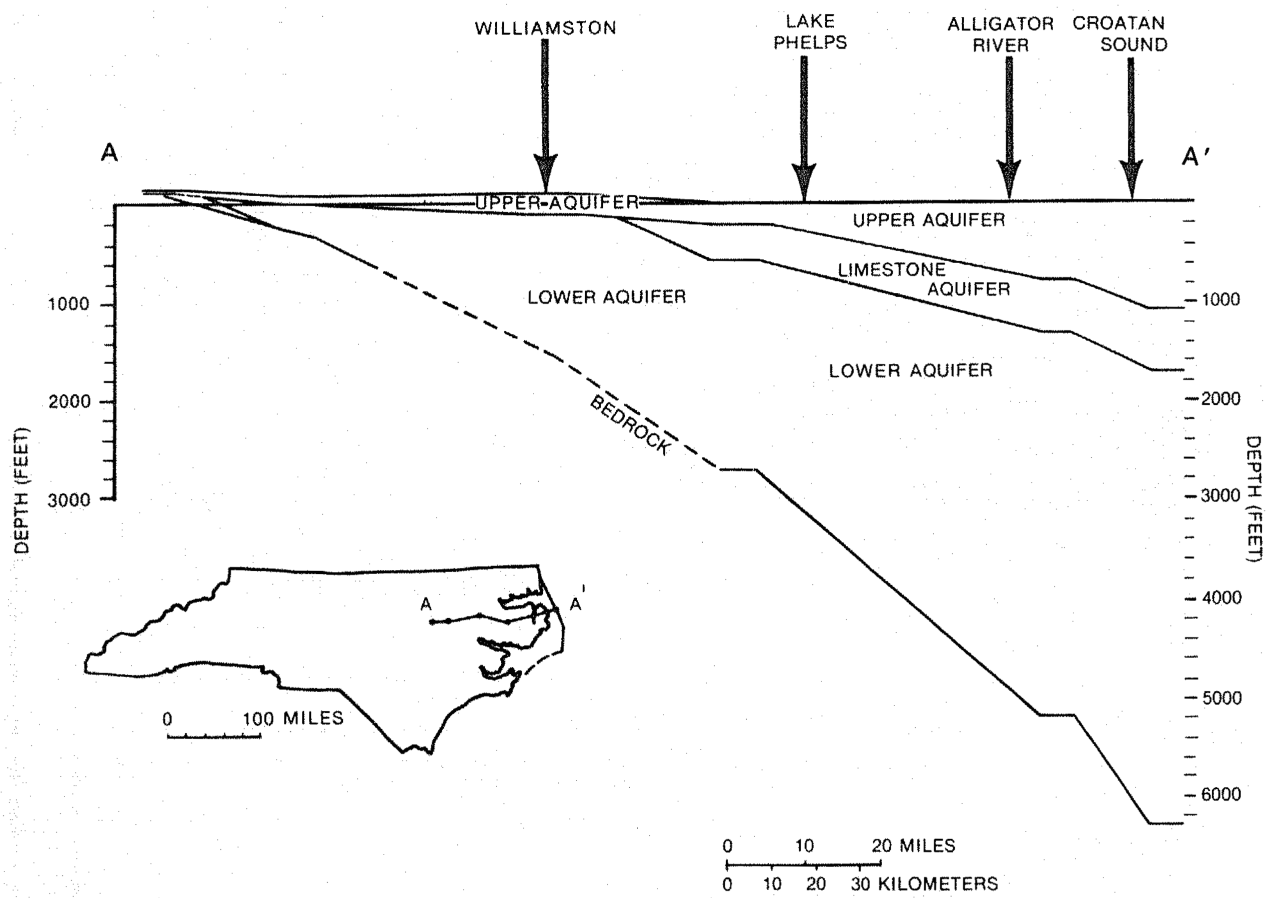

Figure 14. Cross-section of sediments and aquifers underlying the N.C. coastal plain (Heath 1980).

Washington, N.C. The Tar River drains 10,750 km^2, which is 77% of the entire (14,000 km^2) drainage basin of the Tar-Pamlico River system. As measured at Tarboro, N.C., the normal annual mean discharge in cubic feet per second (cfs) (Table 4) ranged from a low of 1,034 cfs in 1942 to a high of 4,057 cfs in 1960. The amount of runoff is highest during the late winter and early spring, with another slight increase during the mid summer. The mean normal monthly discharge of the Tar River at Tarboro, N.C., ranges between 1,147 cfs in October and 4,433 cfs in February (Table 5). Durham Creek, Pungo River and Bath Creek are smaller, but important, tributaries to the Pamlico River Estuary. Their inflows follow seasonal variations and annual fluctuations similar to those of the Tar River. Total average outflow from the entire system is about 5400 cfs annually (Giese et al. 1979).

Salt water penetrates the lower reaches of the Tar River and other tribu-

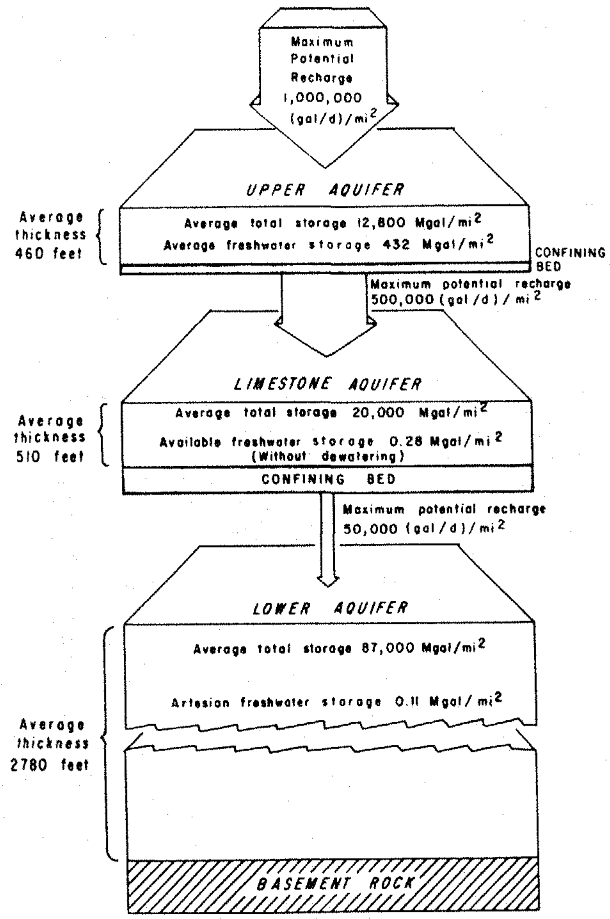

Figure 15. Estimated average amounts of recharge to and storage in the three major aquifers underlying the Pamlico River Estuary (Wilder et al. 1978).

taries, at least during periods of low freshwater flow. On occasion, salt water may penetrate upstream almost to the town of Grimesland, about 7.5 km from the mouth of the Tar (Giese et al. 1979). The channels of the lower portions of the tributaries are oversized for the amount of incoming freshwater they carry. Therefore, current velocities due to freshwater inflow are low.

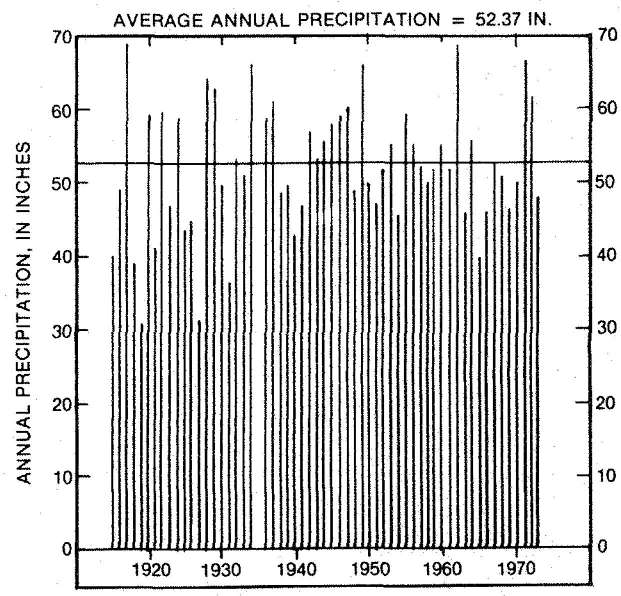

Figure 16. Annual precipitation at New Holland, N.C., 1915-73 (Heath 1975).

The estuary is separated from the ocean by Pamlico Sound and the Outer Banks. Therefore, the lunar tide influence in the estuary is minimal (Giese et al. 1979). The average tidal flux in the estuary is less than 15 cm. The basin is shallow and there is only occasional vertical stratification. Thus, circulation in the estuary is primarily influenced by winds and freshwater inflow.

Water levels in the Pamlico River Estuary are very sensitive to winds (Figure 18). The highest water levels in the Pamlico River Estuary occur when the wind blows directly upstream (i.e., E-SE). Winds from the opposite direction (i.e., W-NW) have an effect of producing low water levels (Giese et al. 1979).

The shallow estuary averages only about 3.3 m deep (Giese et al. 1979), with the deepest portion at about 7 m in the main channel, near its juncture with Pamlico Sound. A depth profile along the main channel of the estuary is typical of

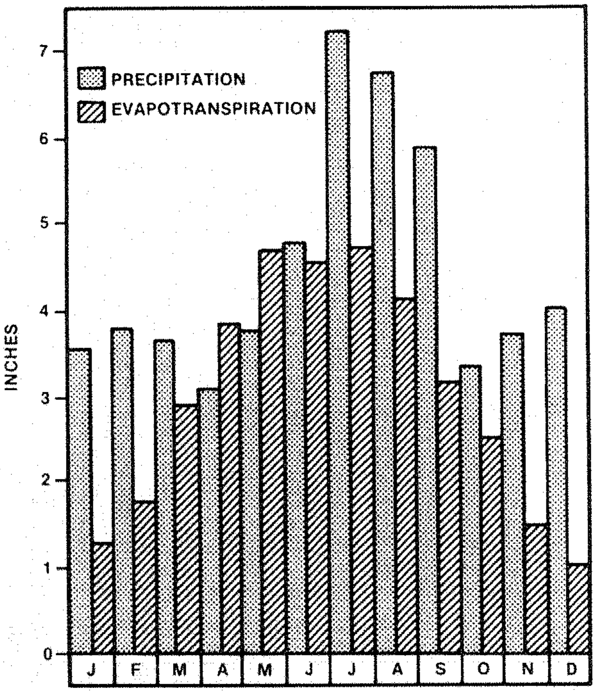

Figure 17. Mean monthly precipitation and evapotranspiration at New Holland, N.C. (Heath 1975).

coastal plain estuaries. The total volume of the Pamlico River Estuary, including the open-water segment of the Pungo River, is about 2 billion cubic meters (Giese et al. 1979).

A navigation channel, 60 m wide and 3.6 m deep, is maintained in the estuary by the U. S. Army Corps of Engineers, from the mouth of the estuary to Washington, N.C., about 65 km upstream. The Intracoastal Waterway crosses the estuary from the Pungo River to Pamlico Point. There is also a ferry turning basin just east of Bath, N.C., on the north side and near Hickory Point on the south side. The ferry channels are maintained by the N.C. Department of Transportation.

Table 4. Normal annual mean discharge (cfs) of the Tar River at Tarboro, N.C., 1897-1978. (Data from U.S. Geological Survey, Raleigh, N.C.)

Year	Mean discharge (cfs)	Year	Mean discharge (cfs)
1897	2,212	1953	2,193
1898	1,639	1954	2,229
1899	3,474	1955	1,952
1900	2,284	1956	1,948
1901-1931	No record	1957	2,000
1932	1,136	1958	3,647
1933	1,728	1959	2,623
1934	1,760	1960	4,057
1935	2,532	1961	2,325
1936	3,346	1962	2,347
1937	3,527	1963	1,775
1938	2,236	1964	1,933
1939	3,068	1965	2,689
1940	2,234	1966	1,478
1941	1,492	1967	1,149
1942	1,034	1968	1,394
1943	2,277	1969	1,821
1944	2,044	1970	1,755
1945	3,403	1971	1,652
1946	2,676	1972	2,566
1947	1,479	1973	3,332
1948	2,721	1974	2,080
1949	3,000	1975	3,117
1950	1,470	1976	1,517
1951	1,117	1977	1,519
1952	2,252	1978	3,002

2.6. AQUATIC ENVIRONMENT

Wetlands around the Pamlico River Estuary are generally classified as three types: swamp forests, pocosins, and irregularly flooded marshes. Due mainly to the lack of lunar tide, there are few acres of regularly flooded salt marsh around the Pamlico River Estuary (Wilson 1962; Bellis et al. 1975). By far the majority of wetland area is in pocosins (Table 6), about 75% of the total wetlands in the counties adjacent to the estuary.

The wooded swamp is characerized by a long period during which water stands, although the floor may be dry during a portion of the growing season. The peaty or mucky soil supports characteristic hardwood trees. The three most common canopy trees are black gum, tupelo gum,

Table 5. Monthly mean discharge (cfs) of the Tar River at Tarboro, N.C. (Data from U.S. Geological Survey, Raleigh, N.C.)

Month	Mean discharge (cfs)
January	3,261
February	4,433
March	4,187
April	3,164
May	1,848
June	1,229
July	1,457
August	1,543
September	1,347
October	1,147
November	1,267
December	2,102

and bald cypress, in single stands or in combinations. Nutrient release in the wooded swamp is slow with most of the nutrients being held in the sediments (Woodwell 1958), which act as a filter for the neighboring estuary.

Irregularly flooded salt marshes border the estuary along much of its shoreline (Table 2). Black needlerush (Juncus roemerianus) characterizes the lower elevations. Salt meadow cord grass (Spartina patens) and salt grass (Distichlis spicata) grow in higher elevations. The irregularly flooded salt marsh is thought to contribute organic matter to the estuary during times of flooding (Wilson 1962), although there is considerable controversy as to the magnitude of the contribution.

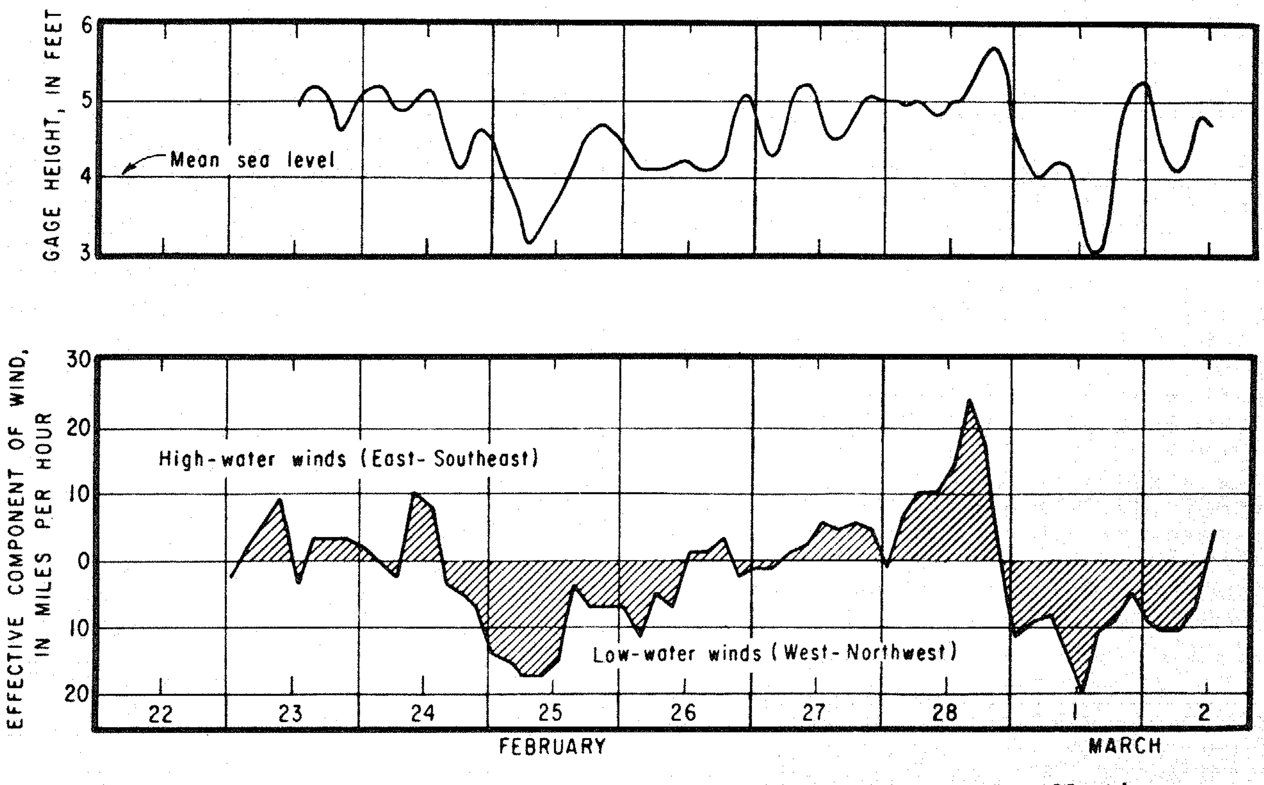

Figure 18. Response of water levels in the Pamlico River Estuary to the effective component of wind speed, 23 February to 2 March 1966 (Giese et al. 1979).

Table 6. Approximate acres of wetlands by county in the vicinity of the Pamlico River Estuary (Wilson 1962).

County	Area	Wooded swamp	Pocosins	Irregularly flooded marshes
Beaufort	532,000	21,850	119,700	4,500
Hyde[a]	203,000	17,300	108,350	16,650
Pamlico	218,000	3,450	40,300	15,000
Totals	953,000	42,600	268,350	36,150

[a]Only half of Hyde County is regarded as being within the Pamlico River Estuary watershed.

The aquatic environment of the Pamlico River Estuary is typically oligohaline/mesohaline, i.e., below about 18 ppt (Hobbie 1970b, Heath 1975; Cowardin et al. 1979). The average surface salinity of the Pamlico River Estuary is generally lowest during spring and does not usually exceed about 30% (10-12 ppt) seawater (Figure 19). Surface water salinity gets as high as 50% (16-18 ppt) seawater or more (Figure 20), during the drier months of late fall and early winter. Salt water penetrates on the bottom of the estuary all the way to the mouth of the Tar River near Washington, N.C., during most of the year (Hobbie 1970b). During the drier fall months, salinity concentrations on the bottom of the estuary near the mouth of the Tar River may be as high as 10 ppt (Hobbie 1970b). Due to the shallowness of the estuary and the prevailing winds, intense salinity stratification only occurs during the calm, dry periods of late summer and early fall (Davis et al. 1978), and during short periods following intense freshwater runoff (Hobbie 1970b).

Mean monthly water temperatures in the Pamlico River Estuary range between about $5^{\circ}C$ during January to about $27^{\circ}C$ during July and August (Figure 21). There are fluctuations about these means, so that the extremes in the estuary are as low as $0^{\circ}C$ and as high as $30^{\circ}C$ (Hobbie 1970b).

During late summer, water stratifies in the deeper areas, which lose most of their dissolved oxygen. The vertical stratification is induced by low wind velocities, high surface turbidity, and high surface water temperatures during that time. Stratification may also begin when local late-summer thundershowers result in sudden freshwater inflows. Sinking organic matter in the estuary may then contribute to a decrease in the dissolved oxygen supply near the bottom. The low oxygen conditions during the late summer result in fish kills, sometimes of tremendous proportions (N. C. Division of Marine Fisheries data). During other seasons the dissolved oxygen seems to be adequate to support fish populations (Hobbie 1970b; Davis et al. 1978).

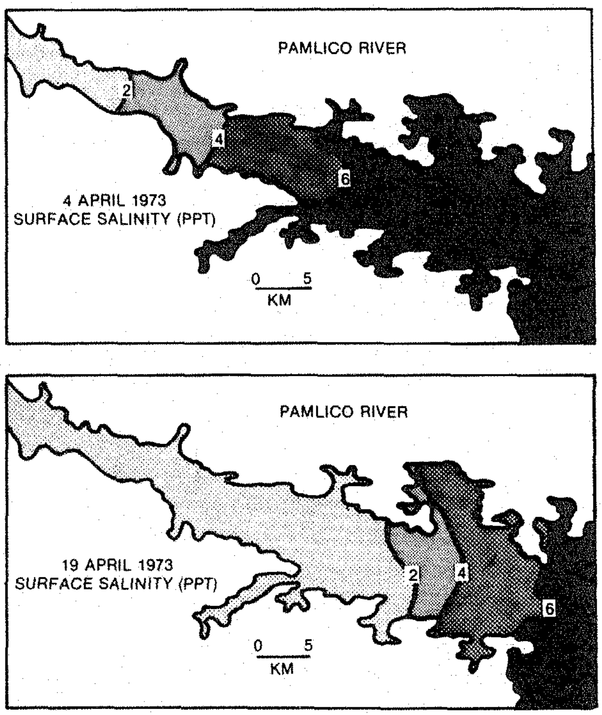

Figure 19. Surface salinity in the Pamlico River Estuary during spring (Hobbie 1974).

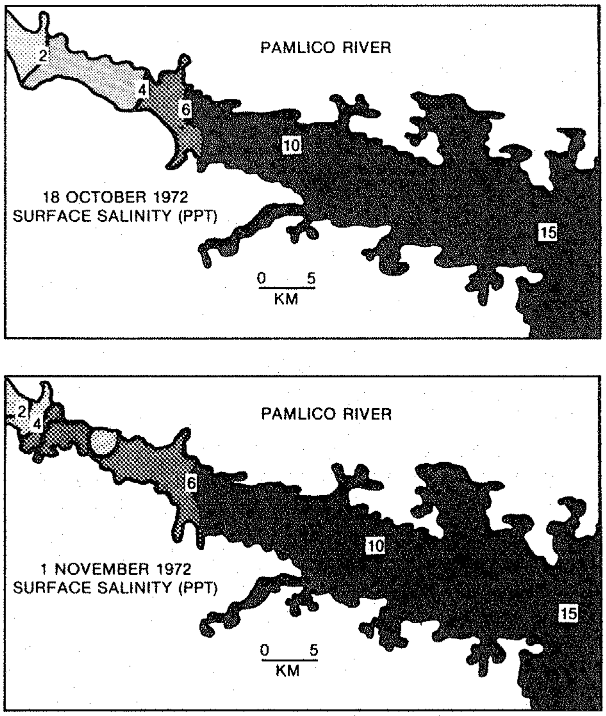

Figure 20. Surface salinity in the Pamlico River Estuary during fall (Hobbie 1974).

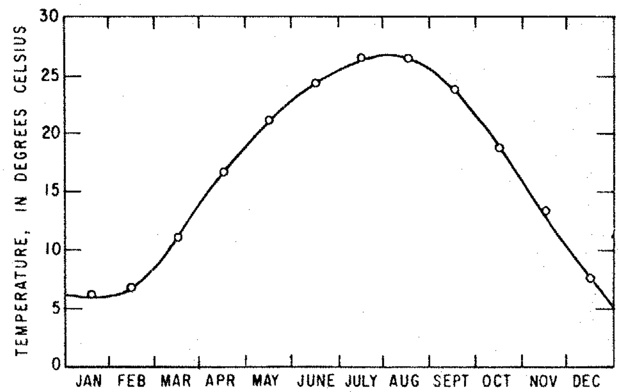

Figure 21. Average monthly temperature of the Pamlico River Estuary at Washington, N.C. (Giese et al. 1979).

CHAPTER 3

BIOLOGICAL CHARACTERISTICS

3.1. PRIMARY PRODUCERS

Phytoplankton are an important biological component of the Pamlico River Estuary. Changes in the quality and quantity of phytoplankton are thought to be basic to the health and well-being of the estuary. As is characteristic of most estuaries, phytoplankton abundance in the Pamlico River Estuary shows extreme patchiness (Figures 22 and 23). Over a small range of space and time, phytoplankton abundance can vary over orders of magnitude (Hobbie 1971). Sampling on a daily basis at one place in South Creek (Figure 22) for 56 days yielded algal biomass ranging from less than 1 mg/l to nearly 100 mg/l. Similarly, samples from several places in the estuary on the same date (Figure 23) yielded mean biomass from less than 1 mg/l to nearly 50 mg/l. This variability from day to day, from place to place and from depth to depth, makes it difficult to place confidence in estimates of phytoplankton biomass based on a few samples and/or discreet sampling points in an estuary (Hobbie 1971).

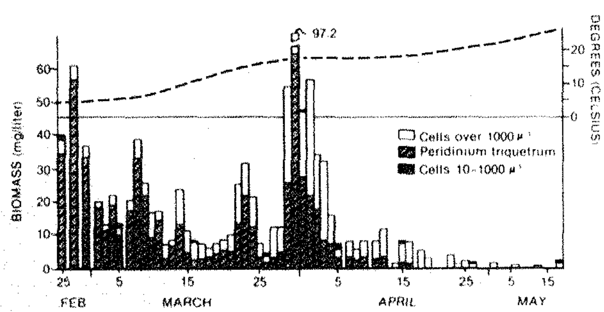

Figure 22. Algal biomass in South Creek, February-May, 1968 (Hobbie 1971).

