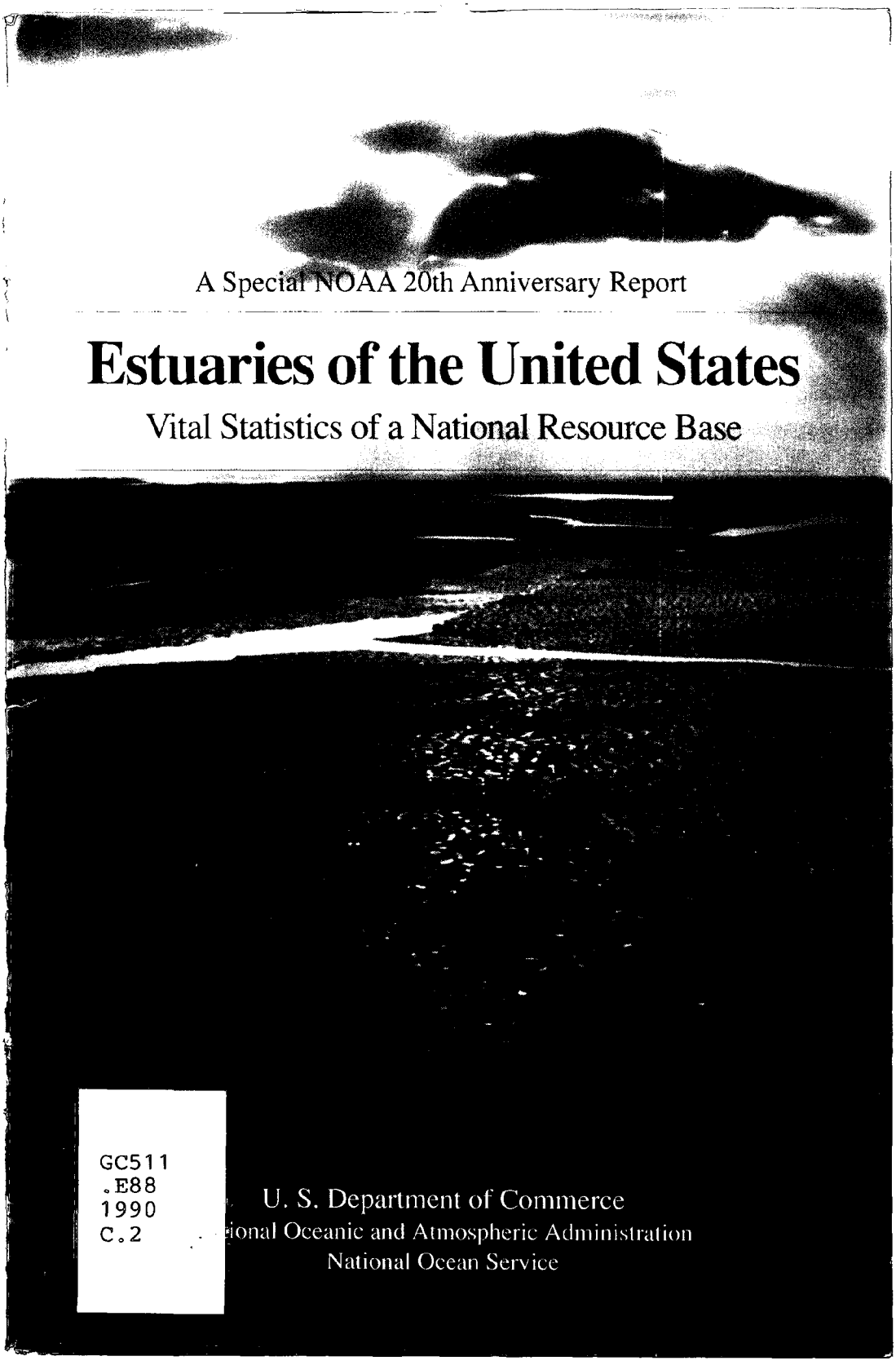

A Special NOAA 20th Anniversary Report

Estuaries of the United States

Vital Statistics of a National Resource Base

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NOAA's National Estuarine Inventory

The National Estuarine Inventory (NEI) is a series of activities within the Office of Oceanography and Marine Assessment of the National Oceanic and Atmospheric Administration (NOAA), to define and characterize the Nation's estuarine resource base and develop a national estuarine assessment capability. NOAA began the NEI in 1983 because no comprehensive inventory of the Nation's estuaries or their resources existed, despite increased conflicting demands for the goods and services they provide: habitat for fish and wildlife, food, areas for recreation, waste disposal, energy, and transportation. Four major NEI atlases, six national data bases, and numerous technical reports, including a Supplement Series, containing thematic information about the Nation's estuaries, have been produced.