Phytoplankton abundance and biomass in the Pamlico River Estuary exhibits two peaks during the year (Hobbie 1971), the first during winter and early spring, and the second during the summer (Figure 24). The maximum abundance occurs in the middle and upper reaches of the estuary, where a dinoflagellate (<u>Heterocapsa equiperidinium triquetra</u>, formerly <u>Peridinium triquetrum</u>), attains bloom levels at times during January to April. In the upper portions of the estuary, the late summer peak is also dominated by dinoflagellates. Farther down the estuary, where salinities are higher, the dominant phytoplankton are composed of diatoms characteristic of more mesohaline east coast estuaries (Hobbie 1971; Kuenzler et al. 1979). Densities are extremely variable, with ranges of 1 to 300 million cells/liter during the winter-spring blooms and 1 to 100 million cells/liter in the summer peak.

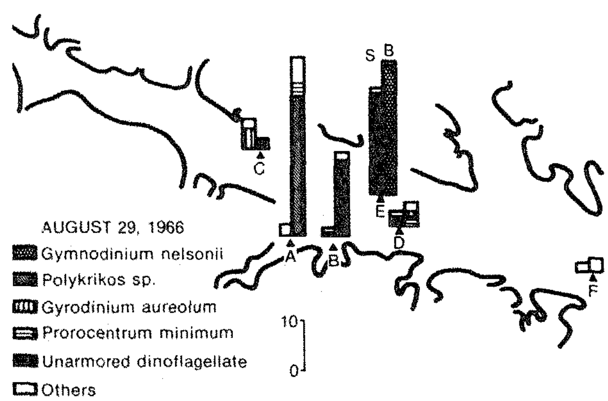

Figure 23. Biomass (mg/liter) of phytoplankton in the Pamlico River Estuary at surface (S) and bottom (B) stations, August 1966 (Hobbie 1971).

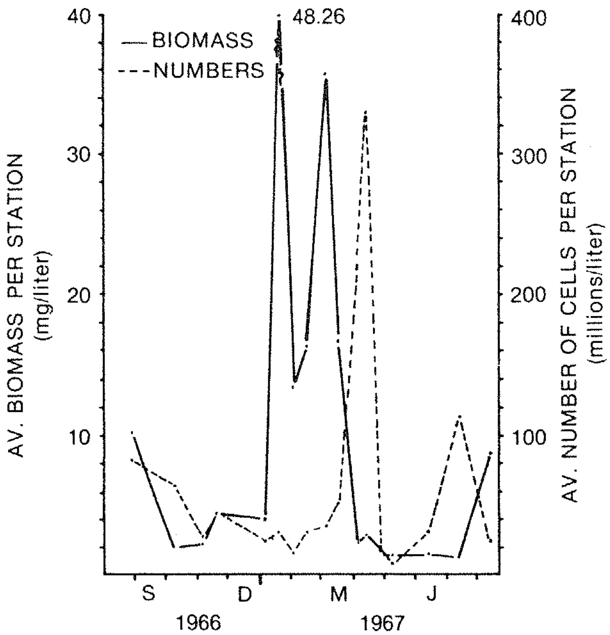

Figure 24. Average algal biomass and numbers in the Pamlico River Estuary, 1966-67 (Hobbie 1971).

The periods of maximum algal numbers, however, are somewhat out of phase with the periods of maximum algal biomass (Figure 24). The dominant dinoflagellate (*Heterocapsa*) in the winter-spring bloom is of medium size (about 3,200 μ^3), and creates a large biomass peak with relatively low numbers during the winter. The cell number peak in April is made up of primarily small blue-green algae, less than 10 μ^3 in size. The summer peak is diverse, with a larger number of genera attaining moderate to high numbers (e.g., *Gymnodinium*, *Gyrodinium*, *Polykrikos*, and unidentified flagellates).

Chlorophyl *a* is a good indicator of phytoplankton abundance. Chlorophyll *a* distribution patterns (Figure 25) indicate seasonably high biomass in the upper reaches of the estuary and low biomass in the lower reaches (Kuenzler et al. 1979). On the average, phytoplankton concentrations are maintained between the upper to middle sections of the estuary (Hobbie 1971; Kuenzler et al. 1979). As

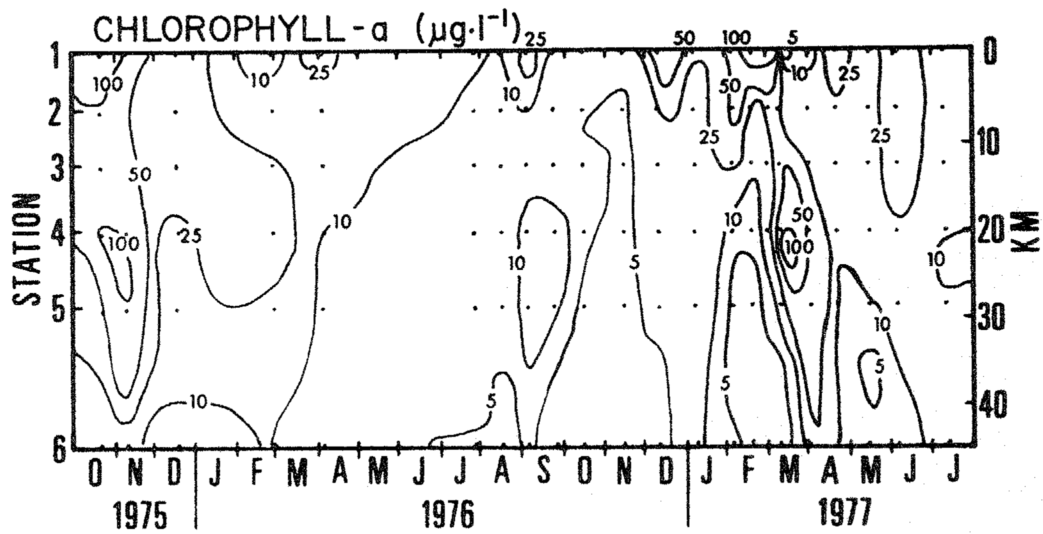

Figure 25. Chlorophyll *a* distribution in surface waters of the Pamlico River Estuary (Kuenzler et al. 1979).

river flow flushes the estuary each spring, zones of high biomass concentrations are displaced downstream. For example, Kuenzler et al. (1979) found that the phytoplankton volume of 46 mm^3/l at the upstream station on 20 February 1977 had dropped to 0.2 mm^3/l when they sampled there on 12 March 1977. The concentration at a mid-estuary location increased from 1 to 39 mm^3/l on those two dates, respectively.

The photosynthetic rate (using the C^{14} technique) of phytoplankton in the Pamlico River Estuary reflects the general pattern of chlorophyll distribution. The highest productivity occurs during the spring and during late summer/early fall (Figure 26). There is a general decrease down the estuary, with an average in the upper portion of the estuary of 6 μg-at of carbon/liter/hour compared to 2.5 μg-at of carbon/liter/hour at downstream stations (Kuenzler et al. 1979). Productivity seems to follow phytoplankton biomass distribution.

There appears to have been little or no change in the dominant species composition of phytoplankton in the estuary between the 1966-68 study period by Hobbie (1971) and the 1975-77 study period by Kuenzler et al. (1979). This is also true of the abundance of phytoplankton and the photosynthetic productivity. Thus, the estuary, while called eutrophic by Hobbie (1971), seems to have maintained its characteristic phytoplankton identity at least since 1966-68.

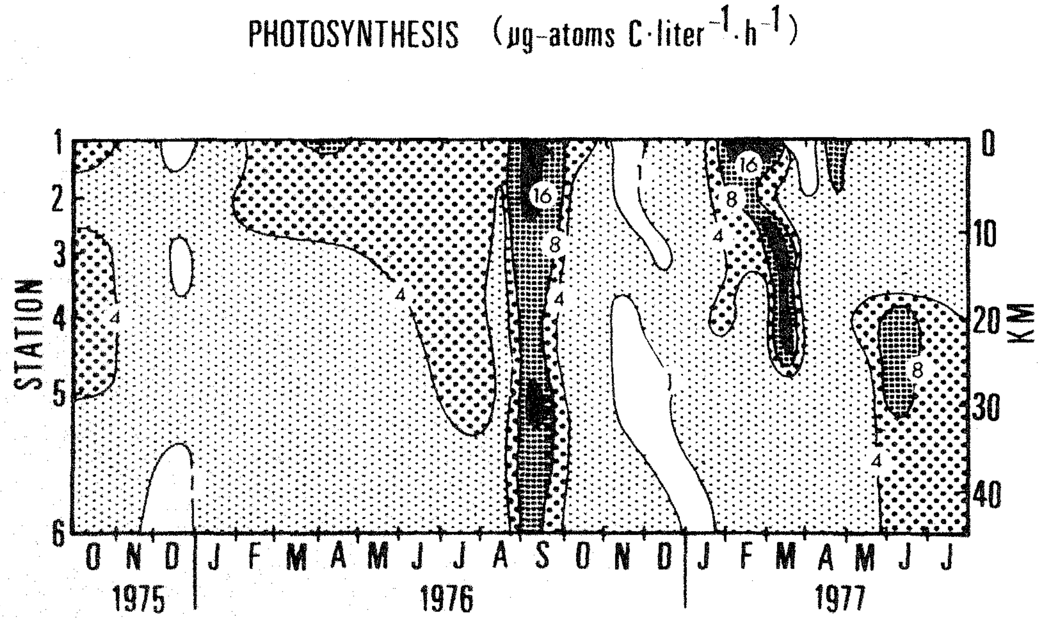

Figure 26. Seasonal patterns of primary productivity in the surface waters of the Pamlico River Estuary (Kuenzler et al. 1979).

A detailed study of the total biomass of rooted aquatic plants in the Pamlico River Estuary by Davis and Brinson (1976) included a complete survey along the 60-km length of the estuary (Figure 27). The dominant attached plant was Vallisneria sp., which contributed the most biomass in the upstream 30 km. Potamogeton sp. and Najas sp. were also common throughout the same area. Several dense beds of Ruppia sp. were observed, especially along the southern shore near Indian Island. The total estimated biomass (Table 7) accounted for almost 200 tonnes organic weight in the estuary during August 1975. The highest density of attached aquatic plants occurred in water depths of 50 to 90 cm (Figure 27).

The attached aquatic plant communities showed a general response over various physical gradients (Davis and Brinson 1976). Many of the plants were sensitive to salinity levels and the degree of light penetration in the water. Vallisneria, the dominant plant in the estuary, was either absent or replaced by Ruppia at the downstream sampling sites, and during times when salinity was slightly higher upstream.

There was a strong seasonal pattern in the abundance and biomass of the attached aquatic plants (Figure 28). Following the summertime productivity, peak standing crop biomass was achieved during early fall, before the decline of day length and temperatures in late fall (Davis and Brinson 1976). Ruppia did not change appreciably over the annual cycle in terms of average biomass; but, in comparison with Vallisneria, it contributed more toward total biomass during the winter and spring. Some filamentous algae are present in the estuary in scattered, localized dense clumps (Davis and Brinson 1976), primarily Compsopogon and Enteromorpha. They form dense shoreline mats that can disrupt fishing by clogging nets. They generate objectionable odors when they decay. They do not, apparently, contribute much to the overall productivity (Table 8). The net primary productivity of the macrophytic plants for the whole estuary amounts to about 1.7% of the total (Table 8). Since they occupy less than 1% of the total area (Davis and Brinson 1976), their productivity is differentially higher on an areal basis. Compared to phytoplankton (17,100 tonnes/year vs. 301 tonnes/year) their total contribution seems small; but, in the nearshore shallow environment, macrophyte production is important.

3.2. DETRITUS AND ORGANIC CARBON

Determining the sources and standing crop of organic matter is fundamental to understanding the functional aspects of an estuary. Many estuaries rely on the input of allochthonous organic materials to support their productivity (Teal 1962; Odum and de la Cruz 1967). It has been assumed that, due to the large inflow from the Tar River and other contributaries, and many miles of fringing marsh shorelines, the Pamlico River Estuary has relied on allochthonous organic carbon to support its secondary productivity (Copeland et al. 1974b). Recent studies (Davis et al. 1978; Kuenzler et al. 1979), however, have concluded that autochthonous organic carbon is extremely important, and perhaps is the source of the bulk of the organic carbon cycled in the estuary.

Surveys of organic carbon in the Pamlico River Estuary (Sick 1977; Davis et al. 1978) show that the highest concentrations occur upstream and the lowest concentrations downstream (Table 9 and Figure 29), lending credence to the idea that allochthonous carbon inputs are large. Undoubtedly, the large watershed ensures that organic carbon in the estuary has

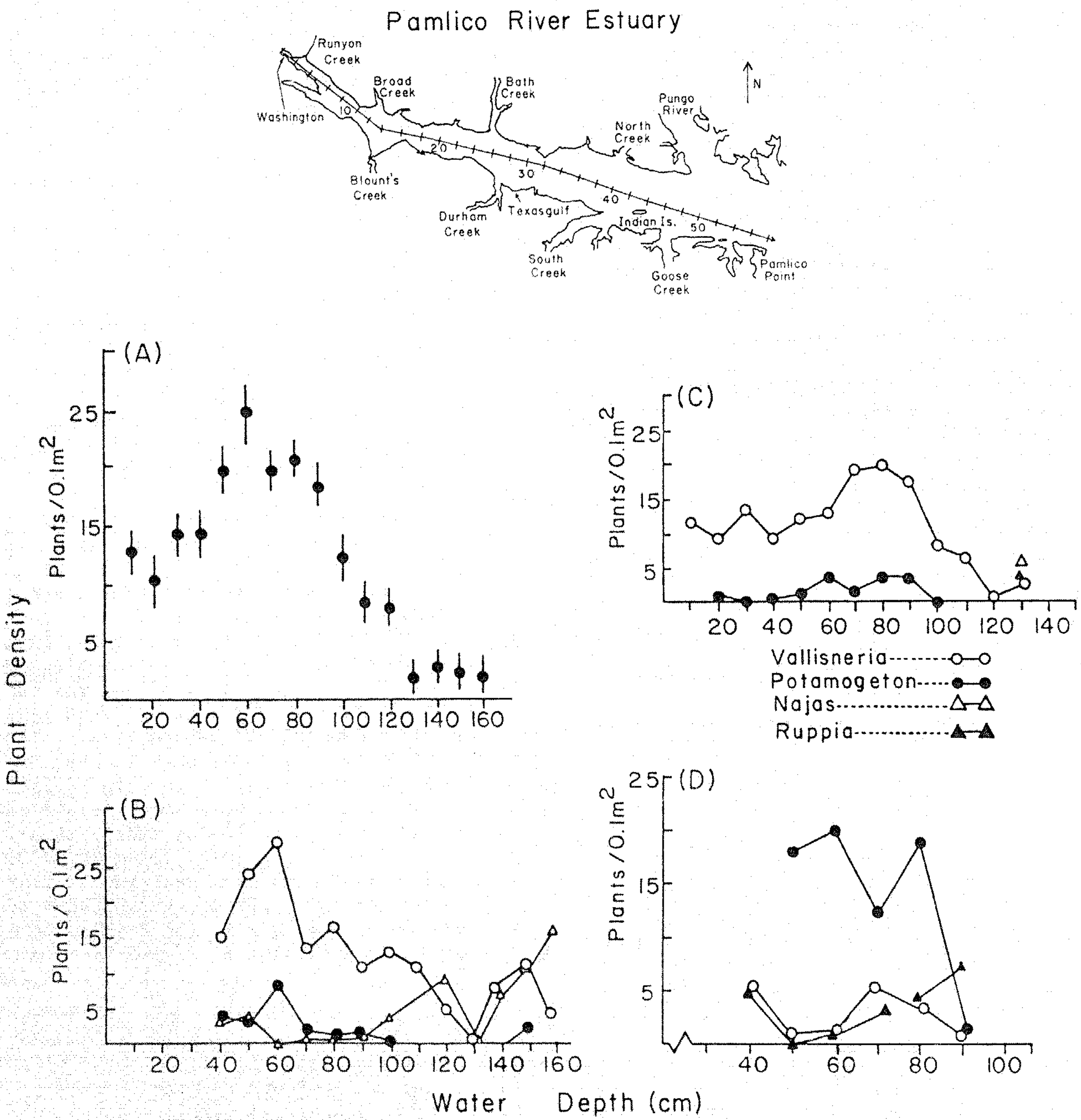

Figure 27. Plant density as a function of water depth for transects perpendicular to the shoreline along the Pamlico River Estuary. Map shows transect locations along mid-estuary. A: all species and strata; B: km 10-17 (see map above); C: km 17-25; D: km 25-32 (Davie and Brinson 1976).

Table 7. Estimated total biomass of rooted aquatic macrophytes in the Pamlico River Estuary (tonnes organic weight) (Davis and Brinson 1976).

North Shore	km 0-10	km 10-18	km 18-23	km 23-30	km 33-40	Total
July 1974	---	9.16	5.71	14.40	0.001	29.30
August 1974	---	17.70	10.20	2.30	0.003	30.20
August 1975	17.30	12.20	26.70	10.60	0.000	66.80
South Shore	**km 0-10**	**km 10-13**	**km 13-16**	**km 16-29**	**km 43-44**	**Total**
July 1974	---	10.30	17.70	16.00	0.072	47.10
August 1974	---	17.40	18.90	32.20	0.009	73.40
August 1975	12.30	24.80	17.00	72.40	0.000	131.00

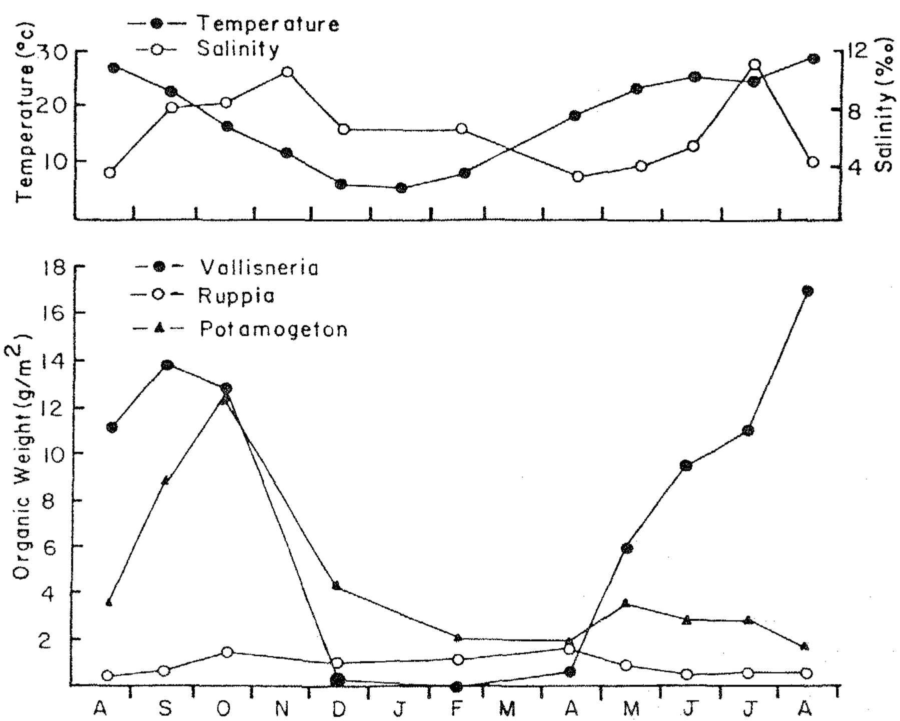

Figure 28. Seasonal trends in biomass (ash free dry weight) for the three dominant rooted macrophytes, August 1973-74 (Davis and Brinson 1976).

Table 8. Comparative annual estimates of net primary productivity and accumulation of nitrogen and phosphorus in rooted aquatic macrophytes, filamentous algae and phytoplankton (Davis and Brinson 1976).

Production or accumulation	g/m^2 of Plant Bed		Area covered ($m^2 \times 10^6$)		Total quantity for estuary (tonnes)			
	Rooted	Algae	Rooted	Algae	Rooted	Algae	Both	Phyto-plankton
Organic carbon net production	78.40	35.70	3.84	3.74	301.00	124.00	425.00	17,100
Nitrogen accumulation	1.04	2.51	3.84	3.47	3.66	8.71	12.40	3,000
Phosphorus accumulation	0.49	0.35	3.84	3.47	1.36	1.21	2.57	417 to 4,520

significant allochthonous origins. Its importance, however, can be understood only when compared to the autochthonous standing crop.

The surveys showed a large seasonal variability in the amount of water column organic carbon in the estuarine water column (Figure 29). The highest concentrations occurred during late summer and fall, which corresponded to the dieoff of macrophytes and plankton, and to increases in rainfall. Although most of the organic carbon in the water is in the dissolved form (Table 9), the percentage of particulate carbon increased during the summer/fall peak (Davis et al. 1978). This indicated that phytoplankton and other plants were a major source of organic matter. Particulate organic matter and phytoplankton concentrations were positively correlated (Figure 30).

An annual organic carbon budget for the Pamlico River Estuary (Davis et al. 1978) indicated that autochthonous sources of organic carbon were more important than allochthonous carbon for the estuary (Table 10), and accounted for almost 65% of the total. The Tar River contributed about half of the allochthonous input, while all the other tributaries provided most of the remainder. Much of the organic matter that was generated within the estuary (autochthonous) comes from phytoplankton production. Most of the organic carbon in the estuary was used up by respiration within the system, with about 20% being exported (Davis et al. 1978). Data are not available to estimate the amount of carbon coming into the system from non-point sources, marshes, sediment release, and ground water. Likewise, we can not estimate the carbon use by sediment microbial respiration and the amount stored in the sediments through the process of sedimentation. Autochthonous organic carbon is important, however, and ecosystem respiration would require more organic carbon than is produced in situ.

A carbon flow model for the Pamlico River Estuary (Figure 31), using data taken during the summer of 1977, has been developed by Davis et al. (1978). Large storages of organic carbon indicate that much of this pool of carbon is refractory. The major flow appears to be through the phytoplankton component. Available evidence (Sick 1977; Davis et al. 1978) indicates that a large source of dissolved organic carbon (DOC) is allochthonous, but this source is not allowed for in the model (Figure 31).

Detrital metabolism is a critical process during the warmer months of the year because of its contribution to low dissolved oxygen levels in the estuary.

Metabolism of the standing stock of dissolved and particulate organic carbon used during microbial respiration in the estuary requires dissolved oxygen (Davis et al. 1978). During times of little

Table 9. Distribution of organic carbon in the Pamlico River Estuary (means by sector for August 1975 to July 1976) (Davis et al. 1978).

	Avg mean tonnes sector for 10 months					Avg mg/liter/sector for 10 months		
Sector[a]	Km^2	Km^3	DOC[c]	POC[d]	TOC[e]	DOC	POC	TOC
1	5.9	0.0079	57(7)[b]	16(4)	73(11)	7.3(1.1)	2.0(0.5)	9.3(1.4)
2	12.9	0.0223	153(18)	42(8)	194(21)	6.8(0.8)	1.9(0.3)	8.7(0.9)
3	21.9	0.0514	330(41)	83(13)	413(42)	6.4(0.8)	1.6(0.2)	8.0(0.8)
4	20.5	0.0510	316(34)	77(6)	393(32)	6.2(0.7)	1.5(0.1)	7.7(0.6)
5	11.7	0.0377	235(31)	55(6)	290(32)	6.2(0.8)	1.5(0.1)	7.7(0.8)
6	22.3	0.0781	473(31)	122(12)	595(35)	6.1(0.4)	1.6(0.2)	7.6(0.4)
7	37.7	0.1237	774(43)	199(16)	973(48)	6.3(0.3)	1.6(0.1)	7.9(0.4)
8	43.3	0.1355	769(76)	215(13)	984(73)	5.7(0.6)	1.6(0.1)	7.3(0.5)
9	35.7	0.1421	823(89)	230(20)	1,053(93)	5.8(0.6)	1.6(0.1)	7.4(0.7)
10	49.2	0.2155	1,245(138)	342(38)	1,588(150)	5.8(0.6)	1.6(0.2)	7.4(0.7)
11	21.8	0.0974	566(62)	154(30)	721(74)	5.8(0.6)	1.6(0.3)	7.4(0.8)
Total	282.7	0.9626	5,742	1,535	7,277	6.2($\bar{X}$)	1.6($\bar{X}$)	7.8($\bar{X}$)

[a]Location shown in Figure 29.
[b]Standard error of mean.
[c]Dissolved organic carbon.
[d]Particulate organic carbon.
[e]Total organic carbon.

mixing in the estuary (Figure 32), the bottom water runs out of dissolved oxygen, due to the decomposition and respiration of decaying plant and detrital materials (Davis et al. 1978). For many years, during this period of high oxygen demand, there have been numerous fish kills (Copeland et al. 1974b), and seasonal elimination of benthic organisms (Tenore 1970). This phenomenon apparently occurs in other estuaries when water temperatures are high, winds are calm, and freshwater inflow is low (May 1973; Terry Sholar, N. C. Division of Marine Fisheries, Morehead City, pers. comm.).

3.3. NUTRIENT DYNAMICS

Nitrogen and phosphorus are elements frequently considered limiting to phytoplankton productivity in natural waters, and nitrogen is more commonly the limiting factor in Atlantic Coast estuaries

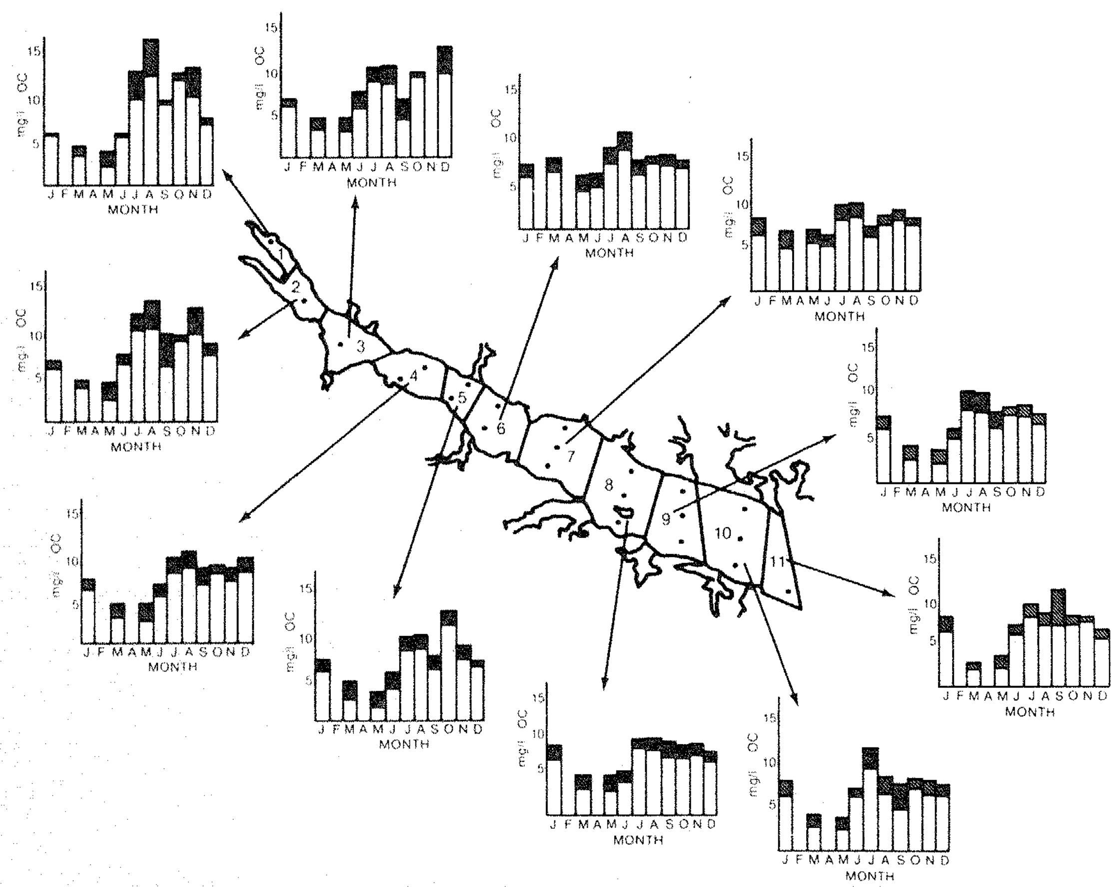

Figure 29. Organic carbon in the Pamlico River Estuary, 1975-76 (Davis et al. 1978). Shaded portions indicate DOC.

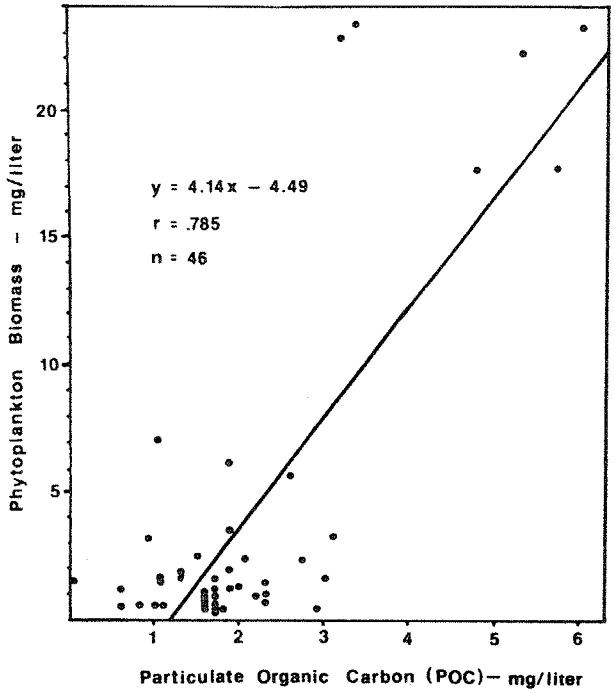

Figure 30. Phytoplankton biomass as a function of particulate organic carbon in the Pamlico River Estuary, 1976-77 (Davis et al. 1978).

(Kuenzler et al. 1979). The Pamlico River Estuary has traditionally been thought to have supplies of both phosphorus and nitrogen sufficient (at least seasonally) for abundant phytoplankton growth (Hobbie et al. 1972; Hobbie 1974). The key to how nutrients are involved in the phytoplankton cycles, however, lies in the relationship of nutrient inputs to the estuary and the seasonal requirements for phytoplankton growth.

Nutrients and their fates have been relatively well studied in the Pamlico River Estuary (Kuenzler et al. 1979). Inputs of nitrogen and phosphorus from freshwater inflows to the Pamlico River Estuary (Tables 11 and 12) have been calculated by multiplying concentrations times flow rates. A large portion of the nutrient input is from Pamlico Sound (Kuenzler et al. 1979). A large part of the nitrogen is in the form of dissolved organic nitrogen (Table 11). Inputs of nitrogen are not enough to support the primary productivity, particularly during low-flow times in summer and fall (Kuenzler et al. 1979). Since recycling is apparently the major means of supporting nitrogen demands by the phytoplankton, the large dissolved organic

Table 10. Annual organic carbon budget for the Pamlico River Estuary (Davis et al. 1978).

Budget compartment	Input (Tonnes C)	Percent of total
Allochthonous		
Tar River	18,918	17.5
Durham Creek	1,064	1.0
All other tributaries	18,155	16.8
Rainfall[a]	509	0.4
Dryfall	?	-
Ground water and septic tank seepage	?	-
Marsh input	?	-
Sediment release	?	-
	38,646	35.7
Autochthonous		
Phytoplankton production	56,501	52.2
Phytoplankton secretion	12,218	11.3
Macrophyte production[b]	301	0.3
Benthic production[c]	401	0.4
Periphyton production[d]	57	0.1
Chemosynthesis	?	-
	69,478	64.3
Total input	108,124	100.0
	Output (Tonnes C)	Percent of total
Water column respiration	89,726	80.0
Estuarine discharge	21,916	20.0
Sediment respiration	?	-
Sedimentation	?	-
Total output	111,642	100.0
Balance (tonnes C)	-3,518	

[a] Extrapolated from Brinson et al. (1977).
[b] Davis and Brinson (1976).
[c] Extrapolated from Stanley (1971).
[d] Extrapolated from Sherk (1969).

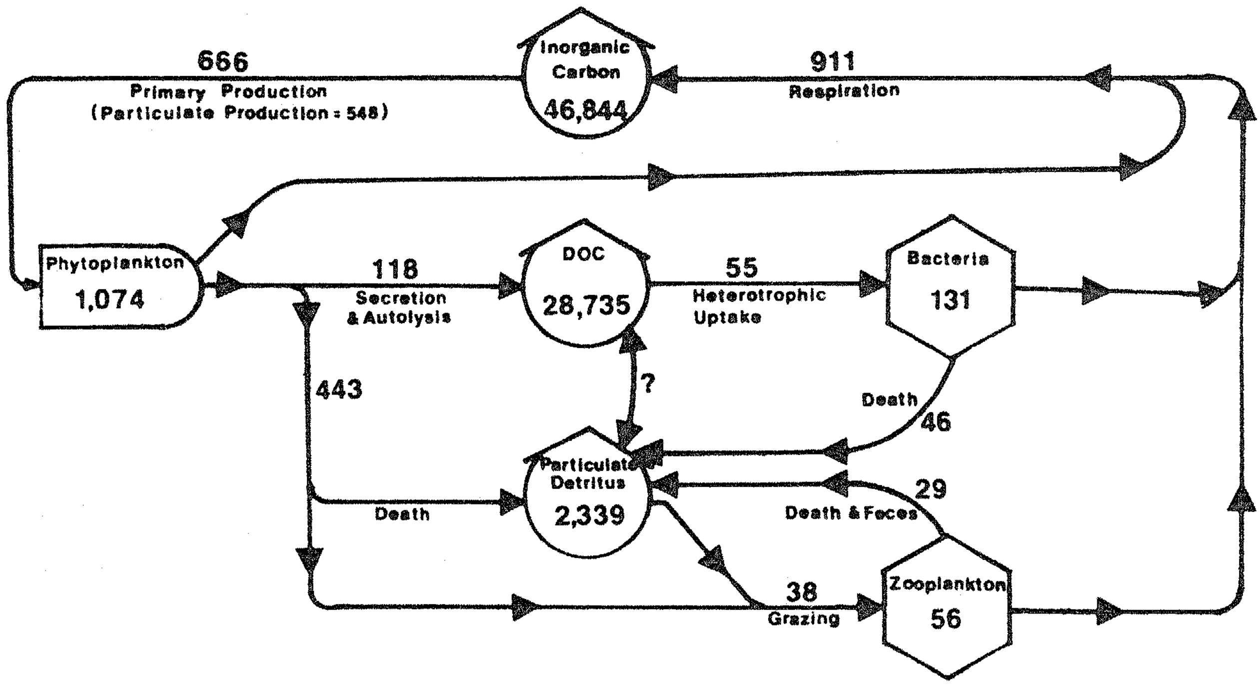

Figure 31. Suggested model for open water carbon flow in the Pamlico River Estuary. Standing stock in mg C/m^2 and flowrates in mg C/m^2/day (Davis et al. 1978).

nitrogen pool may be important in meeting these needs. The greatest nitrogen inputs to the estuary are during the winter (Figure 33). About 75% of the annual input of nitrogen to the estuary entered during the four-month period of December through March. Typically, the concentration of nitrogen forms in the estuary is low during the summer and high during the winter (Hobbie et al. 1972; Kuenzler et al. 1979).

Although most of the nitrogen input to the estuary occurs during the winter, most of the uptake occurs during the summer (Table 13). Dissolved inorganic nitrogen from the watershed accounts for only 2% of the total inorganic nitrogen uptake (Kuenzler et al. 1979). The major nitrogen form used by the phytoplankton is ammonia (Harrison and Hobbie 1974), which is generally present in low concentrations (Figure 33b). Recycling of nitrogen within the estuary, particularly regeneration of ammonia, is very important for supporting the observed primary productivity, but unfortunately, few direct measurements of the transfers have been made (Kuenzler et al. 1979).

The distribution of nitrogen forms in the estuary follows a seasonal pattern (Hobbie 1974), with the highest concentrations of incrganic nitrogen (i.e., nitrate, primarily) during the winter (Figure 33a). Sometimes, when the fall is wetter than normal, higher concentrations may be seen earlier than usual (Hobbie 1974). Ammonia, generally in lower concentrations than nitrate during winter, was distributed throughout the year (Figure 33b). Perhaps the summer concentrations reflect the tremendous recycling documented by Kuenzler et al. (1979).

The inorganic nitrogen was more concentrated at the upper end and decreased down the estuary. Organic

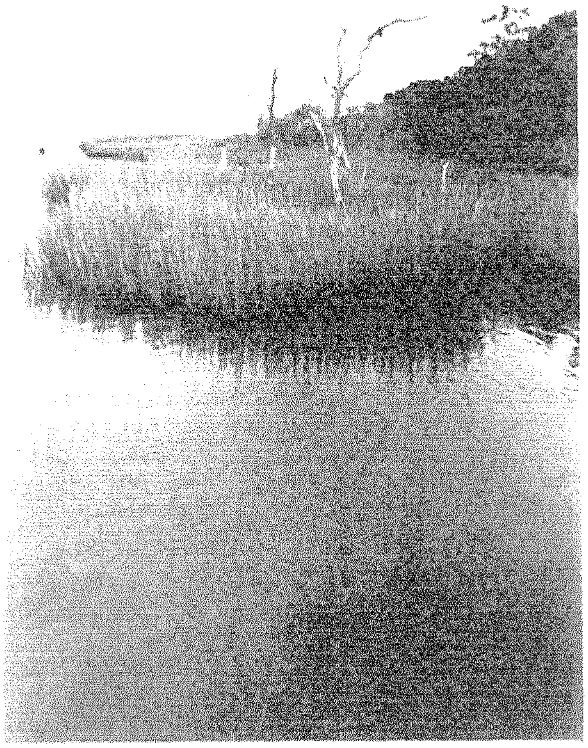

Figure 32. Calm, salty water leads to stratification.

nitrogen was distributed widely throughout the estuary with minor peaks near the mid-estuary (Figure 33c and d). This correlates well with the distribution of chlorophyll concentrations (Hobbie 1974; Kuenzler et al. 1979). Also, seasonal distributions were similar in pattern to primary productivity.

Calculated inputs of phosphorus from the watershed (Table 12) showed seasonal patterns similar to those for nitrogen (Figure 34). About 70% of the phosphorus entered the estuary during December through March, again reflecting the variations in river and estuary discharge and phytoplankton productivity. A large source of phosphorus to the estuary is Texasgulf's phosphate mining operation, 25 km downstream on the south shore of the mid-estuary (Hobbie 1970a; Hobbie 1974; Kuenzler et al. 1979), which contributes phosphorus on a year-round basis. Most, if not all, of the phosphorus in the Texasgulf effluent is in the form of reactive phosphorus (i.e., orthophosphate), which is immediately available for direct algal uptake (Kuenzler et al. 1979). The effluent sources are settling ponds and wash from the phosphoric acid refinery.

A descriptive model has been constructed for some of the phosphorus storages and fluxes in the water and plankton

Table 11. Total annual nitrogen inputs to the Pamlico River Estuary (tonnes N/yr) (Kuenzler et al. 1979).

	Dissolved inorganic nitrogen (DIN)						
Source	Ammonia	Nitrite	Nitrate	Total DIN	Dissolved Organic Nitrogen	Particulate Organic Nitrogen	Total
Watershed	206	10	306	522	1,860	1,430	3,812
Pamlico Sound	370	18	210	598	4,090	1,290	5,978
Precipitation	67	76	143		85		228

Table 12. Total annual phosphorus inputs to the Pamlico River Estuary (tonnes P/yr) (Kuenzler et al. 1979).

Source	Reactive phosphorus	Unreactive phosphorus	Particulate phosphorus	Total
Watershed	84	57	190	331
Pamlico Sound	184	103	190	477
Precipitation	13	4	-	17
Texasgulf, Inc.	843	-	843	

of the Pamlico River Estuary (Figure 35; Kuenzler et al. 1979). The model compartments (Q's) and the primary phosphorus concentrations (averaged over all sampling times and stations) are given in Table 14. Twenty different pathways of phosphorus movement (J's) among compartments were distinguished and are tabulated in Table 15. Measurements were not made of the zooplankton, nekton, and benthos processes, and they are excluded from the model. Two forcing functions, light intensity (I) and temperature (T), impact the rates (X) of uptake and the level of biological functions, and are shown at the appropriate junctions in the model. The exact rates and impacts on rates are not known; therefore, these pathways are indicated by dashed lines in Figure 35.

According to the model, the largest compartments for the Pamlico River Estuary were the reactive phosphorus (Q_1), the phosphorus taken up by the phytoplankton (Q_5), and the unreactive phosphorus (Q_9); whereas, particulate phosphorus (Q_2) and colloidal reactive phosphorus (Q_3) were the two smallest compartments. The main reaction in the estuary is the removal of reactive phosphorus from the water by phytoplankton and bacteria (Pathways $J_{1,5}$ and $J_{1,4}$, respectively, in Table 15).

The efflux of phosphorus from the phytoplankton (Q_5) and bacterial (Q_4) compartments back to inorganic reactive phosphorus (Pathways $J_{5,1}$ and $J_{4,1}$, respectively) is also large (Table 15). Phosphomonoesterase activity ($J_{9,1}$) is thought to be negligible. All other pathways are small and difficult to measure (Kuenzler et al. 1979). Thus, the major aspects of phosphorus cycling in the estuary are the uptake and release of reactive phosphorus by phytoplankton and bacteria. This substantiates the observation that the major source of phosphorus for primary productivity is through recycling in the estuary rather than inputs from the watershed. No such model has been constructed for the more complex nitrogen flux in the estuary.

Comparisons of the annual primary productivity rates with the uptake of nitrate, ammonia, inorganic nitrogen and phosphate (Table 16) indicate that the highest productivity values occur in the mid-sections of the estuary (Stations E-G), with a rapid decrease downstream (Kuenzler et al. 1979). The gross phosphate uptake rates decreased tenfold down the estuary (Table 16). The high phosphorus inputs from Texasgulf, situated at mid-estuary, apparently do not influence the overall phosphate uptake rates. The exceptionally high phosphorus uptake rate at Section C (upstream) appears to be associated with the wintertime phytoplankton bloom. The nitrogen uptake rates seem to follow the productivity rates along the estuary. The slightly higher ammonia uptake rate at Station H may reflect inorganic nitrogen inputs from Pamlico Sound.

Inputs of reactive phosphorus from land drainage amount to less than 1% of the calculated gross annual phytoplankton requirements (Kuenzler et al. 1979). Adding the inputs from Pamlico Sound, Texasgulf, and rainfall, only about 12% of the total annual requirement can be accounted for. Thus, recycling of phosphorus in the estuary appears necessary to provide the high levels of phytoplankton growth. Phosphorus recycling, however, apparently does not need to be quite as rapid as nitrogen recycling to support the observed phytoplankton growth.

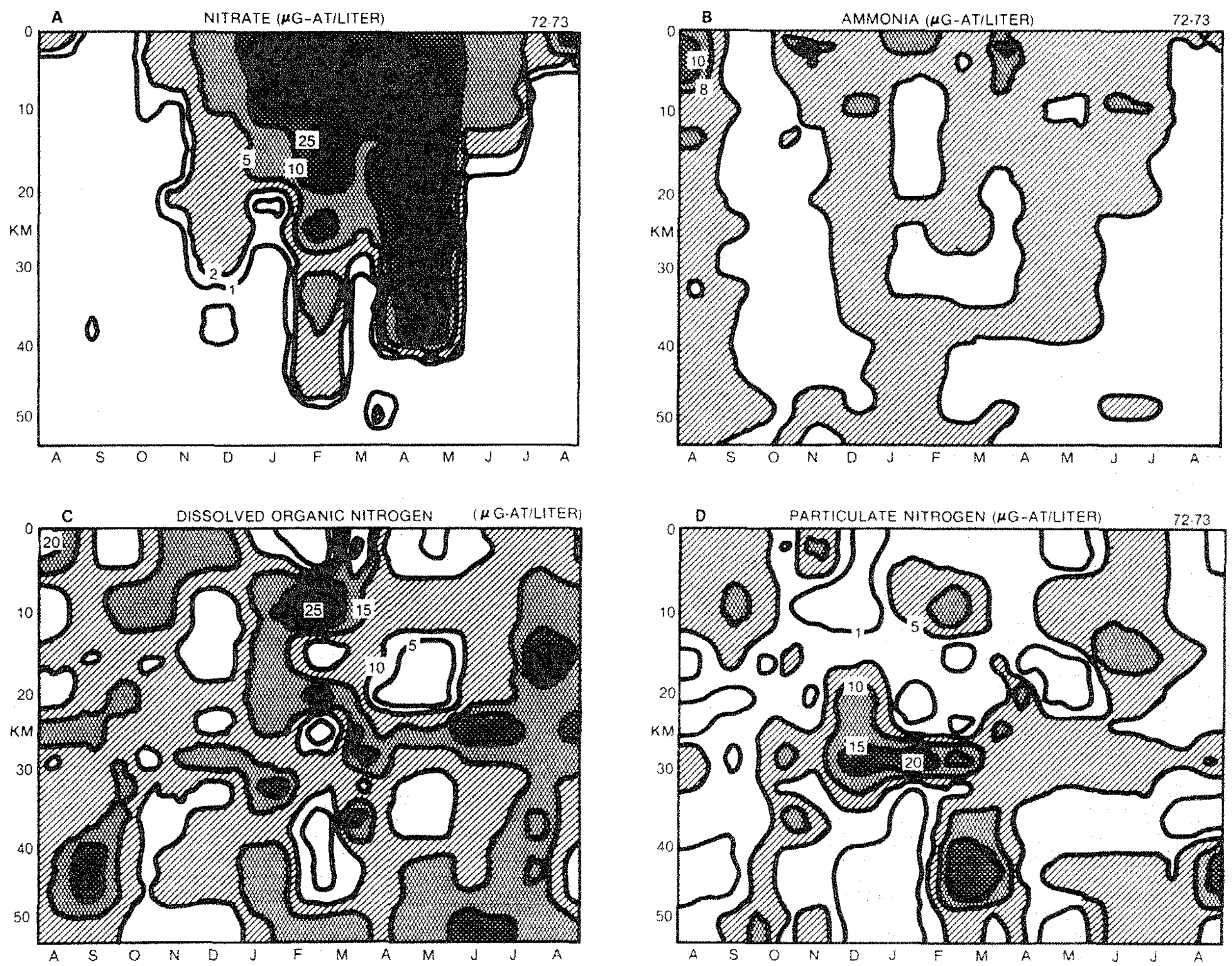

Figure 33. Distribution of nitrogen in the Pamlico River Estuary, 1972-73. A = nitrate, B = ammonia, C = dissolved organic nitrogen, and D = particulate nitrogen (Hobbie 1974).

Table 13. Biological uptake of nitrogen (tonnes/month), 1976-77 (Kuenzler et al. 1979).

Month	Ammonia	Nitrate	Total
July 1976	4,050	621	4,670
August 1976	2,800	487	3,290
September 1976	4,490	477	4,967
October 1976	4,370	220	4,590
November 1976	1,550	103	1,650
December 1976	627	115	742
January 1977	364	129	493
February 1977	381	125	506
March 1977	971	303	1,274
April 1977	1,110	541	1,651
May 1977	1,070	563	1,630
June 1977	1,080	545	1,625
Annual Total	22,900	4,230	27,091

A recent study of the sediment chemistry and exchange with the water (Matson et al. 1983) indicates that the sediment is a significant source in the nutrient cycle of the Pamlico Rivery Estuary. The flux of ammonia and reactive phosphorus from the sediments made up 6.3% and 1.9%, respectively, of the total annual phytoplankton uptake requirements (Table 17). These values are thought to be too low by a factor of 2, due to the necessity of taking measurements under a dome, where normal water movement is impossible (Matson et al. 1983). Even so, the transport of nutrients across the sediment/water interface still does not account for the differences between uptake requirements and input.

3.4. MICROBIAL COMPONENT

Estimations of summer bacterial biomass have been made in the Pamlico River Estuary water column (Davis et al. 1978). There was a gradient downstream, with individual biomass samples ranging from 0.374 to 1.320 wet weight/m^3. Bacterial carbon accounted for about 3% of the total particulate organic carbon in the estuary. The standing stock of bacteria was estimated at about 469 tonnes wet weight for the total estuarine volume.

Although the actual biomass of bacteria during the winter has not been measured in the estuary, measurements of bacterial uptake rates have been made. Crawford et al. (1974) found that maximum heterotrophic uptake of free amino acids occurred from July through September, with

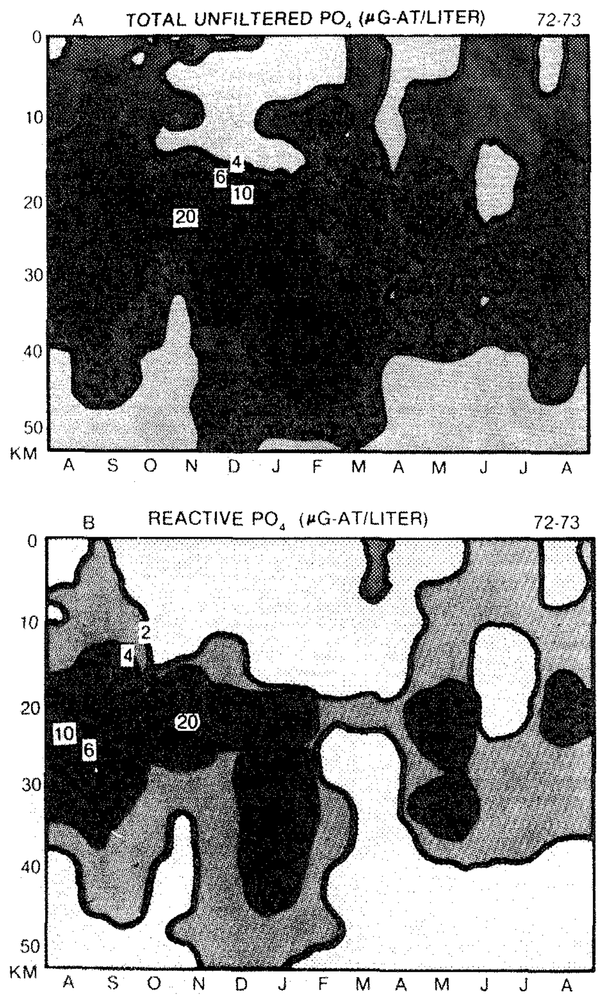

Figure 34. Distribution of phosphorus in the Pamlico River Estuary, 1972-73. A = total unfiltered phosphorus, and B = reactive phosphorus (Hobbie 1974).

minimum rates during the winter. Phytoplankton excretion and the decay of algal cells are thought to be the primary sources of the amino acids. This activity was variable temporally and spatially as a result of the patchiness of raw materials (See Section 3.1.) and variable concentrations of bacteria. Uptake studies of the bacteria in the sediment indicated a direct relationship between bacterial concentrations and the standing crop of organic solutes (Wood 1970).