The first volume of the National Estuarine Inventory data atlas series was completed in November 1985. This atlas identified 92 of the most important estuaries of the contiguous U.S., specified their fundamental physical and hydrologic characteristics, and defined consistently-derived spatial boundaries for each estuary. This volume established the NOAA framework for data collection and analysis of the Nation's estuarine resource base. Other volumes in the atlas series have since been produced on land use and population, wetlands, and outdoor public recreation facilities. Data from other strategic assessment projects have been adapted to the NEI framework to characterize important resource themes. Projects on classified shellfishing waters, distribution of fishes and invertebrates, and pollutant susceptibility are a few examples.

Development of the data bases and assessment capabilities of the NEI is a dynamic and evolving process. NOAA continues to evaluate the scale and scope of information in the NEI and to make the necessary additions and refinements to improve its capability to assess the Nation's estuaries. The information now assembled in the NEI can be used for comparisons, ranking, and other analyses related to the resources, environmental quality, and economic values among the Nation's estuaries.

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Introduction

This report describes briefly the Nation's estuarine resource base. It updates information presented in a number of previous NOAA reports and atlases developed through its National Estuarine Inventory (NEI) program, characterizing the Nation's estuaries.

Estuaries, among the most productive natural systems, are important features of coastal regions, especially along the Atlantic Coast and the Gulf of Mexico. They form a transition zone between freshwater and marine ecosystems.

Estuaries are most commonly defined as semi-enclosed coastal bodies of water having a free connection with the open sea and within which seawater is diluted measurably by freshwater from land drainage (Pritchard, 1967). The important role estuaries play in sustaining the health and abundance of marine fishes, shellfish, and birds has long been recognized. Estuaries are important coastal habitat, particularly during early life stages of many animals. The freshwater and nutrients they provide to coastal areas are critically important to living resources.

Estuaries are most commonly defined as semi-enclosed coastal bodies of water having a free connection with the open sea and within which seawater is diluted measurably by freshwater from land drainage.

Bays are semi-enclosed areas connected with the open ocean in a way that moderates and controls their circulation, producing an environment and ecosystem different from adjacent waters. They exhibit many estuarine characteristics and processes.

"....Because many characteristic features of estuaries extend into the coastal areas beyond their mouths,....the field of estuarine oceanography is often considered to include the study of some waters which are not strictly, by the above definition, estuaries." (Dyer, 1977).

In this report, selected bays, sounds, and other coastal waters are included as "estuaries."

Society places a high value on estuarine areas as places for living, working, and recreating. It demands that estuaries provide cooling waters for industry and energy production, accommodate the needs of large ships and tanker traffic, sacrifice wetland and bottom habitat to supply space for coastal development, and filter pollutants from the Nation's rivers and streams into coastal waters. Estuarine areas are among the most densely populated and heavily used in the Nation; an estimated 45 percent of the U.S. population now lives within these areas (Culliton et al., 1990).

In spite of their high value, intense use, and frequent overuse, estuaries only recently have been recognized as a unique and important depleted ***resource base of national significance***. Major oil spills, shellfish bed closures, and habitat losses have increased awareness of the declining quality of the Nation's estuaries. Because of their importance to both economic development and ecological processes, estuaries are among the Nation's most highly stressed natural systems. As demands for increased use of estuarine resources continue, so will conflicts among competing users of this important national resource base.

Unlike other resources, no Federal program is dedicated to developing a comprehensive and consistent national policy on the use and management of estuaries. Current Federal legislation (including the Rivers and Harbors Act; Coastal Zone Management Act; Marine Protection, Research, and Sanctuaries Act; Clean Water Act; and Safe Drinking Water Act) only partially or indirectly affects how the Nation's estuaries are used.

In 1987, Congress established the National Estuary Program (NEP) under the jurisdiction of the U.S. Environmental Protection Agency. The program was established to identify the probable cause of major environmental problems in estuaries of ***national significance*** and to promote and sustain long-term state and local commitments to solving these problems. The program is also intended to generate meaningful public involvement and participation; focus existing regulatory, institutional, and financial resources on identifying problems; and to encourage innovative management approaches. The NEP currently includes 17 estuaries (identified in Appendix B) selected to reflect specific regional problems, as well as problems common to all the Nation's estuaries.

When physical features (volume, freshwater inflow, and water surface area) only are considered, a small number (11) of large estuaries and bays accounts for the majority of the Nation's resource base. Chesapeake Bay, Puget Sound, Albemarle/Pamlico Sound, and Long Island Sound are most prominent.