Some evidence exists for year-round chemosynthetic production of carbon in the sediments by bacteria (Matson et al. 1983). They found chemosynthetic production at about 12 mol C/m^2/yr in sediments from the mid-estuary, which, if prorated over the total estuary, amounts to about

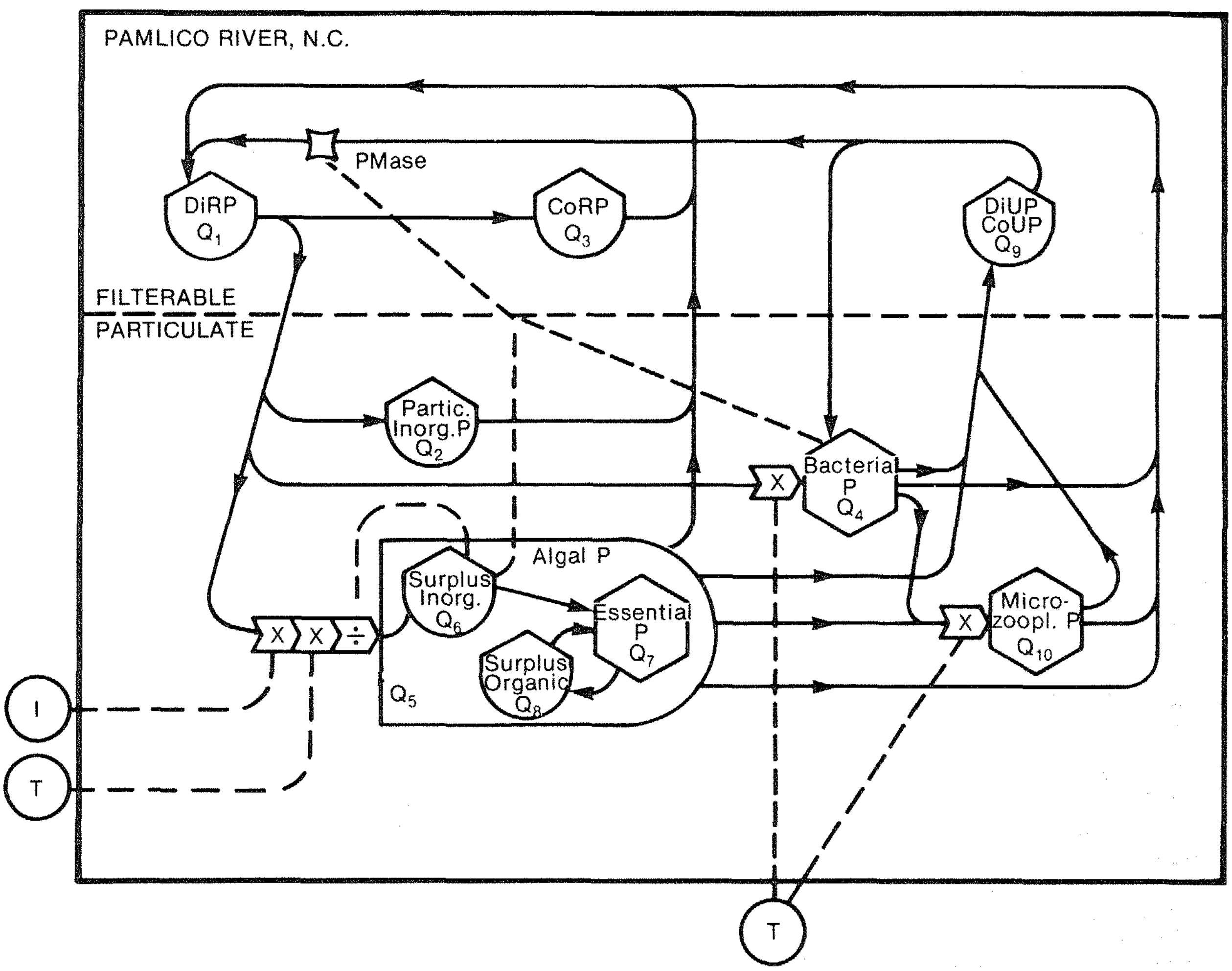

Figure 35. Descriptive model of phosphorus cycling. Major compartments are listed in Table 14 and the flux rates are listed in Table 15 (Kuenzler et al. 1979).

13% of the total annual organic carbon available in the estuary.

3.5. SECONDARY PRODUCERS

Zooplankton

Few studies have been made to characterize zooplankton populations in the Pamlico River Estuary. Peters (1968) completed a survey of zooplankton at several stations during 1965 through 1967, and Miller (1974) surveyed the ctenophores in the estuary during the same time.

Table 14. Major phosphorus compartments in Pamlico River Estuary water exclusive of larger zooplankton and nekton. Mean concentrations are for 1976-77 (Kuenzler et al. 1979).

	Compartments	Mean P concentration (g-at./liter)
Q1	Dialyzable Reactive P (DiRP)	1.34
Q2	Particulate Inorganic P	0.23
Q3	Colloidal Reactive P (CoRP)	0.24
Q4	Bacterial P	Included in Q5
Q5	"Algal" P (=Q6, Q7, Q8)	1.11
Q6	Algal Inorganic Surplus P	0.35
Q7	Algal Essential P	0.34
Q8	Algal Organic Surplus P	0.42
Q9	Dialyzable + Colloidal Unreactive P (DiUP + CoUP)	0.74
Q10	Microzooplankton P	Included in Q5

Table 15. Pathways between compartments and rates of phosphorus flux in Pamlico River Estuary water. Range or approximate mean rate for 1976-77 (Kuenzler et al. 1979).

Flux path	Process	Rate (ug-at/liter/hr)	Percent of algal uptake
$J_{1,2}$	Precipitation and sorption		1-10%
$J_{1,3}$	Exchange with colloids, polymerization	Not detectable	
$J_{1,4}$	Bacterial uptake		13-62%
$J_{1,5}$	Algal uptake (gross)	0.01-2.0	
$J_{2,1}$	Dissolution and desorption	Not measured	
$J_{3,1}$	Exchange and dissolution	Not detectable	
$J_{4,1}$	Bacterial mineralization	(Incl. in $J_{5,1}$	
$J_{4,9}$	Bacterial excretion of organic P	(Incl. in $J_{5,9}$)	
$J_{4,10}$	Microzooplankton grazing	Not measured	
$J_{5,1}$	Algal efflux of reactive P		37-90%
$J_{5,6}$	Algal storage as inorganic P		20%
$J_{5,9}$	Algal release of organic P		0.1-0.6%
$J_{5,10}$	Microzooplankton grazing	Not measured	
$J_{6,7}$	Conversion of inorganic P		9%
$J_{7,8}$	Storage of surplus organic P		2%
$J_{8,7}$	Conversion of surplus organic P	Not measured	
$J_{9,1}$	Hydrolysis via phosphomonoesterase	Negligible	
$J_{9,4}$	Bacterial assimilation	Not measured	
$J_{10,1}$	Microzooplankton mineralization	(Incl. in $J_{5,1}$)	
$J_{10,9}$	Microzooplankton release of organic P	(Incl. in $J_{5,9}$)	

While representatives from several phyla were collected (Table 18), a calanoid copepod (Acartia tonsa) made up a large percentage (70% to 90%, depending on the season) of the zooplankton in Peters' samples. This observation is typical of estuaries of this type (Herman et al. 1968). Harpacticoid copepods were common in some night samples, but virtually absent from samples taken during daylight hours. This nocturnal abundance was positively correlated with wind speed, which could account for the entrance of these ordinarily benthic organisms into the water column.

The seasonal distribution of calanoid copepods (predominantly Acartia tonsa) indicated high concentrations during the summer and fall and low concentrations during winter and spring (Figure 36). This distribution pattern paralleled the seasonal distribution of the total zooplankton in the Pamlico River Estuary, except during the winter, when cladocerans were prominent in the samples (Figure 37). Peters (1968) concluded that the copepod abundance was related to several environmental variables. For example, in the lower portion of the estuary, higher temperatures were associated with higher concentrations of zooplankton. When dissolved oxygen was lower than saturation in the upstream section, the zooplankton tended to decrease.

Ctenophores (Mnemiopsis leidyi) are abundant and dominate the zooplankton at times (Miller 1974). These free-floating animals are abundant in the spring and fall of each year. In a study of ctenophore feeding rates in the Patux-

Table 16. Comparison of annual depth-integrated primary productivity rates with uptake of nitrate, ammonia, total-dissolved inorganic nitrogen (total DIN) and reactive phosphate (Kuenzler et al. 1979).

Station[a]	Dissolved inorganic nitrogen (gN/m^2/year) Nitrate	Ammonia	Total DIN	Reactive phosphate gP/m^2/yr	Productivity gC/m^2/yr
C	20	57	77	182	487
D	11	44	55	44	449
E	19	82	101	44	512
F	24	101	125	38	624
G	16	93	109	35	514
H	12	113	125	18	415
Mean	17	82	99	61	500

[a]See Figure 4 for station location.

ent River Estuary, Maryland, Bishop (1967) estimated that approximately 31% of the standing crop of Acartia tonsa was consumed by the ctenophores each day. Thus, ctenophores may be important consumers of zooplankton in the Pamlico River Estuary, and may compete with postlarval fish for the zooplankton standing crop.

Benthos

The benthos is dominated by mollusks, which comprise about 45% of the total species of the Pamlico River Estuary macrobenthos (Tenore 1970). This is typical of estuarine systems (Gunter 1961), since mollusks, with their heavy shells, are adapted to withstand the shifting

Table 17. Total annual flux (m mol/m²/yr) of ammonia and reactive phosphorus in relation to phytoplankton uptake (m mol/m²/yr) in the Pamlico River Estuary (Matson et al. 1983).

	Ammonia		Reactive phosphorus	
Station[a]	Flux	Uptake[b]	Flux	Uptake[b]
C	385	4,070	54	5,900
D	573	3,100	71	1,450
E	313	5,860	31	1,450
F	395	7,210	30	1,200
G	359	6,640	28	1,100
H	186	8,070	12	580
Mean	369	5,830	38	1,950
	6.3% of total		1.9% of total	

[a]See Figure 4 for station location.
[b]From Kuenzler et al. (1979).

Table 18. Zooplankton prominent in the Pamlico River Estuary, 1965-67 (Peters 1968).

Pylum	Class	Subclass	Genus
Protozoa			Rhoefax
Rotifera			Synchaeta
			Keratella
			Filinia
Annelida	Polychaeta		
Mollusca	Gastropoda		
	Pelecyopoda		Rangia cuneata
Arthropoda	Arachnida		
	Crustacea	Brachiopoda	
		Cladocera	Evadne
			Podon
		Ostracoda	
		Cirripedia	Balanus
		Branchiura	Argulus
		Copepoda	Acartia tonsa
			Eurytemora
			Oithona
			Ergasilus versicolor
			Microstella
			Canuella
		Malacostraca	Aegathoa oculata
			Gammarus

sediments, and are able to temporarily isolate themselves from unfavorable conditions by closing their shells. Also prominent among the macrobenthos are polychaete worms (Nereis), particularly during the spring and summer.

Tenore (1970) conducted an extensive survey of the macrobenthos in the Pamlico River Estuary (Figure 38). His transects spanned the estuary from its freshest portion (Transect 4) near Washington, down to its most saline portion (Transect 1), where the estuary joins Pamlico Sound. Each transect was subdivided into strata based on depth (i.e., sediment type), with shallow (0 to 1 m) and medium (1 to 2 m) strata on each side of the estuary and a deep (2 + m) stratum in the middle. Three samples were taken at each of three stations, in each of the five strata, during October (fall), January (winter), April (spring), and July (summer), 1968-69. The following conclusions about distribution and seasonal densities are based on a total of 45 samples for each transect during each season.

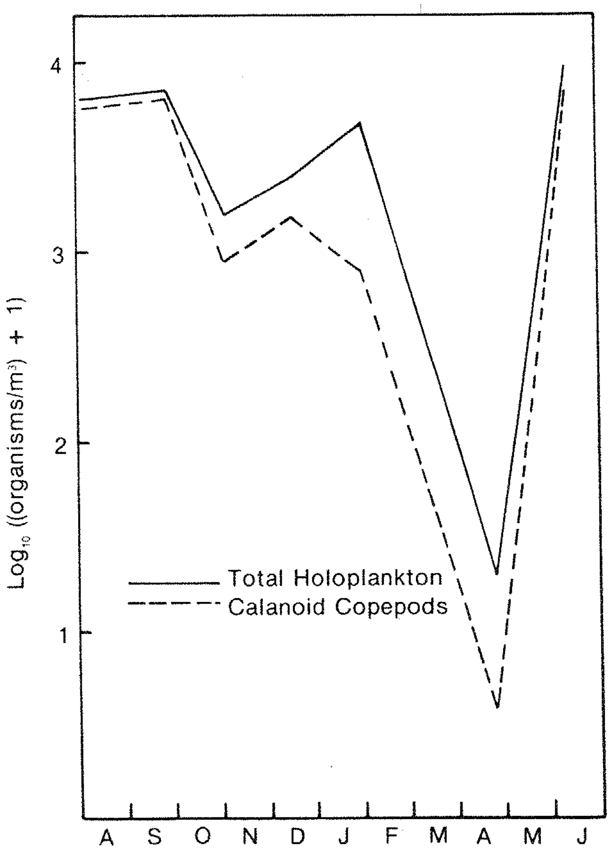

Figure 36. Seasonal changes in abundance of calanoid copepods and total holoplankton in the Pamlico River Estuary, 1966-67 (Peters 1968).

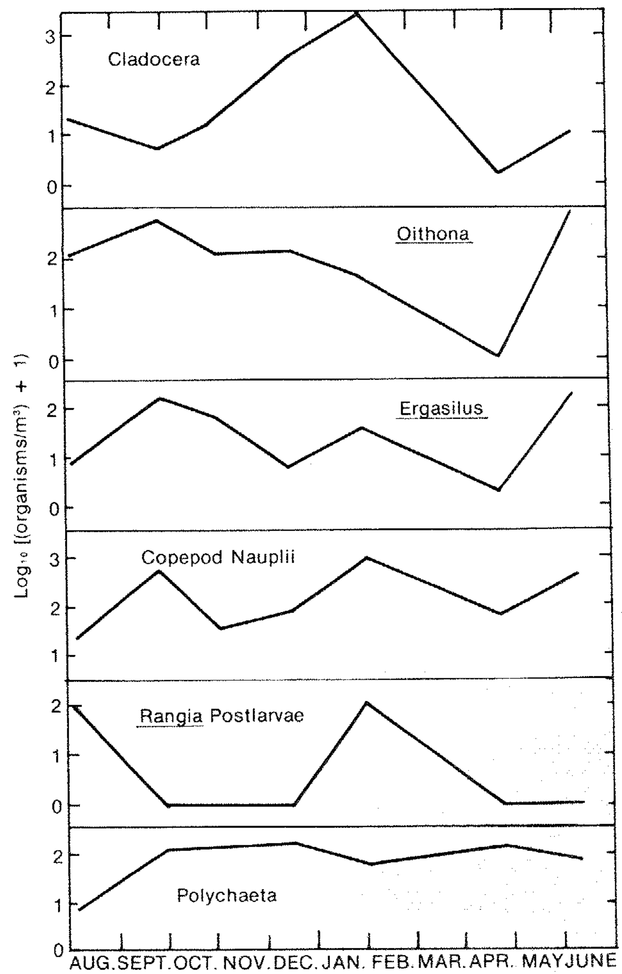

Figure 37. Seasonal changes in abundance of selected zooplankters in the Pamlico River Estuary, 1966-67 (Peters 1968).

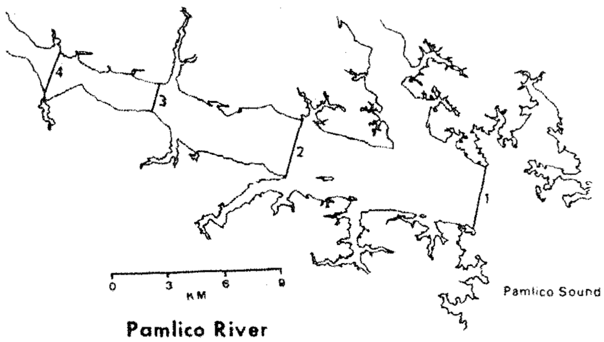

Figure 38. Transects for macrobenthic sampling in the Pamlico River Estuary (Tenore 1970).

The diversity and density of macrobenthos was relatively low (Tenore 1970). This was attributed to shifting sediments in large portions of the estuary; absence of tidal flats due to the low tidal flux; changing salinity regimes; and the annual occurrence of conditions leading to anoxic sediment conditions. The seasonal ranges of distribution and density of the dominant macrobenthic species in the shallow portions of the estuary are given in Figures 39, 40, 41, and 42. Animals do not exist on a year-round basis in the sediments of the deeper waters of the estuary, due to the anoxic conditions there during the summer. Thus, the bulk of the benthic productivity in the Pamlico River Estuary is in sediments under water less than 1.5 m deep. Unfortunately, data on actual production rates are still lacking for this estuary.

An analysis of the macrobenthic samples indicated that the estuary could be divided into three community types (Tenore 1970). This analysis was accomplished with the aid of a trellis diagram (McFayden 1963), whereby an index of affinity (Sanders 1960) was calculated for the fauna from each depth section of each strata during each season (Tenore 1970). This index of affinity was defined as the percentage of fauna common to a pair of samples. The analysis was completed by comparing the index of affinity for all possible combinations of sample pairs. An index value was determined for each pair by summing the smaller of two percentages of species present in any two samples (e.g., when sample 1M, which has 40% species a, 20% species b and 40% species c, is compared to Sample 1S, which has

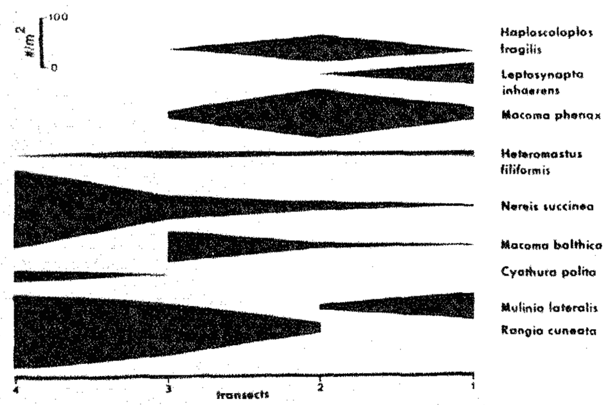

Figure 39. Distribution and density of dominant macrobenthos in shallow sediments during fall (Tenore 1970).

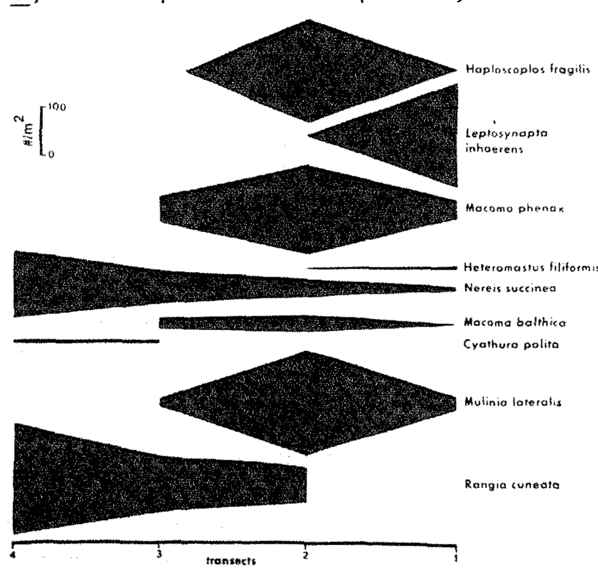

Figure 40. Distribution and density of dominant macrobenthos in shallow sediments during winter (Tenore 1970).

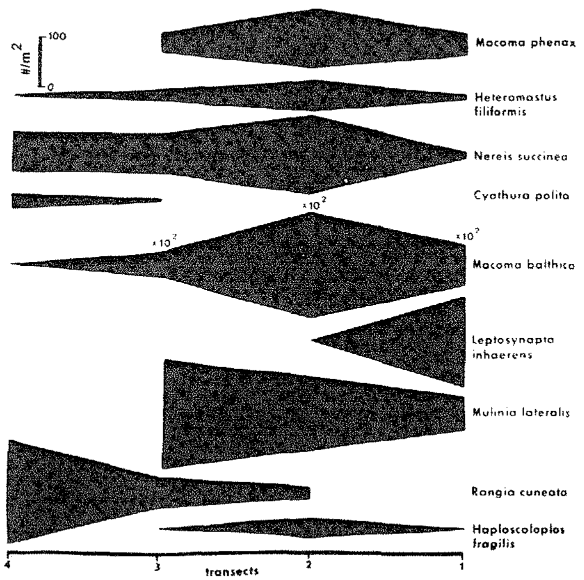

Figure 41. Distribution and density of dominant macrobenthos in shallow sediments during spring (Tenore 1970).

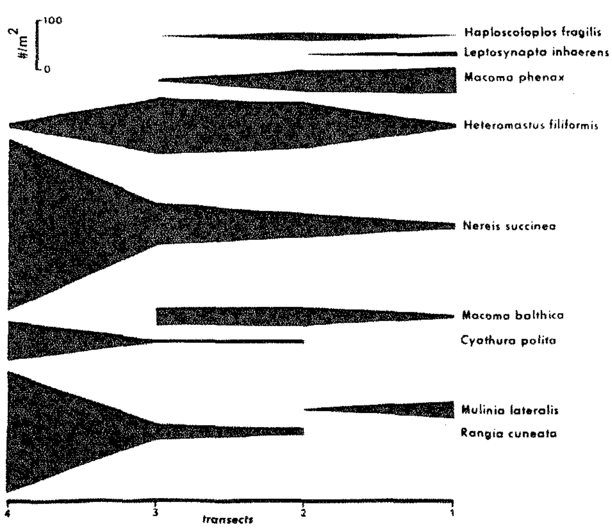

Figure 42. Distribution and density of dominant macrobenthos in shallow sediments during summer (Tenore 1970).

20% species a, 40% species b and 40% species, d the index of affinity is 20 + 20 + 0 = 40). By rearranging all samples compared to bring those with high values together, one can group similar samples together. A trellis diagram for the 12 possible combinations (i.e., 4 transects x 3 strata at deep (D), medium (M), shallow (S) locations) in the Pamlico River Estuary during the fall of 1968 is shown in Figure 43. Samples with a high degree of similarity (an index of affinity 40) are indicated by darkened squares on the diagram.

The upper estuarine area (Transect 4 in Figure 38) is a true oligohaline zone with salinities below 5 ppt (Cowardin et al. 1979). The community association of

	2D	1D	1S	1M	2M	2S	3M	3S	4M	4S	3D	4D
2D												
1D	0											
1S	0	28.7										
1M	0	55.8	56.8									
2M	0	6.6	17.4	17.4								
2S	0	5.1	12.4	18.8	68.5							
3M	0	2.4	9.4	13.1	54.6	46.7						
3S	0	2.2	10.0	8.0	40.8	47.9	50.4					
4M	0	0.7	2.4	0.5	22.4	13.5	29.4	67.9				
4S	0	0.7	4.4	0.5	22.9	13.5	31.8	40.7	44.1			
3D	0	0	0	0	0	0	0	0	0	0		
4D	0	0	0	0	0	0	0	0	0	0	0	

FALL >40

Figure 43. Trellis diagram of index of similarity of strata during fall sampling of macrobenthos in the Pamlico River Estuary. Darkened cells indicate greater than 40% index of similarity (Tenore 1970).

Rangia cuneata-Nereis succinea characterizes the upper portion of the estuary, which is subject to aperiodic high fluctuations of salinity due to irregular surges of river water during periods of high surface runoff. Large amounts of organic matter are also present in the sediments. This oligohaline assemblage is much like the benthic community found in Albemarle Sound farther north along the North Carolina coast (see Copeland et al. 1983b). The second type of macrobenthic community association is in the mid-estuary (Transects 2 and 3 in Figure 38) and represents the mesohaline zone with salinities generally ranging from about 5 to 18 ppt. This area is characterized by the *Macoma balthica-Nereis succinea* association and represents a somewhat more stable benthic community. The third type, found at the mouth of the estuary (Transect 1 in Figure 38), is a polyhaline zone with salinities at 18 ppt or above. This area is characterized by the *Macoma phenax-Mulinia lateralis-Retusa canaliculata* association. The community has relatively high diversity and the dominant species is unclear.

There is an influx of a new set (i.e., planktonic larvae reaching settling stage) during the winter and spring covering large areas of the estuary (Tenore 1970). During the late fall spawning period and the winter settling period, large numbers of juvenile *Macoma phenax*, *Mulinia lateralis*, *Leptosynapta inhaerens* and *Haploscoloplos fragilis* penatrate farther up in the estuary than during other seasons and reach higher concentrations. The spring settling period brings in *Mulinia lateralis*, *Leptosynapta inhaerens*, *Macoma balthica* and *Macoma phenax*. During this period, these species are transported to the estuary from more saline spawning areas, and their distribution is regulated by how far the fresh water penetrates downstream during the time following setting. *Rangia cuneata* and *Nereis succinea* spawn during the late fall and spring, and increase in abundance during those seasons. They are primarily brackish water species and remain in the zones farther upstream than do those species from more saline environments. Newly set organisms are often reduced or eliminated by environmental selection. In the absence of new set, and as the result of environmental sorting, the community areas in the estuary return to their segmentation during the summer. Thus, the spatial delineation of community grouping is most obvious during the fall (Figure 39). It is evident that any further work must take into account these seasonal changes of the macrobenthos, and any management criteria must be based on that seasonality.