Estuaries in the *North Atlantic* contain the smallest water surface area among regions, are the deepest, receive the least freshwater inflow, and are dominated by tidal forces.

Estuaries in the *Middle Atlantic*, e.g., Chesapeake Bay and Long Island Sound, are the most susceptible to pollutant retention because of their relatively large volumes, moderate to low freshwater inflow, and low tidal exchange.

Most decisionmakers and scientists continue to address selected estuaries on an individual basis only, with little or no directed, comprehensive national framework. Without a comprehensive ***national*** framework and data base, the assessment and comparison of estuarine conditions and development of effective national policies to promote the long-term balance between development and protection are not possible.

This report presents information, primarily from existing sources, on the physical and hydrologic features, population and land use, wetlands, and selected economic characteristics of 102 estuaries that describes the Nation's estuarine resource base. While the NEI currently is limited to the contiguous U.S., estuaries in Alaska and other coastal regions will be added as resources permit. Some estuaries included do not fit the traditional definition of an estuary, such as Cape Cod, Monterey, Santa Monica, and San Pedro bays. These "coastal bays" are semi-enclosed areas connected with the open ocean in a way that moderates and controls their circulation, producing an environment and ecosystem different from adjacent waters. In general, they illustrate on a large scale many estuarine characteristics and processes.

Although the information presented is only a sample of that available in NOAA's NEI data base, it nevertheless sets the nationwide context in which all estuaries may be considered. It enables a number of simple rankings to be made of the estuaries according to some of their most fundamental and important characteristics, and suggests those estuaries that may be most sensitive or most durable to the stresses society has placed on this important resource base.

Physical and Hydrologic Features

Some of the most important factors determining how estuaries work are their physical and hydrologic features. These include estuarine and fluvial drainage areas, water surface area, volume, tidal range, salinity regime, and freshwater inflow. Together, these characteristics help define the ecological processes and habitats within an estuary and determine how human activities affect an estuary's overall condition. The "vital statistics" described below are used throughout this report. Note that ***sub-estuaries*** are portions of a large estuary having definable sub-basin drainage area, and comprising a significant percentage of either freshwater inflow or water surface area.

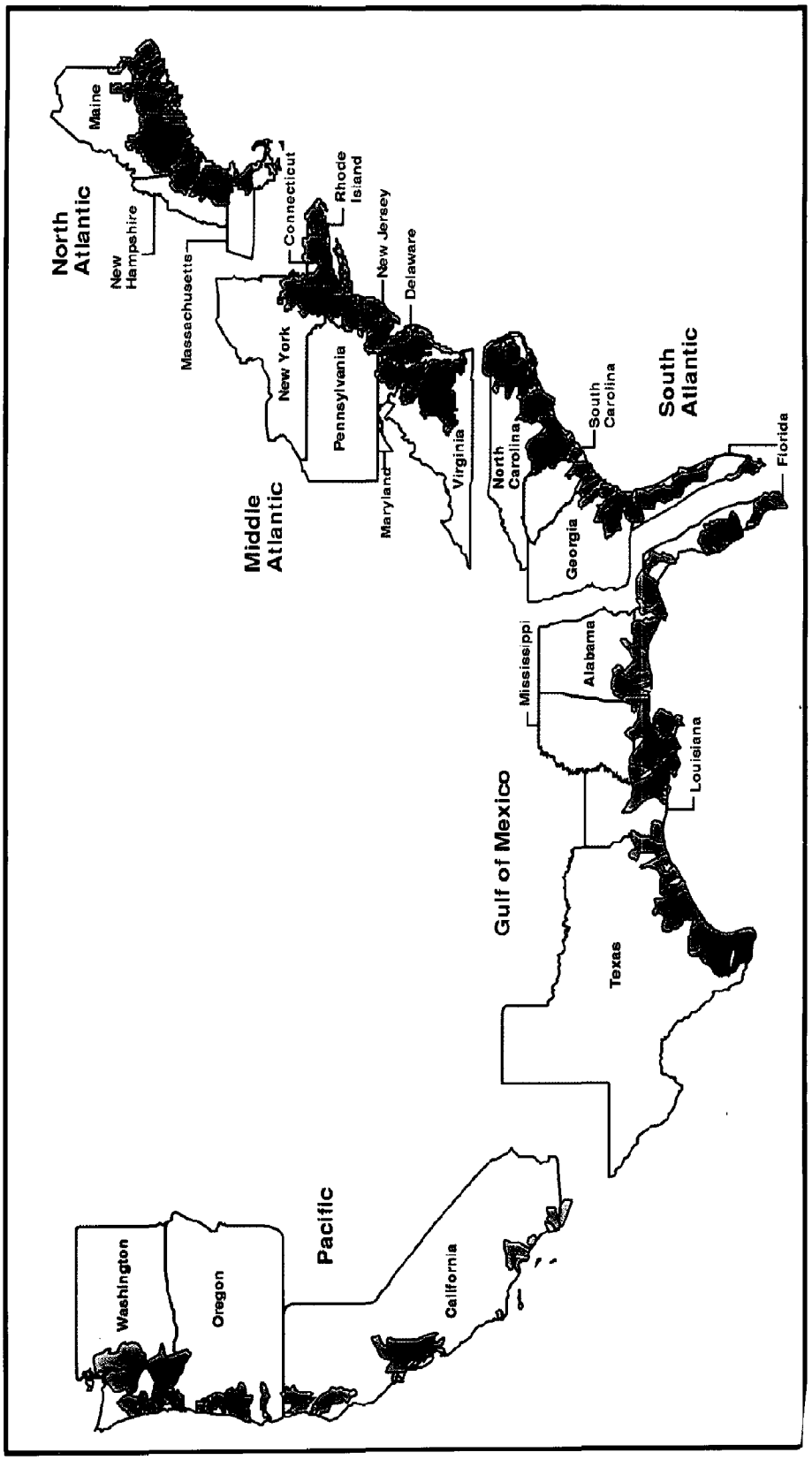
Although estuaries in the *South Atlantic* contain the smallest volume among regions, their relatively shallow depths support extensive wetlands, second only to the Gulf of Mexico. Albemarle/Pamlico Sounds is by far the largest estuary in this region.