A survey of the meiobenthos was made in the Pamlico River Estuary, simultaneously with the macrobenthic study (Reid 1970). Major components of the meiobenthic community in the sandy bottom (i.e., in less than 1.5 m water depth) were nematodes, harpacticoid copepods, and turbellarians in the more brackish areas (Transects 3 and 4) and nematodes, oligochaetes, harpacticoid copepods, hydracarinids, turbellarians, and gastrotrichs in the more polyhaline areas (Transects 1 and 2) (Table 19). In mud bottoms, only

Table 19. Mean numbers of meiobenthos/100 ml in the sand bottom areas of the Pamlico River Estuary, 1968 (Reid 1970).

Taxonomic group	Transect[a] 4	3	2	1
Nematoda	449	516	800	2,425
Polychaeta	3.9	0	9.3	1.7
Oligochaeta	1.0	0.9	0.4	9.7
Ostracoda	2.8	2.7	14.3	4.8
Harpacticoida	8.8	5.0	92	136
Cyclopoida	0	0	0	0.5
C. nauplii	0	0	0	1.8
Hydracarina	0.9	0	0	28
Turbellaria	2.0	1.8	3.4	5.5
Gastropoda	1.1	0	0.4	0
Pelecypoda	0	0	0	1.7
Gastrotricha	0	0	4.8	31
Coelenterata	0	0	0	0.5
Total	470	526	925	2,646

[a]See Figure 38 for transect location.

nematodes were present in significant numbers. There was a general trend of increasing density downstream in the estuary (Reid 1970). Biomass distribution followed the same trend (Figure 44). Compared to other estuaries, the density and biomass of the meiobenthos are relatively low (Parker 1966; Muus 1967; Tietjen 1969), most likely due to the variation in salinity and sediment anoxia. No studies have yet been made of the meiobenthic productivity in the estuary.

Nekton

The diversity of the nektonic populations in the Pamlico River Estuary is typically estuarine (Spitsbergen and Wolff 1974; Purvis 1976), and is very similar to the nektonic populations of the neighboring Neuse River Estuary to the south (Hester and Copeland 1975). Many of the dominant species that make up the nektonic population comprise a significant portion of the commercial fishery for the area (see Chapter 5).

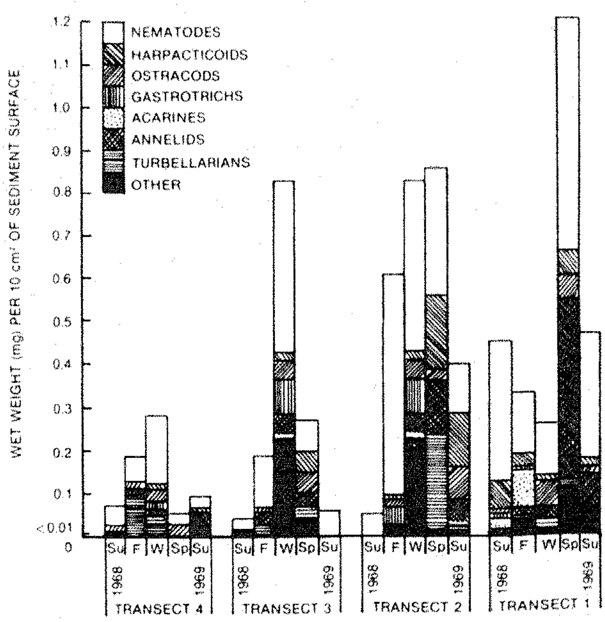

Figure 44. Biomass (mg/10 cm^2) of the major meiobenthos in the shallow sediments of the Pamlico River Estuary, 1968-69 (Reid 1978). Transect locations are given in Figure 38.

A compilation of data from two trawl surveys by North Carolina State University, from commercial fisheries statistics, and from a surface trawl survey conducted by the National Marine Fisheries Service yielded 65 nektonic species from the Pamlico River Estuary (Table 20). By comparing the extensive bottom-trawl surveys in the estuary over a 10-year period, it was shown that the Atlantic croaker, spot, blue crab, and anchovies make up about 97% to 98% of the total nektonic catch (Table 21). These percentages may not be entirely representative, due to the absence of more pelagic species some of which were missed by using the technique of bottom trawling.

A large seasonal fluctuation occurs in the nekton population for the Pamlico River Estuary (Purvis 1976). Peak abundance occurs during the spring and is dominated by migratory species such as spot, Atlantic croaker, shrimp, Atlantic menhaden, flounder, and blue crabs. In contrast to a secondary peak during winter in Albemarle Sound (Copeland et al. 1983b), which is made up primarily of freshwater and anadromous species, there is a distinct scarcity of nekton in the Pamlico River Estuary during winter. Blue crabs are the major over-wintering species. During the springtime peak (Figure 45), population numbers for spot and Atlantic croaker, the two most dominant species in the estuary, exceed 10,000/ha, compared to less than 1,000/ha for all others. These observations emphasize the dominance of migratory fish in the Pamlico River Estuary.

Waterfowl

The Pamlico River Estuary is used by at least 19 species of overwintering waterfowl (Table 22), based on yearly mid-

Table 20. Fishes collected from the Pamlico River Estuary during various years from 1965 to 1980 (Miller and Peters 1983).

Scientific name	Common name	Collection method: Trawl 1965-66	Trawl 1971-73	Commercial fishery 1966-80	Surface trawl	Other
Sphyrna tiburo	Bonnethead					X
Rhinoptera bonasus	Cownose ray					X
Acipenser oxyrhynchus	Atlantic sturgeon			X		
Lepisosteus osseus	Longnose gar				X	
Anguilla rostrata	American eel	X	X	X		
Conger oceanicus	Conger eel				X	
Alosa aestivalis	Blueback herring		X	X	X	
Alosa mediocris	Hickory shad			X		
Alosa pseudoharengus	Alewife		X	X	X	
Alosa sapidissima	American shad			X	X	
Brevoortia tyrannus	Atlantic menhaden	X	X	X	X	
Dorosoma cepedianum	Gizzard shad		X	X		
Dorosoma petenense	Threadfin shad				X	
Sardinella aurita	Spanish sardine	X				
Anchoa hepsetus	Striped anchovy		X			
Anchoa mitchilli	Bay anchovy		X		X	
Anchoa sp.	Anchovy	X				
Esox niger	Chain pickerel	X				
Synodus foetens	Inshore lizardfish	X				
Cyprinus carpio	Common carp		X	X		
Notemigonus crysoleucas	Golden shiner				X	
Ictalurus catus	White catfish	X	X	X	X	
Ictalurus nebulosus	Brown bullhead		X	X		
Opsanus tau	Oyster toadfish	X	X			
Strongylura marina	Atlantic needlefish	X				
Membras martinica	Rough silverside				X	
Menidia beryllina	Inland silverside		X		X	
Menidia menidia	Atlantic silverside				X	
Syngnathus fuscus	Northern pipefish	X				
Morone americana	White perch		X	X	X	
Morone chrysops	White bass	X				
Morone saxatilis	Striped bass		X	X		
Enneacanthus gloriosus	Bluespotted sunfish		X			
Lepomis gibbosus	Pumpkinseed		X		X	
Lepomis macrochirus	Bluegill		X			
Lepmois sp.	Sunfish		X			
Micropterus salmoides	Largemouth bass				X	
Perca flavescens	Yellow perch	X	X	X	X	
Pomatomus saltatrix	Bluefish	X	X	X	X	
Caranx hippos	Crevalle Jack				X	
Lutjanus griseus	Gray snapper	X				
Orthopristis chrysoptera	Pigfish	X		X		
Archosargus probatocephalus	Sheepshead			X		

Table 20. (Concluded).

Scientific name	Common name	Collection method: Trawl 1965-66	Trawl 1971-73	Commercial fishery 1966-80	Surface trawl	Other
Lagodon rhomboides	Pinfish	X	X		X	
Bairdiella chrysoura	Silver perch	X	X		X	
Cynoscion nebulosus	Spotted seatrout	X		X		
Cynoscion regalis	Weakfish	X	X	X		
Leiostomus xanthurus	Spot	X	X	X	X	
Menticirrhus sp.	Kingfish			X	X	
Micropogonias undulatus	Atlantic croaker	X	X	X	X	
Pogonias cromis	Black drum			X		
Sciaenops ocellatus	Red drum			X		
Chaetodipterus faber	Atlantic spadefish			X		
Mugil cephalus	Striped mullet	X	X	X	X	
Gobiosoma bosci	Naked goby	X	X			
Peprilus alepidotus	Harvestfish	X		X		
Peprilus triacanthus	Butterfish	X		X		
Prionotus evolans	Striped searobin		X			
Citharichthys arctifrons	Gulf Stream flounder		X			
Paralichthys dentatus	Summer flounder		X	X		
Paralichthys lethostigma	Southern flounder		X	X		
Paralichthys sp.	Flounder	X		X		
Trinectes maculatus	Hogchoker	X	X			
Symphurus plagiusa	Blackcheek tonguefish		X			
Monacanthus hispidus	Planehead filefish		X			

winter waterfowl surveys during the overwintering season by the U.S. Fish and Wildlife Service (Don Harke, USFWS, Wildlife Assistance, Raleigh, pers. comm.). Little useful data exist from the published statewide summaries from which to evaluate population trends and hunting in the area. According to survey field sheets, the overwintering, migratory waterfowl (ranging from 8,200 to 53,500 birds surveyed during the 1978 to 1982 censuses) represent about 5.8% of the overwintering waterfowl in the State of North Carolina. In contrast, waterfowl populations averaged about 3.6% of the State total in Albemarle Sound and 20.5% of the State total in Currituck Sound during the same period.

The ruddy duck, canvasback, and scaup make up more than 75% of the total overwintering waterfowl in the Pamlico River Estuary. This is in contrast to Albemarle Sound, where geese and swans were the dominant overwintering species (Copeland et al. 1983b).

3.6. LIFE HISTORY STRATEGIES

A majority of the nektonic species of the Pamlico River Estuary uses the estuary during only a portion of their life cycle (Street 1979; Miller and Peters 1983). Consequently, the estuary is used by many species as a nursery ground. Three life history strategies are observed

Table 21. Relative abundance of dominant species collected in bottom trawl surveys of the Pamlico River Estuary during various years from 1965 to 1973 (Miller and Peters 1983).

Species	1965-66 survey		1971-73 survey	
	Number caught	% of total	Number caught	% of total
Atantic croaker *Micropogonias undulatus*	15,303	48.4	20,592	50.4
Spot *Leiostomus xanthurus*	12,852	40.6	14,234	34.8
Blue crab *Callinectes sapidis*	1,414	4.5	206	0.5
Anchovy *Anchoa* sp.	1,291	4.1	4,512	11.0
All other species	760	2.4	1,304	3.2

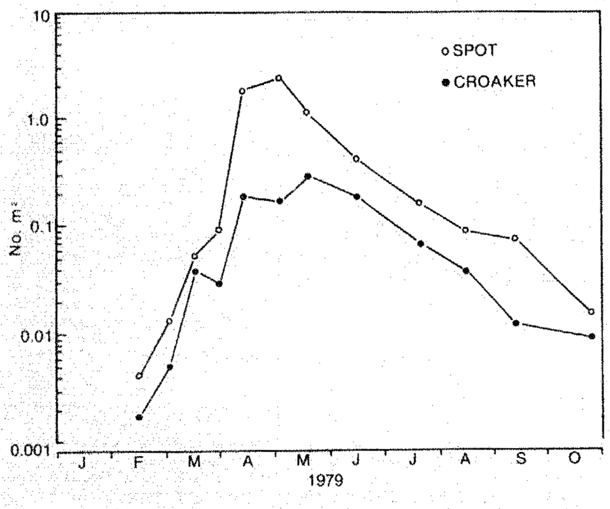

Figure 45. Pattern of entry of juvenile spot and croaker into a Pamlico River Estuary nursery area (Miller et al. 1982).

Table 22. Migratory waterfowl species present in Pamlico River Estuary, ranked in approximate order of abundance. (Based on USFWS unpublished data, Midwinter Waterfowl Surveys, 1978-82).

Common name	Scientific name
Ruddy duck	*Oxyura jamaicensis*
Canvasback	*Aythya valisineria*
Scaup	*Aythya* spp.
American coot	*Fulica americana*
Black scoter	*Melanitta nigra*
Bufflehead	*Bucephala albeola*
Whistling swan	*Cygnus columbianus*
Canada goose	*Branta canadensis*
Snow goose	*Chen caerulescens*
American black duck	*Anas rubripes*
Mallard	*Anas platyrhynchos*
American wigeon	*Anas americana*
Redhead	*Aythya americana*
Merganser	*Mergus* spp., *Lophodytes cucullatus*
Common goldeneye	*Bucephala clangula*
Ringed-neck duck	*Aythya collaris*
Green-winged teal	*Anas crecca*
Gadwall	*Anas strepera*
Northern pintail	*Anas acuta*

among the nektonic population: migratory, anadromous, and catadromous. In addition to these life history strategies, there are a few species that are indigenous to the estuary. The migratory strategy is the most dominant.

In contrast to the more oligohaline Albemarle Sound Estuary to the north, the anadromous fish population in the Pamlico River Estuary is relatively low (Copeland et al. 1983b; Hawkins 1980). About 97% of the anadromous fish population of the Pamlico River Estuary is made up of the blue-back herring (Alosa aestivalis), although the remainder, represented by American shad, alewife, hickory shad, and striped bass, were more prominent historically. These fish spend a large portion of their life at sea and ascend into the Tar River as ripe adults to spawn (Talbot and Sykes 1958; Walburg and Nichols 1967). The young remain in the river until late spring or early summer, when they move downstream into the Pamlico River Estuary (Hawkins 1980). The juveniles remain in the estuary most of the summer before moving out to the ocean, where they may migrate south during the winter, remaining until they reach maturity.

A moderate river flow rate is required for the spawning success of many of the anadromous species, especially blueback herring and striped bass (Trent and Hassler 1968; Pate 1972), and the Tar River is the only tributary providing enough flow. High river discharge can be detrimental if the eggs and larvae are carried into river swamps, where their survival is low or if the larvae are carried out of the river system beyond the general nursery area (Pate 1972). Low river flow is detrimental because the eggs need to be kept in suspension order to complete their hatching cycle.

The one important species of catadromous fish in the Pamlico River Estuary is the American eel (Anguilla rostrata). The American eel supports an important commercial fishery during the adult influx to the estuary from the tributary streams and when subadults move downstream during the spring's high river flow. Postlarval eels (elvers) are present in the estuary during early spring migrations from offshore spawning areas. As the water warms during March, they rapidly make their way upstream to the tributaries, where they metamorphose to juveniles and subadults. After 7 to 14 years in the tributaries, mature adults move back through the estuary to offshore waters to spawn (Forrest 1976).

The majority of the nektonic population in the Pamlico River Estuary is sciaenids, which represent the migratory life history strategy (Miller and Peters 1983). Atlantic croaker (Micropogonias undulatus) and spot (Leiostomus xanthurus) are the most prominant species in the estuary (Table 21). Blue crabs (Callinectes sapidus) are the most prominent shellfish. Of lesser importance, numerically, are the grey trout (or weakfish) (Cynoscion regalis), Atlantic menhaden (Brevoortia tyrannus), southern flounder (Paralichthys lethostigma) and penaeid shrimp (Penaeus sp.). The life history strategy of the migratory species begins with spawning at sea (except the weakfish which probably spawns in the salty Pamlico Sound). After hatching, the postlarvae make their way through inlets in the barrier islands and up into the estuary, where they selectively occupy shallow, productive nursery areas (Gerry 1981; Woodward 1981; Miller and Peters 1983). This generally occurs during the early spring (Figure 45), and the young remain in the estuarine nurseries through most of the summer. Young-of- the-year fish migrate back to the ocean to complete their life cycle. The estuary is an important nursery area, where the high production provides food for the postlarvae to develop through the juvenile stage. These shallow habitats also allow protection from predators and provide suitable temperatures and salinities.

Many of the migratory species have long spawning seasons (e.g., the Atlantic croaker spawns from October to March), and postlarvae migrate to the estuarine nursery grounds primarily during February to April (Miller and Peters 1983). This continuous recruitment tends to maximize the opportunity for finding suitable habitat in what can be a highly variable ecosystem. The timing of the entrance into the estuary corresponds to the burst in springtime productivity of zooplankton and benthos (see Section 3.5), which serve as primary food resources. Further discussion of the temporal and spatial interrelationships is given in Section 4.3.

Some species are indigenous to the Pamlico River Estuary and occupy the estuary year-round, although their total density is small compared to the great hordes of migratory species present in the spring. Their movement strategies are restricted to short distances in and out of the tributary streams, and back and forth in the estuary. The most prominent indigenous species is the bay anchovy (Anchoa mitchilli), which constitutes a significant portion of the forage fish for migratory and anadromous species in the estuary (Table 21). Another species of the indigenous nekton, the grass shrimp (Palaemonetes pugio), is an important fish food in shallow areas, primarily around submerged aquatic vegetation. Some freshwater species, such as white perch, catfish, yellow perch, and centrarchids, are highly sought by recreational fishermen during the spring, when the salinity is low.

CHAPTER 4

ECOLOGICAL INTERRELATIONSHIPS

4.1. TROPHIC STRUCTURE

The concept of the trophic structure in an estuarine ecosystem is more of a food web than a food chain (Odum 1959). In contrast to the longer, more direct food chain relationships observed in the ocean, the food web trophic structure found in the estuary is generally abbreviated.

A simplified diagrammatic representation of the major food web components of the Pamlico River Estuary is presented in Figure 46. While the interrelationships are intricate, the direct pathways in this generalized food web are relatively short.

A change at one trophic level can impact other portions of the ecosystem by altering the direction or size of the

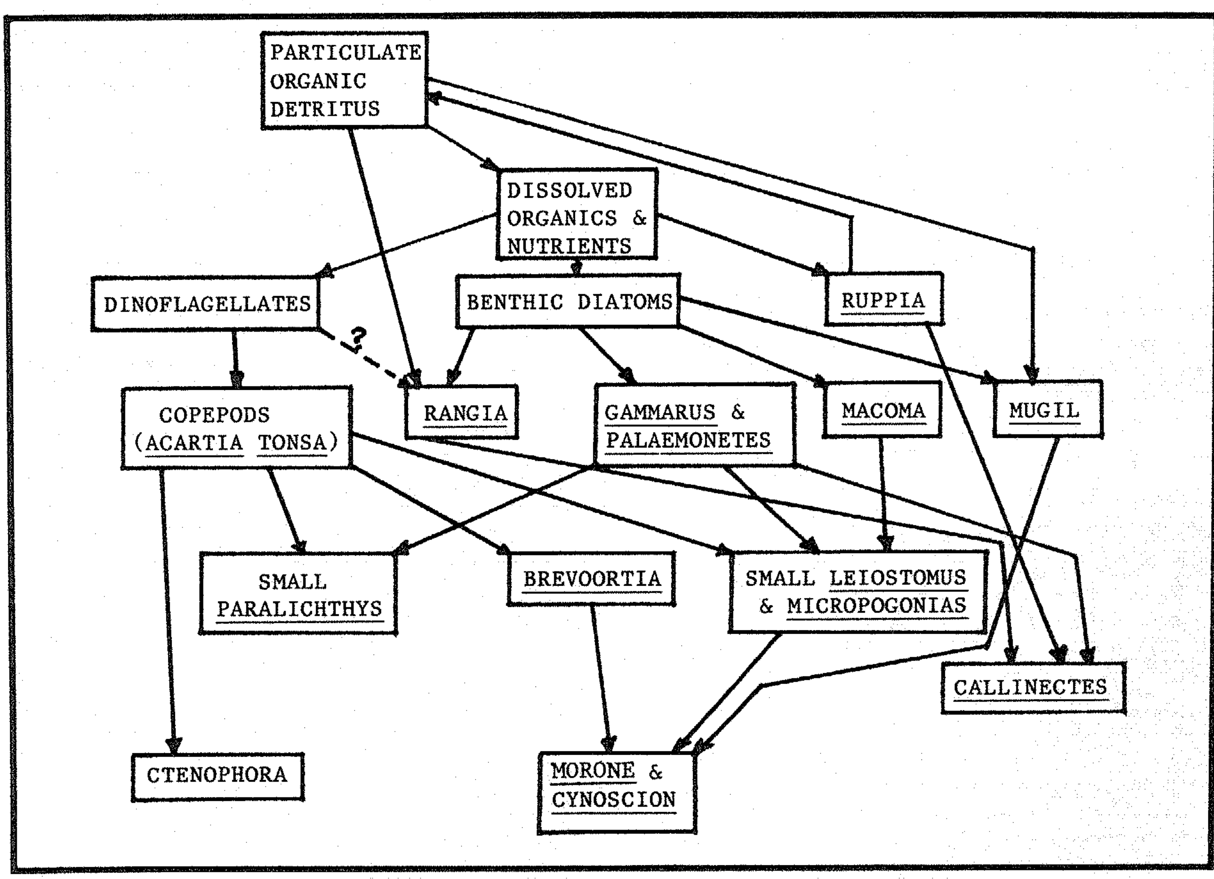

Figure 46. Generalized food web for the Pamlico River Estuary (Copeland et al. 1974b).

flows. Because of the large number of interrelationships, organisms may be affected by factors acting on other trophic levels. For example, even though an environmental perturbation does not directly impact a particular species, that species could still decline if survival tolerances of a key food organism were exceeded. Similarly, changes in the population of a predator, parasite, or competitor could affect the abundance of a species.

The Atlantic menhaden (Brevoortia tyrannus) is an example of the complexities of the trophic structure of the estuary. The Atlantic menhaden is a prominent member of the finfish species using the Pamlico River Estuary as a nursery (Purvis 1976). Phytoplankton production, zooplankton production, and incoming detritus form the basis for the menhaden trophic relationship (Figure 47). The menhaden example represents those fish that primarily graze the water column, where plankton serves as the major food source. Postlarval menhaden eat small zooplankton, switching to primarily phytoplankton as they grow into juvenile stages. This change in diet couples the menhaden component more directly to the nutrient cycle and to the standing crop of organic matter in the estuary. Young mullet, another major estuarine nekton component, follow a similar habit.

Many of the species of fish using an estuary like the Pamlico River Estuary shift in their food preferences as they grow (Miller and Dunn 1980; Miller and Currin 1982). The Atlantic croaker, for example, shifts from a predominantly zoo-

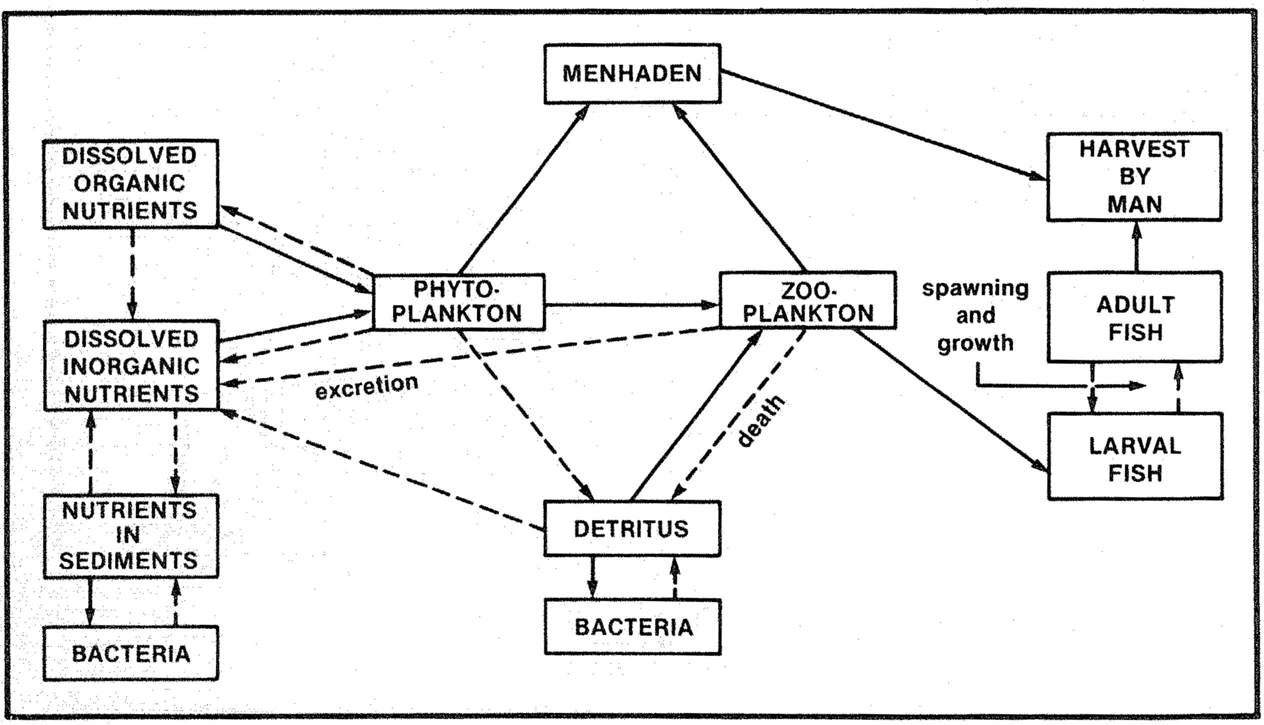

Figure 47. Simplified trophic diagram showing a phytoplankton to menhaden pathway.

plankton diet during the very young postlarval stage to a more diversified diet of macrobenthic animals at early juvenile stages to other fish and macrobenthos as adults (Woodward 1981; Miller and Currin 1982). Although this shift seems to be the trend, it would be more proper to characterize estuarine fish as omnivorous and/or opportunistic feeders. For example, Woodward's (1981) benthic exclusion studies in the Pamlico River Estuary showed that, when benthic feeding was prevented by covering the bottom sediments, the Atlantic croaker shifted to zooplankton even during the late juvenile stages. This would seem to indicate that sciaenids at various life stages could be a major force in coupling benthic productivity and the water column. Flounder apparently follow a pattern similar to the croaker (Miller and Currin 1982). The coupling of benthic plankton and fish is further integrated by primary carnivores, such as grey trout and striped bass, which feed extensively on other fish (Figure 46).