Estuaries in the *Gulf of Mexico* contain the greatest amount of water surface area, are the most shallow overall, and receive the largest freshwater inflow among regions, even when the Mississippi River is not considered. As a result, they support the largest wetlands area in the Nation and are the least susceptible to pollutant retention.

Estuaries along the *Pacific Coast* are relatively small compared to other regions. Exceptions are Puget Sound, which accounts for almost 60 percent of estuarine volume and 40 percent of water surface area in the region; and the Columbia River, which accounts for almost 60 percent of the freshwater inflow.

Estuarine and Fluvial Drainage Areas. An estuarine drainage area or EDA is the land and water component of a watershed that drains directly into estuarine waters (NOAA, 1985). EDAs are defined for all estuaries in the inventory. The EDA was established by NOAA to provide a spatial framework for organizing information within the NEI. The assumption is that those natural processes and human activities in close proximity to estuarine waters generally affect them the most. In most cases, EDAs coincide with hydrologic cataloging units of the U.S. Geological Survey (USGS). An EDA includes all or part of the cataloging unit containing the most upstream extent of tidal influence. Depending on the complexity of coastal drainage patterns, certain cataloging units were modified to eliminate the portion of the drainage area not draining directly to estuarine waters. Figure 1 shows the distribution and extent of EDAs currently included in the NEI. Appendix A shows the EDA and fluvial drainage areas for selected estuaries.

Figure 1. *Estuarine Drainage Areas by Region*



The extent to which the watershed of an estuary is contained within an EDA determines the degree to which actions taken in close proximity to an estuary may effect its overall quality. For example, for many estuaries, especially those with small watersheds along the Atlantic and Pacific coasts, the EDA comprises the entire watershed. For estuaries with watersheds that have large inland fluvial areas outside of EDAs, actions taken within EDAs may have little impact, depending on the problem of concern. For example, while the Mississippi and Columbia rivers drain huge inland areas, their EDAs comprise only a small fraction of their watersheds. Estuarine drainage areas range in size from 14 square miles (Netarts Bay) to over 21,000 square miles (Chesapeake Bay). Table 1 summarizes selected characteristics of the Nation's estuaries.

Fluvial drainage areas or FDAs are the land and freshwater portions of watersheds upstream of estuarine drainage areas. FDAs coincide with hydrologic cataloging units of the USGS and include a majority of the Nation's hinterland. Consequently, estuaries with large freshwater inflow, such as the Mississippi and Columbia rivers, Chesapeake and Delaware bays, and Albemarle/Pamlico and Mississippi sounds, receive significant contaminant inputs from upstream agricultural runoff and municipal and industrial facilities.