4.2. NURSERY AREAS

Nursery grounds in estuaries are typically shallow nearshore areas (Figure 48) that support large populations of growing postlarval and juvenile fishes and shellfish during their first year of life. Nursery ground utilization and its role in fisheries production has long been suggested to be one of the more important functions of estuaries (McHugh 1966). In the Pamlico River Estuary, nursery areas generally have low salinity and mud and/or mud-grass bottoms. The density of postlarvae and juveniles in these areas is relatively high (as much as 100 times the density of the adults of these species), and, in the Pamlico, the nursery utilizer species are primarily those with migratory life history strategies (Purvis 1976). The primary nursery is in the upper-most sections of the estuary and the populations there are uniformly very early juvenile stages (Purvis 1976).

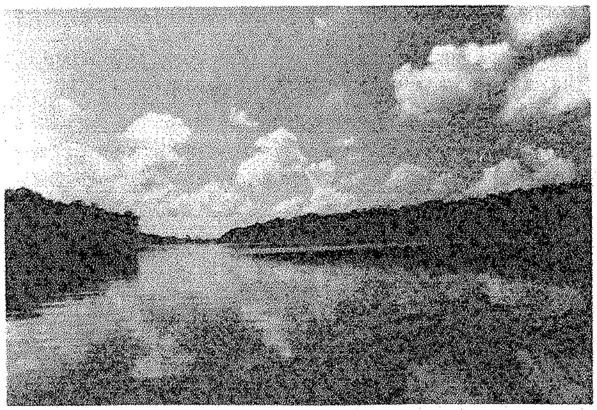

Figure 48. A nearshore estuarine nursery area.

The area of nursery grounds usually represents only a small portion of the total estuarine system (Copeland et al. 1983a). For example, of the approximately 2.3 million acres of estuaries in North Carolina, only about 75,000 acres have been designated primary nursery grounds (data from N.C. Division of Marine Fisheries, Morehead City). A relatively large portion of the primary nursery areas in Pamlico Sound lies in the Pamlico River Estuary and along the northern shore of the sound, here considered as part of the main stem of the Pamlico River (Figure 49).

The Pamlico River Estuary's primary nursery grounds are used by eight major species (Table 23). The most important user is the spot, which is ubiquitous in all the shallow tributaries along the Pamlico River Estuary (Purvis 1976). Another important nursery user is the croaker. In estuaries with low tidal amplitudes, such as the Pamlico River Estuary, young croaker are generally most abundant in shallow marsh habitats with a soft organic substrate. In contrast, in estuaries with higher tidal amplitudes (as in the Cape Fear River Estuary farther south) croakers may be more common in deeper waters of the

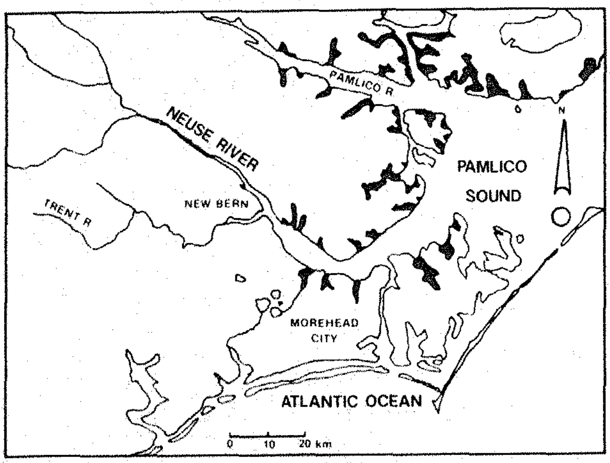

Figure 49. Map of Pamlico Sound, showing primary nursery areas (Copeland et al. 1983).

primary nursery areas (Weinstein 1979; Hodson et al. 1981). Unlike the croaker, young spot are found in great densities in shallow marsh areas irrespective of tidal effects throughout their range (Chao and Musick 1977; Weinstein 1979; Miller and Dunn 1980).

4.3. SPATIAL-TEMPORAL RELATIONSHIPS

A combination of tributary inflows and water-temperature changes characterize the seasons in the Pamlico River Estuary (Kuenzler et al. 1979). Highest tributary inflows occur during January through April (see Section 2.5). Consequently, during the late winter and early spring, when freshwater runoff peaks, the estuary receives nutrients, detritus, and other materials from upland drainage. These are important to the system. As the water begins to warm in the spring and solar radiation increases, phytoplankton productivity increases (Figure 50). This increase in primary productivity is quickly followed by an increase in zooplankton production. High springtime productivity coincides with the recruitment of postlarval fishes and shellfish and supports the postlarvae populations that enter the estuary during that time to use the nursery grounds (Section 4.2).

One of the characteristic adapatations of organisms to the seasonality existing in temperate estuarine systems is that of seasonal migrations (Copeland et al. 1974a). This adaptation permits the rapid proliferation and growth of animal populations during the optimal season of food production and energy availability. At Rose Bay, a tributary nursery area off the Pamlico River Estuary, Miller and Currin (1982) found that the consumption rate of juvenile spot and croaker increased dramatically during late March and April (Figure 51), when the biomass of benthos in that area peaked. Migrating stocks of animals become part of the estuarine energy cycle, become integrated into the functioning ecosystem, and then emigrate to another system. In this way estuaries like the Pamlico River Estuary along the coast are interconnected through the migrating energy and biomass couplings. This pattern of resource utilization among functional groups of fishes maximizes the ecological efficiency of the estuary.

The timing of the combination of physical and biological activities of the

Table 23. Major users of the Pamlico River Estuary primary nursery grounds (Spitsbergen and Wolff 1974; Purvis 1976).

Species	% of total	
	1974	1976
Spot	42.0%	47.0%
Atlantic croaker	27.0%	19.0%
Atlantic menhaden	20.0%	13.0%
Penaeid shrimp	4.9%	12.0%
Blue crabs	1.9%	3.6%
Blueback herring	2.1%	0.1%
Weakfish	0.6%	3.8%
Flounder	0.2%	1.1%

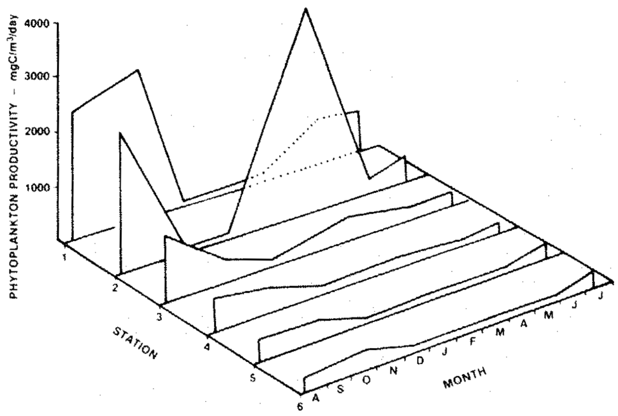

Figure 50. Annual cycle of phytoplankton productivity in the Pamlico River Estuary, 1976-77. Station locations range from upper estuary (1) to lower estuary (6) (Davis et al. 1978).

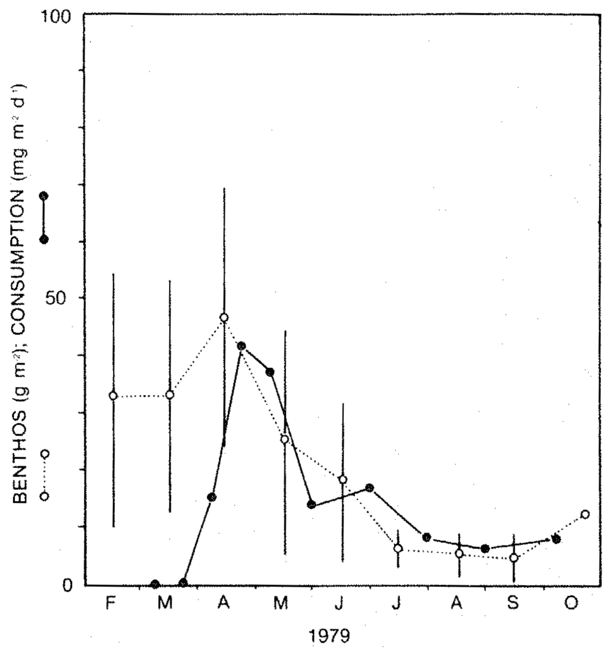

Figure 51. Combined juvenile spot and croaker consumption rates and benthic biomass in Rose Bay, N.C., 1979 (Miller and Currin 1982).

whole estuarine continuum is absolutely critical for the success realized by animals in the estuarine nursery grounds (Miller et al. 1982).

Migrating postlarvae move from the ocean spawning grounds through the inlets into the shallow tributaries, usually during the winter and early spring of each year (Figure 50). The physical conditions that enable this phenomenon to occur begin with the winter winds blowing directly offshore, which sets up an inflowing, below-surface layer of warm salty water flowing in from the offshore spawning grounds (Figure 52; Miller et al. 1982). Thus, the major mechanism to transport larvae from offshore is that thick intermediate layer of water moving toward shore at relatively high speeds (3 to 8 cm/s). The onset of these physical conditions is concurrent with offshore spawning activities. In one example (Figure 52), spot and croaker larvae are advancing in age during this water movement, with the first observations at about 15-18 days after spawning and ranging to about 45-55 days old at the inlet. The onshore movement of water during the winter also establishes a counter-clockwise circulation pattern in Pamlico Sound. This pattern enables the larvae and postlarvae to be carried to the nurseries along the northern and western shores of Pamlico Sound (i.e., the Pamlico River Estuary). The combination of physical movement of water from offshore into and around Pamlico Sound, and the availability of multitudes of postlarvae, help make the nursery grounds in the lower Pamlico River Estuary among the most productive on the east coast.

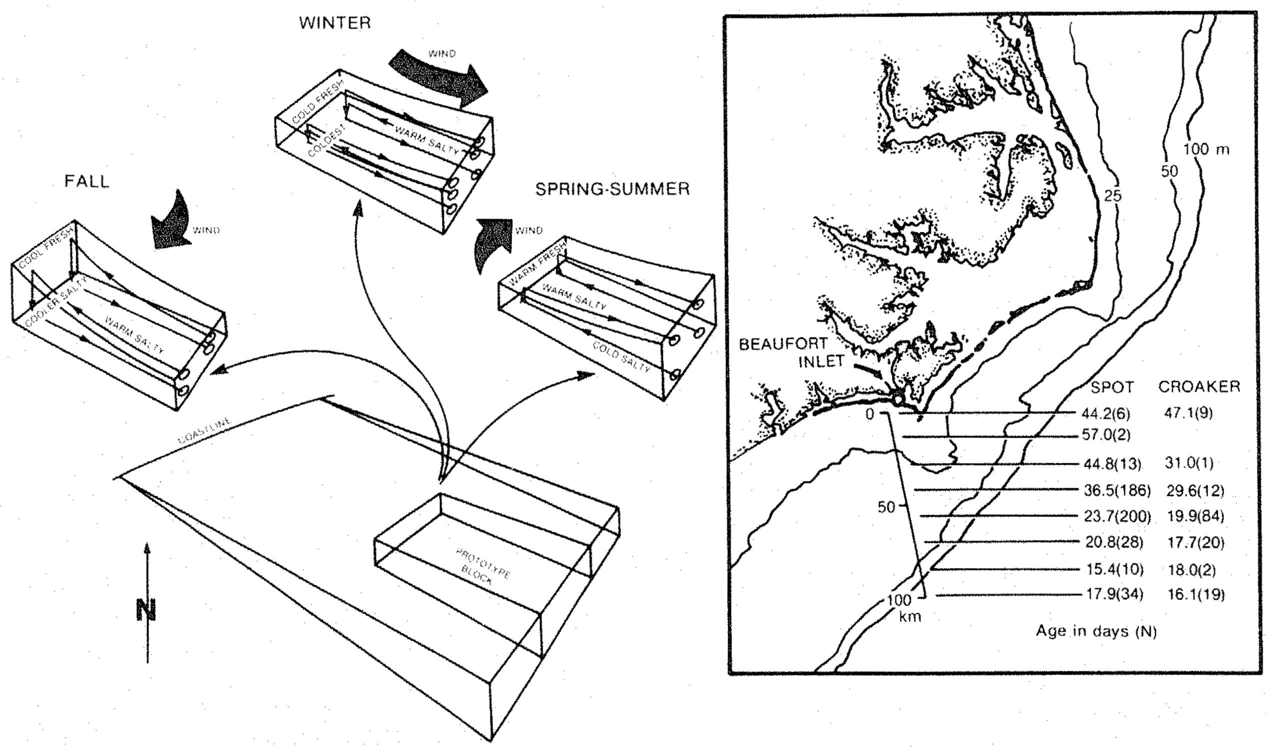

Figure 52. Seasonal wind and onshore/offshore flow patterns over the N.C. continental shelf, with age distribution of larval spot and croaker moving toward inlets (Miller et al. 1982).

CHAPTER 5

FISHERIES

5.1. COMMERCIAL FISHERIES

Fishing has been an important activity in the Pamlico River Estuary (Figure 53) since colonial times (Mauldin et al. 1979). The early settler depended upon the estuary for food, and caught many of the species that are currently major contributors to the present-day commercial fishery.

The Pamlico River Estuary and the Neuse River Estuary are the major contributors of fish and shellfish to Pamlico Sound, which, in turn, constitutes the most important commercial fishery area in the State (Copeland et al. 1983a). A majority of the primary nursery grounds in the State are in both the Pamlico River Estuary and along the contiguous shoreline around Pamlico Sound (see Section 4.2). Thus, it is not possible to accurately separate that portion of Pamlico Sound's commercial catch which is directly attributable to the estuary (Katie West, N.C. Division of Marine Fisheries, Morehead City, pers. comm.).

Pamlico Sound (and its tributaries) is a major contributor to the commercial fisheries catch in North Carolina (Table 24). With 56% of the State's total coastal waters, the sound contributed 78% of the total inshore commercial catch (poundage) in 1980. In contrast, Albemarle Sound, which constitutes 26% of the State coastal waters, contributed 14% of the total commercial fisheries catch. Likewise, the value of the catch from the Pamlico Sound area constitutes about 73% of the total inshore commercial catch value.

As noteworthy as this disproportionately high productivity is, the higher proportion attributed to Pamlico Sound might be even more startling if the offshore catch could be apportioned to the

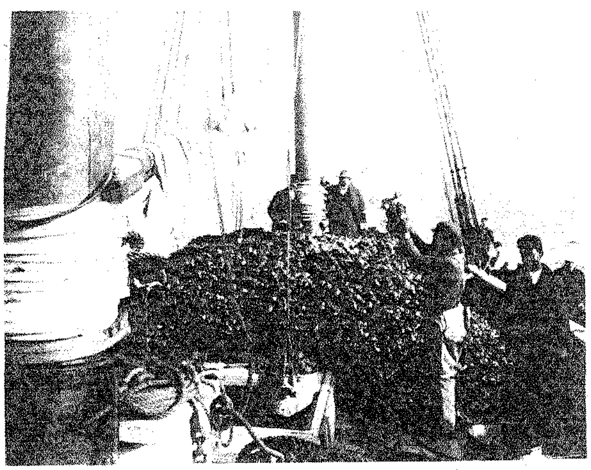

Figure 53. Oystering near Washington, N.C., 1884.

Table 24. Distribution of 1980 commercial fisheries catch and value, Albemarle and Pamlico Sounds, North Carolina (N.C. Division of Marine Fisheries Catch Statistics, Morehead City).

Parameter	Albemarle Sound	Pamlico Sound
Area (mi^2)	940	2,000
% State total	26%	56%
Catch (1,000 lb)	13,200	71,430
% total inshore catch	14%	78%
Value ($1,000)	1,981	26,182
% total inshore value	5%	73%

sounds. The offshore catch exceeds the inshore total in poundage because of the large menhaden contribution, and almost equals the value of the inshore catch. Much of this offshore production is thought to be attributable to Pamlico Sound and its primary nursery areas (Street 1981).

The total commercial fisheries landings reported for Pamlico Sound in recent years (Table 25) ranged between a high of around 71 million pounds in 1980 to a low of about 22 million pounds in 1971. The value of these landings ranged between about 3.6 million dollars in 1970 to over 26 million dollars in 1980. In contrast to the catch in Albemarle Sound (Copeland et al. 1983b), which is dominated by only 5 or 6 species, the catch in Pamlico Sound is made up of 20 or more species (Street 1981). The largest contributors to this catch are flounders, weakfish, blue crabs, penaeid shrimp, Atlantic croaker, spot, eels, and bait fishes. All these species are migratory and use estuarine nurseries. There are 21 other species taken in the commercial catch reported for the Pamlico Sound area, but none of them constitute more than about 5,000 lb/yr.

Table 25. Total commercial fisheries landings for Pamlico Sound complex, 1970-81 (N.C. Division of Marine Fisheries Catch Statistics).

Year	Total landings (1,000 lb)	Total value ($1,000)	Percent of state landings
1970	27,355	3,609	60.9
1971	22,087	4,872	53.8
1972	22,224	4,122	53.8
1973	24,620	5,503	62.4
1974	32,328	6,465	68.3
1975	33,997	6,621	70.4
1976	31,291	10,003	69.3
1977	35,975	10,467	70.1
1978	42,100	9,973	68.9
1979	53,732	15,600	71.9
1980	71,430	26,182	74.6
1931	56,504	18,491	74.7

To underscore the importance of Pamlico Sound and the tributary estuaries to the commercial fisheries of this area, we calculated the yield of commercial catch on a per unit area basis for comparison purposes. If we assume that about 70% of the total inshore and offshore catch in North Carolina is attributable to the productivity of Pamlico Sound (Street 1981), the yield is estimated to be 245 lb/acre on an annual basis using 1980 catch. This compares favorably with the 170 lb/acre calculated for Chesapeake Bay (Rothchild et al. 1981), which is considered to be an important coastal system for the production of commercial fisheries on the east coast of the United States.

In recent years, with better means of keeping statistics, the N. C. Division of Marine Fisheries has attempted to separate fisheries' catch for each water body and county in North Carolina (Street 1981). By attributing catch to the county in which it was landed, it is possible to arbitrarily allocate catch to water bodies. On this basis, commercial fisheries catch to the Pamlico River Estuary amounts to about 10% of the total Pamlico Sound catch. Blue crabs, taken both by trawls and crab pots (Figures 54 and 55), account for a large majority of this catch.

Of the major species caught in the western Pamlico Sound area, trawling for flounder, trawling and potting for blue crabs, long-haul seining for trout, oyster dredging, and trawling for shrimp are major commercial enterprises. The primary area of trawling for southern flounder lies at the lower ends of the estuaries and in the western portion of Pamlico Sound (Figure 56). The major seasons for flounder trawling are during fall and winter (Wolff 1977). The major commercial fishing for blue crabs occurs throughout the Pamlico River Estuary and Neuse River Estuary, as well as in the shallow, nearshore areas around western Pamlico Sound (Figure 57). Fishing activity for blue crabs, either trawling or potting, occurs year-round (Wolff 1978). Shrimping is an extremely important commercial fishery in Pamlico Sound, occurring primarily during summer and fall (McCoy 1972). Shrimp trawlers fish throughout Pamlico Sound in quest for these high value crustaceans, which depend upon the Pamlico River Estuary and similar nursery areas for their production.

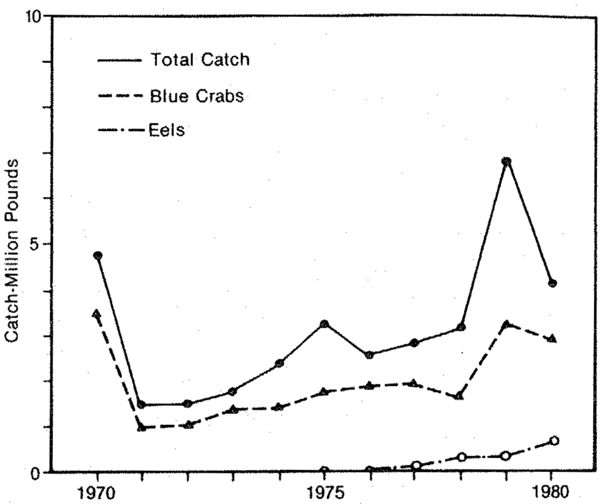

Figure 54. Commercial fisheries catch reported for the Pamlico River Estuary, 1970-80 (N.C. Division of Marine Fisheries Catch Statistics).

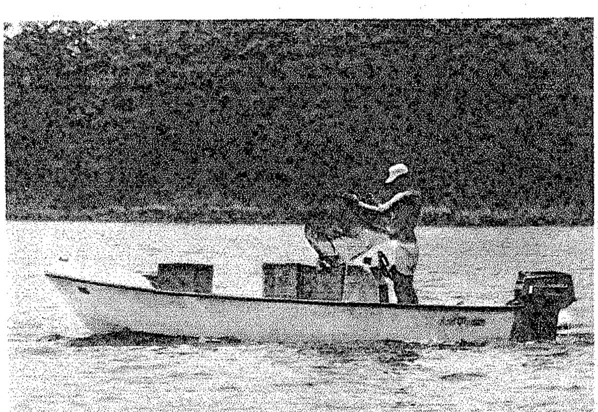

Figure 55. Crab-potting in the Pamlico River Estuary.

5.2. RECREATIONAL FISHERIES

Recreational fishing (Figure 58) has been a traditional activity in the Pamlico River Estuary since colonial times (Mauldin et al. 1979). One of the great needs in the management of fisheries in North Carolina coastal waters is information on the catch-per-unit effort of recreational fishermen (Street 1979, 1981).

A major study is currently underway by the University of North Carolina Sea Grant College Program to determine the social and economic status of recreational fishing in the Pamlico River Estuary (Fricke et al. 1983). Surveys conducted in the Pamlico and Albemarle Sound areas during 1981 and 1982 indicate that the area of highest recreational usage is the Pamlico River Estuary and contiguous shorelines around the sound (Figure 59). This finding includes all recreational boating activities without differentiating between fishing and other water-related recrea-

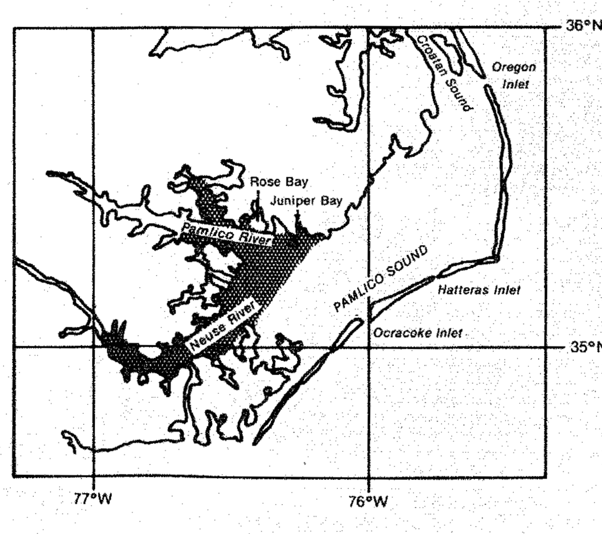

Figure 56. Areas of western Pamlico Sound flounder trawl fishery (Wolff 1977).

tional activities. The season of this intense usage is primarily May to November of each year (Dr. Leon Abbas, UNC Sea Grant, Raleigh, pers. comm.).

The major species sought by recreational anglers include the Atlantic croaker, grey trout (or weakfish), speckled trout, and largemouth bass (Table 26). It should be noted that 36% of the recreational anglers acknowledge that they seek any fish they can catch (see notation of "anything" in Table 26). The frequency of catch is slightly different than the frequency of targeted species, indicating that the fishermen do not always catch what they seek, and are willing to take whatever is active at the time they are fishing. In the frequency of catch, the Atlantic croaker is taken most often in the Pamlico River Estuary (Table 26).

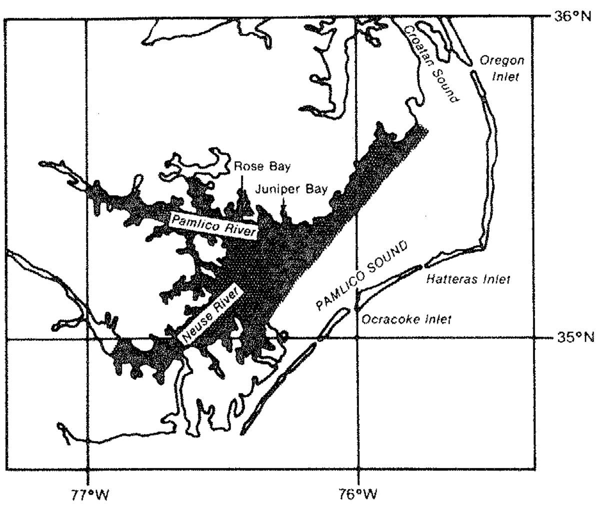

Figure 57. Areas of western Pamlico Sound blue crab fishery (Wolff 1978).

Figure 58. Flounder-gigging in the Pamlico River Estuary.

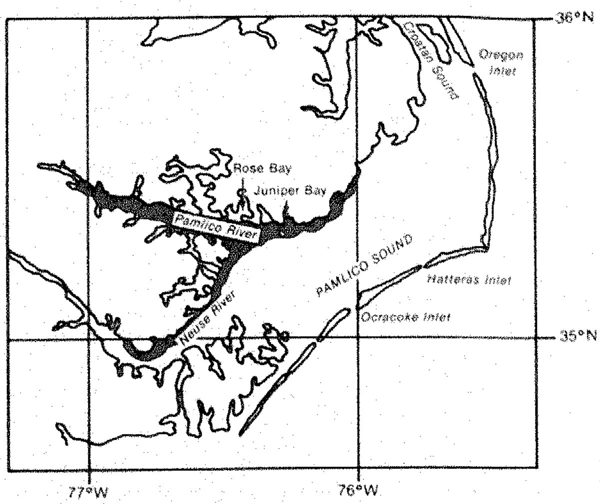

Figure 59. Map of Pamlico Sound, showing the area of intense recreational activity (Dr. Leon Abbas, UNC Sea Grant Program, Raleigh, pers. comm.).

Table 26. Mean percent frequency of catch and targeted species by recreational fishermen in the Pamlico River Estuary, 1981-82 (Fricke et al. 1983).

Species	Frequency of catch (% of Total)	Frequency targeted (% of total)
Atlantic croaker	31.3	12.6
Grey trout	13.7	32.8
Bluefish	12.6	----
Flounder	3.3	----
Speckled trout	2.7	4.2
Spot	3.3	0.8
Sea mullet	3.3	----
Striped bass	----	1.7
White perch	1.6	1.7
Yellow perch	1.6	----
Largemouth bass	1.1	6.7
Sunfish	3.3	2.5
Crappie	0.5	----
No catch	21.4	----
Anything	----	36.1

The recreational catch-per-unit effort (CPUE) in the Pamlico River Estuary during the major season of recreational fishing (i.e., May through November) ranges between less than 0.5 fish per fisherman per hour to over 2.5 fish per fisherman per hour (Figure 60). The highest CPUE occurred during May through August, with a declining catch during the fall. The CPUE reported for the Pamlico River Estuary is relatively high during the summer, compared to other areas in the region (Dr. Jeffrey Johnson, East Carolina University, Greenville, pers. comm.).

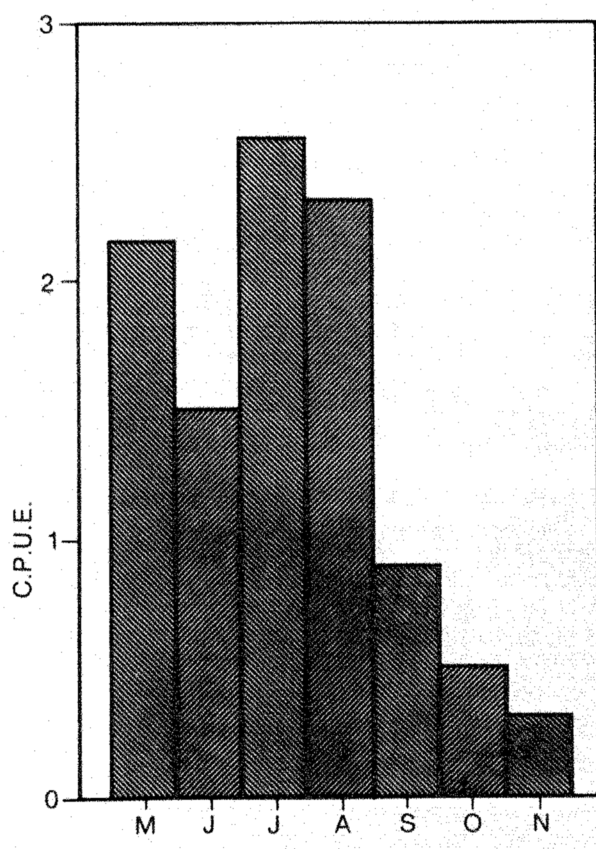

Figure 60. Recreational catch per unit effort (CPUE) in the Pamlico River Estuary, 1981-82 (Dr. Jeffrey Johnson, East Carolina University, Greenville, pers. comm.).

5.3. FISHERIES TRENDS

The dockside value of North Carolina's commercial fisheries has increased from about 9 million dollars in 1965 to about 70 million dollars in 1980 (Street 1981). Some of this increase in value has been caused by inflation, but there has also been a large increase in the poundage landed (Figure 61). While these general statistics are for statewide commercial fisheries landings, the trend in Pamlico Sound, as well as in nearby Chesapeake Bay (Rothchild et al. 1981), has been similar. This recent increase has followed a decline that reached a low point in the early 1970's.

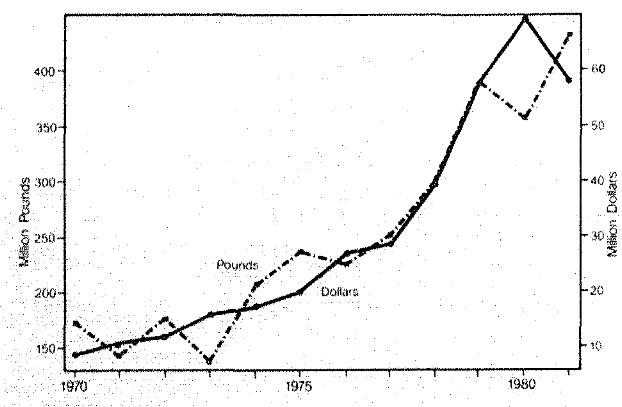

Figure 61. The N.C. annual commercial fisheries catch, 1970-81 (Copeland et al. 1983).

Traditionally, much of the value of North Carolina's commercial fishery has come from shrimp, crabs, and menhaden, which are short-lived species relying upon estuarine nursery grounds for their production. The Pamlico River Estuary is a significant contributor to this production. Edible finfish, however, are usually made up of longer-lived species that also rely on estuarine nursery grounds, but are faced with environmental variability over a longer period. As late as 1970, edible finfish (primarily croaker, flounder, weakfish, and spot) accounted for only about 28% of the total value of North Carolina's fisheries, but by 1980 had increased to about 45% of the total value (Street 1981). The poundage increased from about 30 million pounds in 1970 to about 82 million pounds in 1979 for edible finfish. A large percentage of the edible finfish poundage was harvested from Pamlico Sound and its tributaries (Street 1981).

We do not know exactly how much pressure this intense fishing is putting on the resources, especially in regard to the management of estuarine nursery areas (Copeland et al. 1983a). The overwhelming question, therefore, is whether our coastal fisheries can sustain the tremendous increase that we have seen in the last few years. The answer lies in our skill to resolve the conflicts between uses for estuarine resources.

CHAPTER 6

MANAGEMENT IMPLICATIONS

6.1. MANAGEMENT ISSUES

A number of complex issues must be addressed in whatever management scheme, or schemes, may be devised for the Pamlico River Estuary. The following list includes management considerations important to the estuary and the users of its resources:

Control and fate of nutrient loading. Since inputs make up only a small percentage of the nutrients taken up during primary productivity, the interrelationships of nutrient forms and timing are of prime importance.

Control and fate of exotic substances such as pesticides, herbicides, heavy metals and organic compounds. With the Tar River flowing through areas intensively used for agriculture, and with continuing conversion of the adjacent watershed for additional agriculture, there is a need to provide a management program to minimize inputs of exotic materials.

Impact of phosphate mining. As the mining and processing of phosphate increase, so do the opportunities for phosphorus to enter the middle of the estuary on a year-round basis. The use of settling ponds to handle plant effluents has been effective in the past.

Impacts of urbanization. Even though land use on the watershed is largely agrarian, there has been an increase in urban populations that is expected to continue in the foreseeable future. Sewage treatment facilities along the river will need to be upgraded and enlarged to handle the increasing waste loads.

Determination of impacts of changing forests into agricultural and related land uses. The clearing of large tracts of land in the adjacent watershed is expected to continue. Potential for strip-mining peat may bring additional acres out of their natural state of forests and pocosins. Drainage of water from these cleared lands can have large impacts on the estuary, unless a careful management plan is devised to minimize the problem.

Population enhancement of commercial and recreational fisheries. Closing nursery areas to trawling to protect benthic production and imposing net-size regulations to avoid premature harvests are examples of management plans in place. Additional schemes, to limit such things as catch and numbers of fishermen (limited entry fishery), are options to be considered.

Population enhancement of anadromous fisheries. Hatchery programs to re-establish and/or to increase supplies of juveniles are the usual management actions. Jurisdictional conflicts between several State and Federal agencies threaten the effectiveness of some plans (e.g., one agency allowing trawling in an estuarine area, while another places hatchery-raised juveniles upstream).

Minimizing conflicts of interests. Allocation of resource uses are often settled on economic and political terms, while the needs to protect certain resources are not always considered. An effective management plan will consider and resolve all legitimate uses of the resources.

Impact of commercial and recreational fishing. What are the impacts of harvesting one species on the production of another? Certain kinds of fishing activities damage the habitat of other species. Commercial and recreational fishing alone or in combination can be detrimental to some populations, especially if these populations are being impacted in other ways. Management plans must address the increasing conflicts between commercial and recreational fishermen.

Meshing local, State and Federal jurisdictions. The Coastal Area Management Program has coordinated all jurisdictions in many cases, although "blanket" regulations for a whole country, for example, sometimes can not be effectively applied at the local level.

Maximizing cooperation between users and regulators. Although public hearings are designed to enable the public to learn about and influence regulations, they fall short of developing the cooperation needed to ensure the maximum benefits envisioned by the regulators. An effective management plan would have user-group advisory committees built into the regulatory process. Such processes are in place for the State's programs of coastal management, marine fisheries development, and environmental management.

Education of the public. An informed public can be much more effectively involved in a management program. This can be done through the public schools, extension programs, and community/technical colleges, as well as by the management agencies.

Additional research needs. The estuary is extremely complex and the interrelationships involved require special understanding. In spite of the extensive research completed for the Pamlico River Estuary, critical gaps still exist that limit management.

There are several special management caveats and complexities that require special emphasis. The following sections will cover the most relevant ones.

6.2. MULTI-SPECIES MANAGEMENT

The general fisheries management tendency is to develop a program to maximize the production of a single species (Anderson 1982). Single-species management is probably a futile exercise, especially in an estuary like the Pamlico River Estuary (Richkus et al. 1980). The fishery there is primarily based on stocks that move into the estuarine system from outside spawning areas and use the estuary as a nursery ground. Therefore, a multi-species fishery depends on the balance of flows of materials and productivity occurring there. Multi-species management is absolutely essential to the perpetuation of such a productive system.

The N.C. Division of Marine Fisheries has the statutory responsibility to manage the State's coastal fisheries and wetland resources to achieve optimum benefits for all (Street 1979). This responsibility is currently being met through multi-species programs which manage the entire fishery, gather population dynamics and life history information on fishes, and identify habitat requirements for fishes. The major goal is to optimize the control of environmental perturbations to provide a suitable habitat for maximum production of a variety of species. An example of the effectiveness of a multi-species management program has been the Marine Fisheries Commission's closing of tributary nursery areas to trawling, so that the juveniles of all species concerned can have maximum protection (Terry Sholar, N.C. Division of Marine Fisheries, Morehead City, pers. comm.).

Multi-species management is important to augment annual incomes of fishermen and to provide year-round fish stocks. A multi-species management scheme is even further supported by the fact that about 30 species of fish and shellfish make up the commercial catch in the Pamlico River Estuary and western Pamlico Sound (see Section 5.1). Nursery ground surveys conducted by the N.C. Division of Marine Fisheries (Spitsbergen and Wolff 1974; Purvis 1976) indicate natural variations in abundances of the juveniles of important species in the Pamlico nursery areas. The decline in shrimp harvests during 1978, 1979, and 1981 was partially compensated for by increases in finfish and blue crab harvests during those years (Street 1981). Thus, when the normal, annual fluctuations occur in the availability of stock, the commercial fishermen may turn to another species that may be relatively more abundant during that particular time. Without multi-species management fishermen may not have this flexibility.

6.3. ECONOMIC PARAMETERS

Economic parameters are important considerations and are usually the base of user conflicts. Their importance depends to a large extent on the level of management being considered. One group of parameters is required for single-species fisheries management, and a larger group for multi-species management. An even larger group of parameters will be involved in managing an entire estuary, since other sectors of the economy, in addition to the fishery, are more directly involved.

Several economic tools are available to the management agency for optimizing the catch in a particular ecosystem. These include taxing the catch, taxing vessels, reducing the number of licenses issued, or assigning quotas to the fishermen. All of these are designed to improve the catch-per-unit-effort (CPUE) ratio (Maiolo and Orbach 1982). For example, Clark (1979) has shown that the management tool of assigned quotas is as economically efficient as imposing a tax on the catch. It is generally regarded that taxing the catch is politically impractical; thus, it might be more effective to assign catch quotas.

Multi-species management would involve several additional parameters. The management agency must become concerned with all fish stocks and their harvests simultaneously. If one group of fishermen targets harvesting toward a single species, another species may be adversely affected, resulting in biological and economic problems. For example, shrimpers in Pamlico Sound catch large brown shrimp during the summer, and incidentally catch smaller (and hence cheaper) white shrimp. This, in turn, may reduce the total value of white shrimp later in the year (Waters et al. 1980).

The role of economic parameters in the management of the Pamlico River Estuary takes on greater significance when one considers that agriculture, recreation and tourism, and the commercial fishery all yield different values. Agriculture has played a major role in the watershed of the estuary for several decades, but has intensified during the past ten years (Phillips 1982). Recreation and tourism have increased in value during recent years (N.C. Department of Commerce, Raleigh, statistics). The dockside value of the commercial fisheries (see Section 5.1) is generally less than the values of agriculture or tourism. Since the values of these economic sectors are not precisely known, and the "technical production coefficients" are unknown, it is impossible to compare the relationship of each of these to the total economy of the area. Therefore, any management goal and the tools devised to achieve that goal are surrounded with tremendous uncertainty and built-in conflicts.

6.4. SOCIOLOGICAL IMPLICATIONS

Different uses of the Pamlico River Estuary conflict with one another, due to the many economic forces focused on the estuary. Traditional fisheries techniques, used in small-scale commercial fisheries similar to those of most southeastern U.S. fishing communities, are generally employed (Maiolo and Orbach 1982). Traditional fisheries values (Figures 62 and 63) serve as constraints, and management programs designed to change the use of the estuary will be in jeopardy. This strongly implies that public education is needed to enable any management scheme to succeed.

Agricultural production is a dominating economic force in the watershed, and some have attributed declines in the quality of the Pamlico nursery grounds to farming operations, particularly drainage activities needed for farming the low-lying soils. Due to the small community structure in the area surrounding the estuary, farmers and fishermen live and work closely together. Management schemes designed to minimize conflicts between farmers and fishermen stand a much greater chance of success.

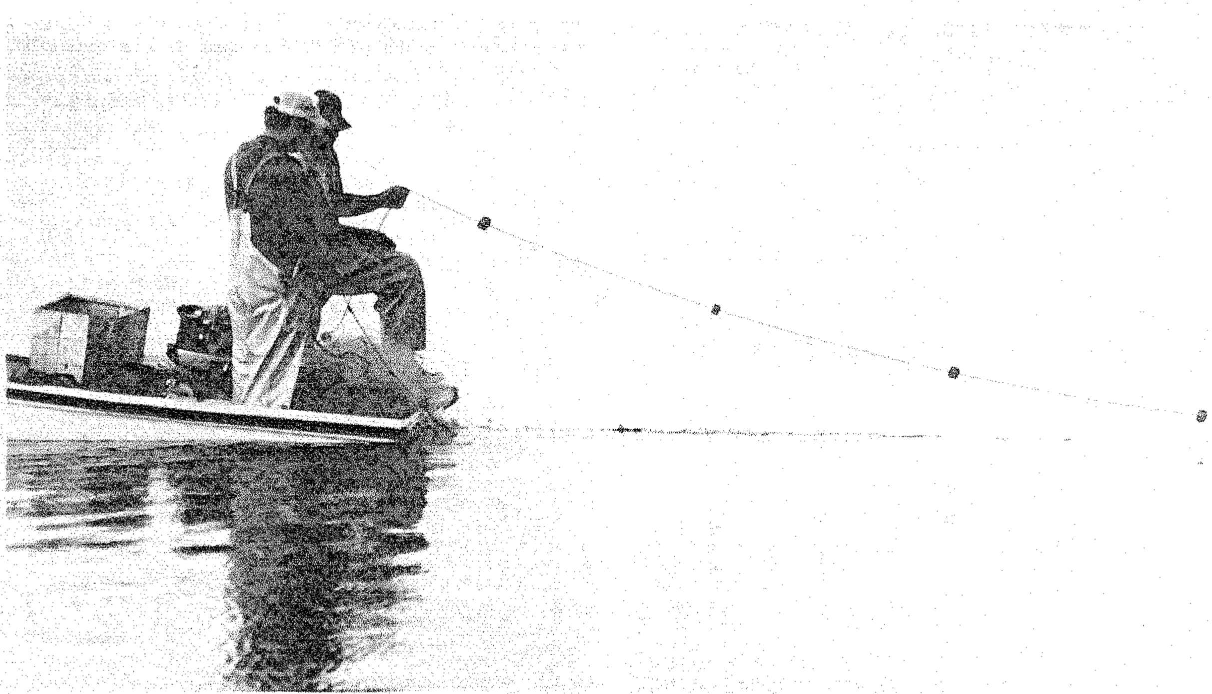

Figure 62. Gill-net fishing activities.

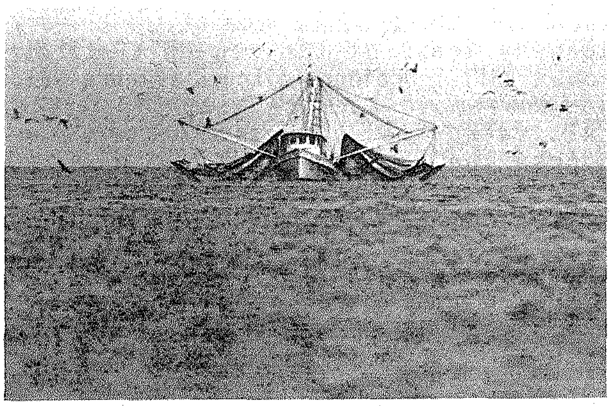

Figure 63. A Pamlico Sound shrimp trawler.

Social conflicts are particularly important when managing within fisheries interests. Although the same environmental criteria are important for the biological management of commercial and recreational fisheries, serious conflicts in economic and social goals exist between the two (Maiolo and Orbach 1982). Often, many of the species sought by both interests are the same. Recreational fishermen blame commercial fishermen for decreasing stocks and catch-per-unit effort, while commercial fishermen accuse recreational fishermen of such things as getting new restrictions enacted to decrease their fishing rights. Social conflicts also exist within the same fisheries group, such as larger boats versus smaller boats, and crab potting versus trawling for crabs. Any management scheme developed for the Pamlico River Estuary must consider these problems if the plan is to have much chance for success.

6.5. EXAMPLES OF MANAGEMENT COMPLEXITY

From the viewpoint of managing a suitable environment for the maximum production of fisheries in the estuary, increases in organic loading and nutrient loading should cause concern (Davis et al. 1978). Control of inorganic nutrients may be more important in controlling the increases in organic loading than attempts to control the input of allochthonous organic matter (N.C. Division of Environmental Management 1982).

The impacts of nutrient loading on the Pamlico River Estuary were discussed by Hobbie (1974) and by Kuenzler et al. (1979) and were an important factor in the production of phytoplankton biomass, which leads to increases in organic matter in the estuary. Recycling of nutrients (Kuenzler et al. 1979) and recycling of organic materials (Matson et al. 1983) within the estuary are apparently major factors affecting productivity (see Section 3.3). A general scheme of management considerations for the control of nutrients and organic carbon in the Pamlico River Estuary was suggested by Davis et al. (1978), following their study of the Pamlico River Estuary deoxygenation patterns. This scheme (Figure 64) emphasized the intricate complexity of management of an open-ended system like the Pamlico River Estuary, particularly as it related to maintaining a multi-species, functioning ecosystem.

Large areas of the Pamlico River Estuary experience summertime deoxygenation in bottom waters during periods of low flow (Davis et al. 1978; Kuenzler et al. 1979). Estuarine waters become warm and calm, and salty water penetrates upstream creating stratification (Figure 65). Large amounts of organic matter settle to the bottom (Davis et al. 1978), requiring dissolved oxygen to oxidize them, and thus depleting the dissolved oxygen concentration in the water (Figure 66). During these periods of anoxia, large numbers of small fishes and blue crabs move to the shallow shoreline areas in an attempt to avoid the oxygen depletion. Fish and other organisms die as the oxygen decreases, further compounding the dissolved oxygen problem, due to the high respiration rates of the bacteria associated with decomposition. While this phenomenon is apparently natural, and has been occurring in the Pamlico River Estuary for years (Hobbie 1970b), man may exacerbate the process with additional organic loading.

The balance of freshwater inflows and saltwater circulation from nearby Pamlico Sound dictates salinity patterns in the estuary, which, in turn, are critical to the maintenance of a productive habitat. Rapid fluctuations of freshwater inflows result in large variations in salinity; whereas, low freshwater inflow allows salt water to penetrate into the estuary which stratifies as a result. In either case, salinity changes lead to changes in biological components which in turn lead to perturbations in productivity and decomposition. Increased rates of freshwater inflow from land drainage in localized areas impact some of the primary nursery areas of the region (Pate and Jones 1981). Drainage ditches (Figure 67), which remove surface water from the cultivated fields (Heath 1975), alter or bypass the ability of inland areas and associated vegetation to act as a natural buffer for surface run-off. The resulting peak runoff rates are earlier and several times higher on developed lands than on similar, undeveloped lands (Skaggs et al. 1980). Salinities in the receiving waters respond quickly and dramatically to these rapid pulses of fresh water, due to the small volume of many tributary nursery areas (Pate and Jones 1981). The increase in salinity fluctuations, resulting from the surges of freshwater flow into the nursery areas, causes changes in

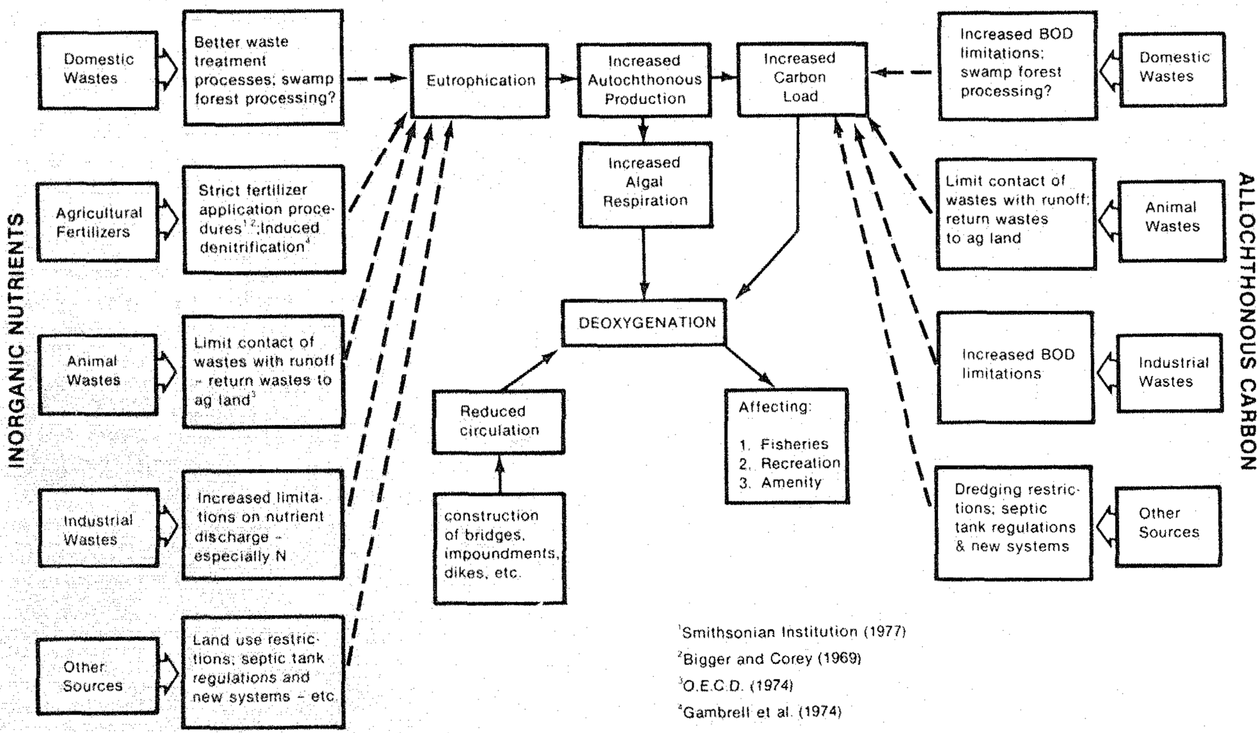

Figure 64. Generalized management considerations for control of deoxygenation in the Pamlico River Estuary (Davis et al. 1978).

biological components, changes likely to decrease the nursery value of the area (Gerry 1981).

Pate and Jones (1981) sampled some tributary estuaries with unaltered drainage basins and some that had been altered by draining cultivated fields. In the altered areas, a 2-inch rainfall in 24 hours resulted in salinity fluctuations of 3 to 5 ppt immediately after the rain. In the unaltered areas, with the same rainfall, the salinity of the receiving water decreased about 1 ppt, and returned quickly to the original salinity levels within a 24-hour period. Subsequent sampling of the juvenile organisms in the estuary showed that spot, menhaden, croaker, and brown shrimp concentrations declined in those areas experiencing the rapid salinity fluctuations, but remained at the same population level in the more stable areas (Figure 68). While this information indicates that tremendous impacts can be experienced by the estuarine nursery area from land-drainage activities, current research indicates that building shallower drainage ditches and reducing tillage may serve to minimize these impacts (Dr. Wayne Skaggs, N.C. State University, Raleigh, pers. comm.).

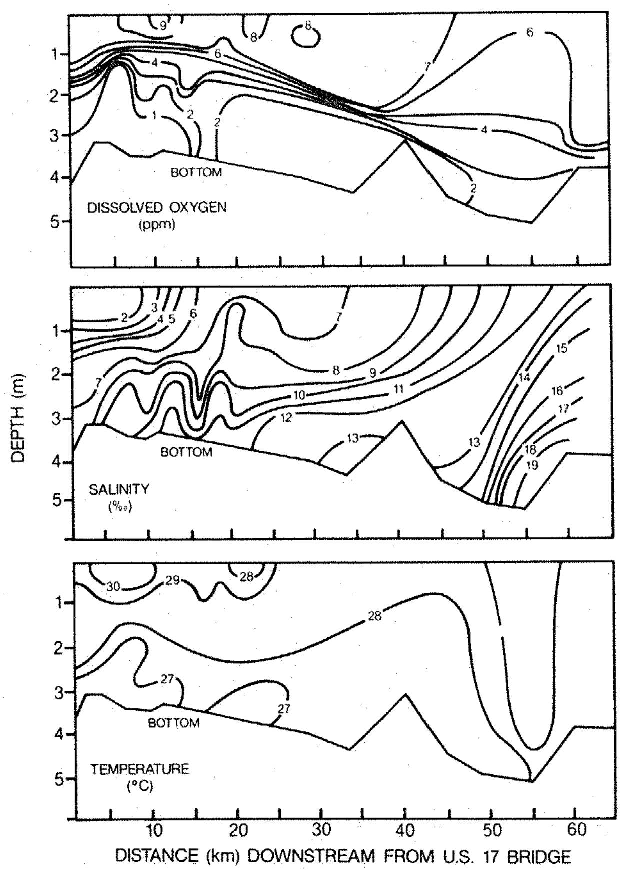

Figure 65. Dissolved oxygen, salinity, and water temperature during a time (5 July 1976) of stratification (Davis et al. 1978).

The complex interrelationships inherent in nutrient and organic loading, primary productivity, materials recycling, salt balance, benthic productivity, and fisheries production are difficult to understand and even more difficult to manage. These factors and their temporal-spatial balance are extremely sensitive to outside influences. Therefore, changes on the watershed can render the complex management questions beyond reasonable comprehension.

6.6. RESEARCH NEEDS

The Pamlico River Estuary is reasonably well-studied and large data sets exist for many functional aspects. In spite of this extensive coverage, there are several serious gaps in information. The following list gives those information needs critical for effective management:

a. Actual exchange rates of nutrients and organic matter among trophic components of the estuary are needed to evaluate changes in inputs.

b. Benthic productivity rates are needed to evaluate the apparent critical component of food support for many fishes.

c. We need to know more about the coupling of fisheries production, primary productivity, and nutrient and organic cycling, so that the management of basic components can be used to enhance or protect commercial fishery yields.

d. The relationship between freshwater runoff and land-use activities needs to be quantified so that estuarine impacts can be minimized by regulating activities on the watershed.

e. Bacterial densities and decomposition rates need to be quantified for all seasons, to evaluate the recycling of materials and nutrient regeneration.

f. The role of nursery areas and their carrying capacity needs to be quantified to identify cause and effect relationships.

g. Better estimates of fisheries standing crops are needed. We especially need to know the amount of take by commercial and recreational harvests, so that we can more accurately assess populations and make predictions of potential harvests.

h. Economic values of the estuary's resources need to be assessed, and technical production coefficients

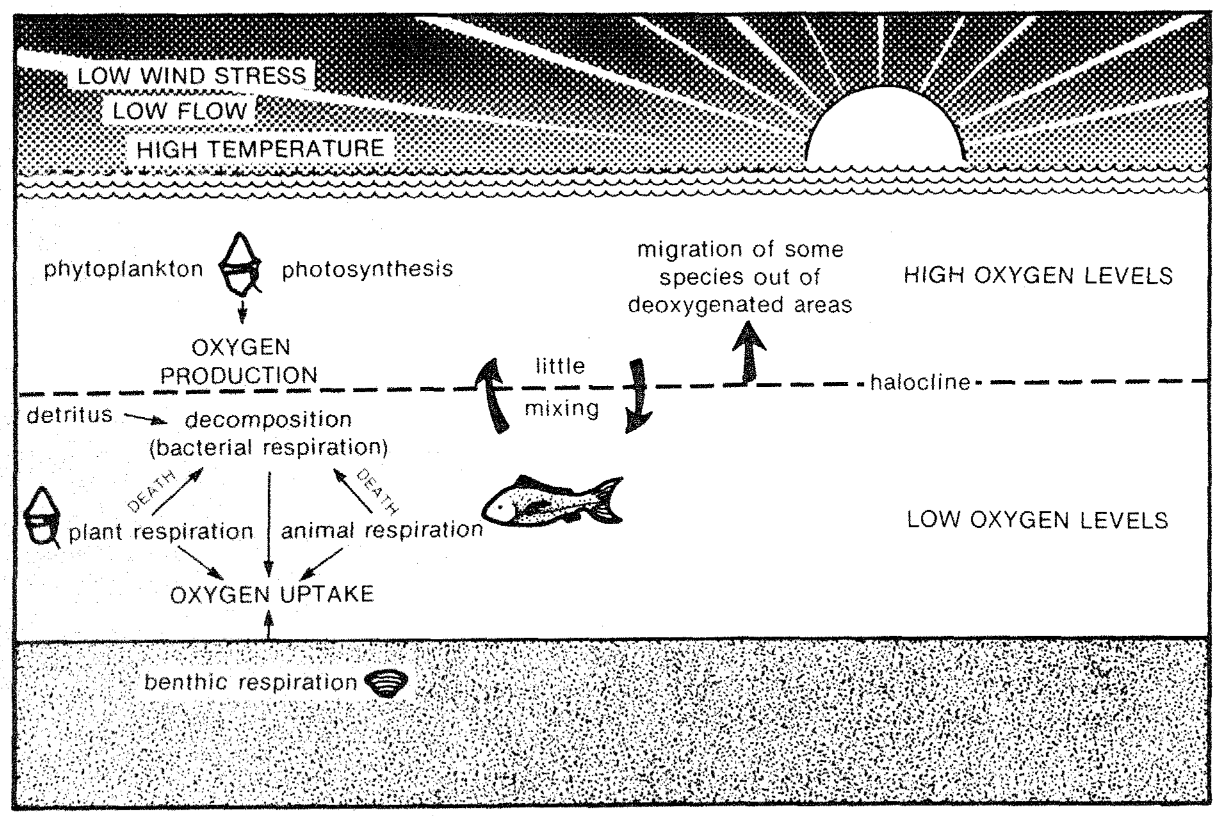

Figure 66. Stylized diagram of the deoxygenation process in the Pamlico River Estuary (Davis et al. 1978).

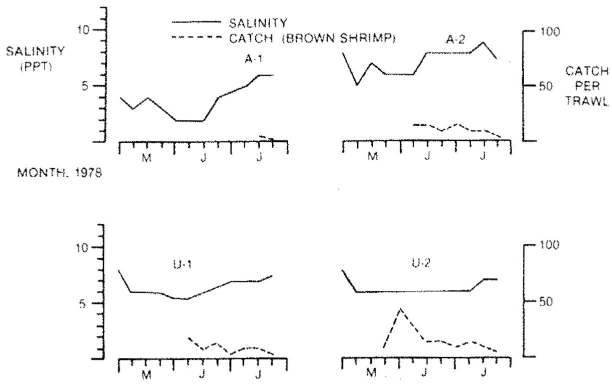

Figure 67. Weekly salinities and catch per trawl of juvenile brown shrimp at two altered (A-1, A-2) and two unaltered (U-1, U-2) drainages into Rose Bay (Pate and Jones 1981).

developed, to enable direct comparisons of conflicting resource uses.

i. Social conflicts need to be identified and techniques developed to transfer information effectively and initiate innovative changes.

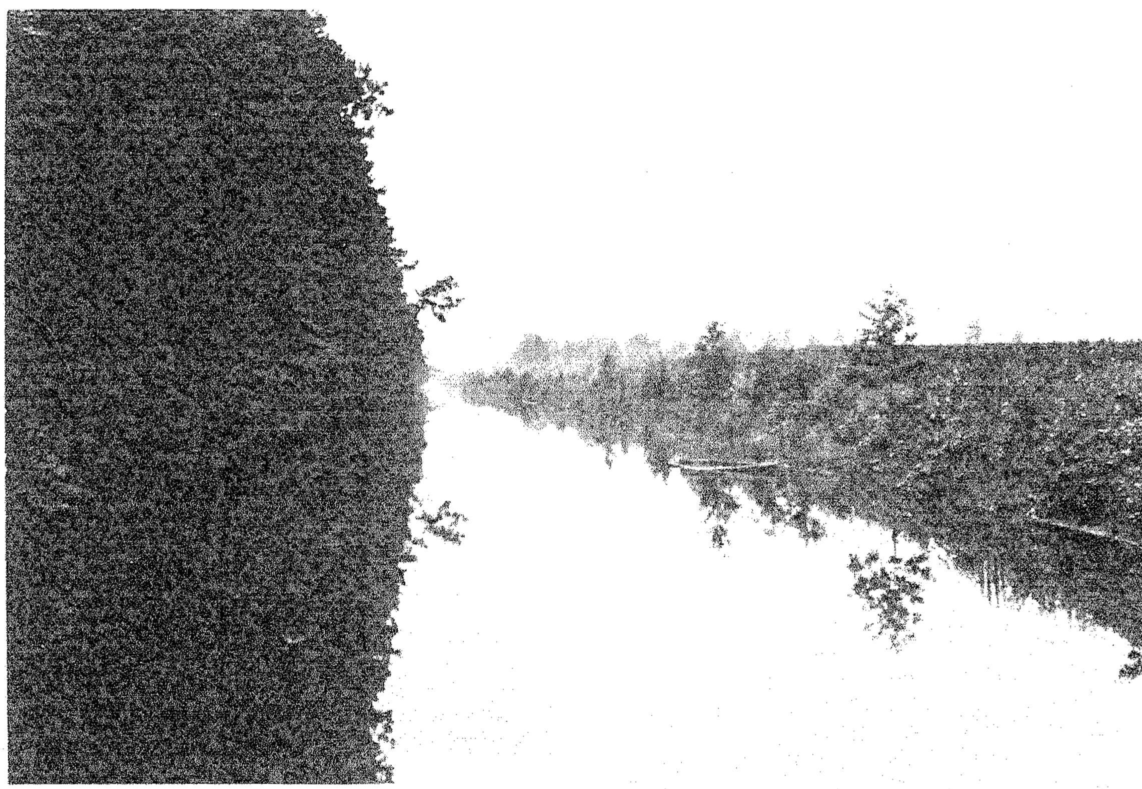

Figure 68. A ditch draining agricultural fields.

CHAPTER 7

COMPARISON TO OTHER ESTUARIES

The Pamlico River Estuary (Figure 69) is typical of many of the coastal plain estuaries of the southeastern coast of the United States (Odum and Copeland 1972). The estuary ranges from brackish near Washington, to mid-estuary conditions as it joins Pamlico Sound (Bellis 1974). Thus, many of the characteristics known about the Pamlico River Estuary, as well as those known about hundreds of other estuaries, compose a body of knowledge that may enable the development of effective model management systems.

While the general physical characteristics of estuaries like the Pamlico River Estuary are similar, similar systems that are geographically separated present very different assemblages of species (Bellis 1974). For example, herring is the principal plankton feeder in the cooler, deeper estuaries of Maine, while menhaden is the dominant planktivore of the shallow, warmer estuaries of the mid to south Atlantic. Comparable levels of a generalized food web are occupied by functionally and often morphologically similar forms. The actual species present in any of these estuaries depends upon environmental factors affecting their distribution, and upon the broad parameters of climate and geography.

Plankton studies conducted in many of these estuaries of similar type indicate that the food web generally rests on a typical phytoplankton/copepod base (Bellis 1974). Most of the primary producers that dominate the Pamlico River Estuary are the same throughout the east coast of the United States. The zooplankton population, which serves as a primary food-supporting population for small fishes, is dominated by the copepods <u>Acartia</u> and <u>Pseudocalanus</u> (Graham and Venno 1968; Sherman and Honey 1968; Peters 1968; Christmas 1973). The important nektonic components of this system vary from the lobster-herring community in Maine (Sherman and Lewis 1967; Scattergood 1960) to alewives and flounders in southern New England (Saila 1961). In the mid-Atlantic estuaries, nektonic populations are dominated by spot, croaker, weakfish, and blue crabs, with shrimp and menhaden becoming more important in the south Atlantic and

Figure 69. A scene from the Pamlico River Estuary.

Gulf of Mexico coast estuaries (Christmas 1973). The benthic community is dominated by clams, by Mya farther north, and by Macoma and Rangia farther south, as typified by the Pamlico River Estuary community (Tenore 1970).

The Pamlico River Estuary and the adjacent Pamlico Sound constitute one of the most extensive estuarine systems along the Atlantic coast of the United States. This complex (2,000 mi^2 area) is exceeded in size only by the Chesapeake Bay complex in Virginia and Maryland. These estuaries are plankton-based systems that enable them to function as nurseries or temporary homes for migrating nekton of commercial importance. The Pamlico region's large size, isolation, and sparse human populations are such that it remains among the least polluted and potentially most valuable estuaries along the east coast (Bellis 1974). This area of the east coast is one of the few places where the commercial yield has been increasing in recent years (see Section 5.1; Street 1981).

The lack of understanding of the relationship between land use and estuarine productivity constitutes a threat to the well-being of this extensive and productive ecosystem. Continuing pressures and public demand for agricultural, recreational, and industrial development suggest that the North Carolina estuaries may be in for a real test of their capacity to absorb impacts without irreversible changes that alter the productivity. It will become increasingly more important for the managers of the Pamlico River Estuary to consult the characteristics of the numerous estuaries scattered along the east coast of the United States to develop a generalized capacity for predicting impacts.

The other major estuarine tributary to Pamlico Sound, the Neuse River Estuary, is not as well studied as the Pamlico River Estuary. Functional and spatial characteristics appear to be similar, although apparently it is less productive than the Pamlico in terms of nursery yield (Purvis 1976). Detailed studies are now in progress in the Neuse, primarily in response to the recent build-up of blue-green algal blooms in the upper estuary. Neuse River watershed activities are different because large municipalities (such as Raleigh, N.C.) discharge sewage effluents into the river, which results in higher nutrient and organic loadings than on the Tar River. Much less land drainage occurs around the shore of the Neuse than does around the Pamlico.

Another major estuarine system, Albemarle Sound, which covers 900 mi^2 north of Pamlico Sound, is much fresher, receiving a larger amount of fresh water in relation to its volume (Copeland et al. 1983b). The low-salinity environment creates a distinctly different ecological system. The fisheries yield in the Albemarle, for example, is dominated by anadromous and indigenous species, whereas, in the Pamlico, the yield is dominated by migratory species and by a larger variety of species.

CHAPTER 8

SUMMARY AND CONCLUSIONS

1. The Pamlico River Estuary is a continuation of the Tar River and extends from Washington, N.C., for about 65 km to its confluence with Pamlico Sound. The estuary is a major tributary to Pamlico Sound on the central coast of North Carolina.

2. The estuary lies within the outer portion of the Atlantic Coastal Plain province, an emergent portion of the continental shelf. The drainage basin is 14,000 km^2 in area. The low, flat plain is underlain by fossiliferous sandy clays deposited during marine incursions. This geologic setting has resulted in a low, poorly drained land area, characterized by extensive swamps and pocosins with organic peat soils that generally thicken eastward.

3. Five different shoreline types characterize the estuarine system. About 62% of the shoreline is classified as marsh, 30% as low banks, 5% as high banks, 1% as bluffs and 2% as swamp forest.

4. The area surrounding the Pamlico River Estuary is sparsely populated. While the population is expected to increase about 20% over the next 50 years, the area is projected to remain mainly rural. Almost two-thirds of the land is forested, but the area devoted to agriculture is increasing due to clearing of forested lands. The changing land use results in increased land drainage through a network of canals.

5. The water table from the surface aquifer lies very close to the ground surface in much of the area around the estuary. Recharge comes primarily from rainfall, and the dominant movement of water is lateral.

6. Average annual rainfall is about 125 cm; the highest precipitation occurs during the summer. The highest runoff occurs during the winter. The climate is moderate with an average winter low of about 7^{o}C and a summertime average high of 32^{o}C. Winds are predominantly S to SW and average about 15 km/h.

7. The major source of freshwater into the estuary is the Tar River. The total annual mean freshwater discharge to the estuary is about 5400 cfs. Circulation is mostly influenced by winds. Salinities range from oligohaline (less than 5 ppt) in the upper reaches to mesohaline (5 to 18 ppt) over most of the estuary to polyhaline (greater than 18 ppt) where the estuary meets Pamlico Sound.

8. Wetlands around the Pamlico River Estuary are classified as swamp forests, pocosins, and fringing, irregularly flooded marshes. The majority (almost 65%) of wetlands are pocosins.

9. The aquatic environment is typically oligohaline/mesohaline, the average salinity not exceeding 20 ppt. Mean monthly water temperature ranges between 5^{o}C in winter and 27^{o}C in summer.

10. Phytoplankton distribution is typically patchy, and concentrations through time and space can vary over orders of magnitude. Early spring and fall peaks are characteristic, and a dinoflagellate bloom typically occurs during January through March. Dinoflagellates dominate in the upper estuary and diatoms dominate in the more saline regions. Chlorophyll *a*

concentrations sometimes reach levels characteristic of eutrophic waters. Of the total carbon budget, phytoplankton production accounts for a greater input than from allochthonous sources.

11. Attached aquatic plants are important contributors to the primary productivity, especially in shallow water. Submerged aquatic vegetation covers less than 1% of the bottom area, and its contribution to total productivity amounts to over 1.7% of the total.

12. There is a large seasonal variability in the amount of organic carbon in the estuarine water column, with the highest concentration in late summer and fall. Major sources of this organic loading include phytoplankton production, submerged aquatic vegetation, and drainage from the watershed.

13. A major phenomenon in the Pamlico River Estuary is periods of widespread deoxygenation, occurring in the bottom waters during summer. Microbial respiration of the standing stock of organic matter during quiescent conditions is thought to be the major cause of oxygen depletion.

14. Nutrient concentrations are high, and their distribution is patchy. Major sources of phosphorus are the watershed, recycling from Pamlico Sound, and phosphate processing activities. The major sources of nitrogen are the watershed and recycling. Peak nitrogen and phosphorus inputs occur during winter, although phosphorus is available year-round.

15. A major component of the zooplankton population is the copepod, *Acartia tonsa*. Its highest abundance occurs during spring and fall.

16. Extensive surveys of macrobenthos reveal that the bulk of benthic productivity occurs under water less than 1.5 m deep. Three macrobenthic communities have been described: *Rangia* / *Nereis* characterizes the upper, oligohaline portion; *Macoma*/*Nereis* represents the mesohaline zone; and *Macoma*/*Mulinia*/*Retusa* is typical of the lower, polyhaline zone.

17. The nektonic population fluctuates seasonally, with the peak during spring, due to great influxes of postlarvae. The total population is dominated by the juveniles of migrating finfish, shrimp, and blue crabs. Migratory nektonic populations are characteristically sparse in the estuary during winter, when the migrating juveniles have moved to Pamlico Sound and/or offshore.

18. The Pamlico River Estuary is used by at least 19 species of overwintering waterfowl. About 5.8% of the State's overwintering waterfowl population, dominated by ruddy ducks, canvasbacks, and scaups, was estimated to use the estuary.

19. The dominant life-history strategy in the estuary is one of migration of ocean-spawned postlarvae to the estuarine nursery grounds during spring, and subsequent growth of juveniles during early summer, with juveniles returning to the ocean as temperatures drop in the fall. Because these species are commercially important, the estuary serves as an important nursery area for a vast fishing resource in Pamlico Sound and offshore.

20. The trophic structure of the Pamlico River Estuary ecosystem is a complex food web containing many short food chains. The basic trophic level is phytoplankton production, supplemented by detritus. Fishes occupying the upper levels of the trophic structure

are opportunistic and shift their food preferences in relation to food availability.

21. The Pamlico River Estuary has a large proportion of the total area of primary nursery grounds in Pamlico Sound. Only a small fraction of the total water area (about 4%) of the Pamlico Sound complex is regarded as primary nursery. These areas are typically shallow, nearshore areas (e.g., Rose Bay). Eight species (spot, croaker, flounder, shrimp, menhaden, weakfish, blue crabs, and herring) are the primary users of the Pamlico River Estuary nursery grounds.

22. The biological seasons in the Pamlico River Estuary are dictated by a combination of tributary inflows, water temperatures, and water circulation on the Continental Shelf. Springtime warming of the water initiates primary production (which is fed by wintertime runoff and subsequent recycling).

23. Large-scale drainage activities on the estuary's watershed have changed local freshwater inflows. Fluctuations in the salinity of nursery grounds receiving some of this new drainage may affect their use by juvenile fish and shellfish. Research is needed to ascertain the linkages involved to effectively manage these systems to sustain productivity.

24. Fishing has long been an important activity in the Pamlico River Estuary. Over 70% of the fish and shellfish taken by North Carolina fishermen come from Pamlico Sound and its tributaries. While the overall catch has increased in recent years, there have been declines in the shrimp catch. Shrimp, blue crabs, and flounder constitute the most valuable of the more than 30 species taken by commercial fishermen.

25. Recreational fishing has traditionally focused on trout, croaker, and flounder. A major study is underway to determine the socio-economic impact of recreational fishing in the area.

26. To be effective, a multi-species management program for the Pamlico River Estuary must be concerned with the control of nutrient loading, with levels of organic matter, and with balanced water management for the nursery grounds. Land-use planning and innovative drainage techniques are required to protect the sensitive, nearshore primary nurseries.

27. Socio-economic values are important management goals and constraints. Institutional arrangements are needed to more adequately provide assessment tools and estimates of coefficients to link production and values.

28. Management of the Pamlico River Estuary is especially difficult due to its open-endedness, and because the socio-economic goals of various segments of the user populations contrast. Knowledge gained from similar estuaries along the eastern coast of the United States should be considered when predicting further responses of current and planned activities around and within the estuary.

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B.J. Copeland,[a] Ronald G. Hodson,[a] and Stanley R. Riggs[b]

8. Performing Organization Rept. No.

9. Authors' Affiliations

[a]Department of Zoology
North Carolina State University
Raleigh, NC 27650

[b]Department of Geology
East Carolina University
Greenville, NC 27834

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16. Abstract (Limit: 200 words)

The Pamlico River Estuary in eastern North Carolina is a continuation of the freshwater Tar River and a major tributary to Pamlico Sound, the primary estuarine fishing ground of the State. Water circulation in the estuary is dominated by wind and freshwater inflow. Water salinities range from oligohaline in the upper reaches of the river to mesohaline in most of the lower estuary. Summer water stratification and deoxygenation of bottom waters is a commonly occurring phenomenon.

The Pamlico River Estuary is a phytoplankton-based system, supplemented by detrital inputs. Phytoplankton concentrations peak in the spring with a dinoflagellate bloom. Three distinct macrobenthic assemblages dominated by mollusks and annelids occur in shallow water along the salinity gradient. The estuary serves as an important nursery ground for the postlarvae and juveniles of a number of migratory fish species as well as shrimp and blue crabs. These organisms exhibit marked seasonality in their occurrence, governed by a combination of tributary inflows, water temperatures, and water circulation.

The Pamlico River Estuary supports a productive fishery in both the river and the Pamlico Sound. Impacts of large-scale drainage activities and nutrient inputs on this fishery are among the issues facing managers of the estuary.

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