Estuarine Water Surface Area. Estuarine water surface area is approximated at mean tide level. It is needed to estimate an estuary's volume, flushing rate, and pollutant susceptibility. Water surface areas range from less than one square mile for small estuaries along the Pacific Coast to nearly 4,000 square miles for Chesapeake Bay. The 31 estuaries in the Gulf of Mexico contain nearly 12,000 square miles of water surface. No single estuary in this region accounts for more than 20 percent of this total. In contrast, the 28 estuaries on the Pacific Coast have about 2,400 square miles of water surface area, over half in Puget Sound and San Francisco Bay.

Estuarine Volume. The volume of an estuary helps determine its ability to

Table 1. *Summary of Selected Characteristics of the Nation's Estuaries*

	PHYSICAL and HYDROLOGIC FEATURES						NATURAL RESOURCES			ECONOMIC ACTIVITIES					
								Classified Shellfish Waters (100 sq. mi.)			Land Use (% of EDA)			Point Sources of Pollution (100)	
Region	Estuarine Drainage Area (1000 sq. mi.)	Total Drainage Area (1000 sq. mi.)	Water Surface Area (1000 sq. mi.)	Average Depth (ft.)	Avg. Daily Fresh-water Inflow (1000 cfs)	Volume (trillion cu. ft.)	Wetlands (100 sq. mi.)	Approved	Total	Population Density, 1980 (per sq. mi.)	Urban	Agriculture	Industrial	MWTP	Public Recreation (1000 Sites)
North Atlantic	23	36	2	48	65	4	12	10	12	211	7	7	2	1	3
Middle Atlantic	48	123	7	20	172	6	35	63	74	822	19	27	18	9	10
South Atlantic	55	148	4	12	158	2	92	30	40	104	4	22	4	8	3
Gulf of Mexico	96	1,562	12	8	970	3	166	38	88	122	5	30	20	13	4
Pacific	38	362	2	37	449	9	18	1	5	529	12	11	7	3	7
National	**260**	**2,231**	**27**	**23**	**1,814**	**24**	**323**	**142**	**219**	**309**	**9**	**23**	**51**	**34**	**27**

Note: All values are rounded.

dilute pollutants. When volume is used in conjunction with freshwater inflow and the portion of total volume that is freshwater, the susceptibility of an estuary to concentrate pollutants can be assessed.

Freshwater Inflow. Freshwater inflow is a major determinant of the physical, chemical, and biological characteristics of most estuaries. It affects the concentration and retention of pollutants, the distribution of salinity, and the stratification of fresh and salt water within an estuary. Freshwater inflow statistics were estimated for gaged and ungaged areas of an estuary's watershed. For gaged areas, data were compiled from USGS streamflow gage records (USGS, 1990) and from records of significant flow diversions not accounted for in the USGS data. For ungaged areas, NOAA precipitation data were used to estimate freshwater runoff and direct precipitation to an estuary.

Fifty-three percent of all freshwater inflow into the Nation's estuaries is discharged into the Gulf of Mexico (nearly one million cubic feet per second). However, over half of the inflow into the Gulf comes from the Mississippi and Atchafalaya rivers. The amount discharged into the estuaries of the Gulf of Mexico is more than twice that discharged into estuaries along the Pacific or Atlantic coasts.

Natural Resources

Estuaries provide the Nation with highly productive habitats and important living resources. Intensive use of these ecosystems for industrial, residential, and recreational activities has had adverse effects on many estuarine resources. Of particular concern are wetlands and fisheries, especially shellfishing.

Wetlands. Wetlands are a vital component of the Nation's estuarine resource base. They are unique areas between terrestrial and aquatic systems that provide critical habitat for fish, shellfish and wildlife; filter and process residential, agricultural, and industrial wastes; and buffer coastal areas against storm and wave damage. Wetlands also generate revenue and provide employment from recreational activities such as fishing and hunting.

The Nation's estuaries presently contain over 32,000 square miles of wetlands (NOAA, 1990a), about 12 percent of the total estuarine drainage area. Despite their apparent abundance, wetlands are disappearing rapidly in many areas due to urbanization, agriculture, hydrocarbon exploration, shoreline erosion, and other factors. Between the mid-1950s and the late 1970s, over 17,000 square miles of wetlands have been lost in inland and coastal areas throughout the Nation due to human activity and natural processes (Frayer et al., 1983).

Estuarine and coastal wetlands alone are decreasing nationally by an average of 31 square miles per year (Tiner, 1987). Chesapeake Bay, for example, which has over 1,500 square miles of wetlands (Reyer et al., 1990a), lost approximately six percent of its coastal wetlands annually between 1955 and 1980 (Tiner, 1987).

A major concern over wetland losses is the long-term impact on the many species of fish and shellfish that depend on

these habitats. Wetland habitat losses can translate into economic losses that affect entire regions. Estimates of the value of coastal wetlands to commercial and recreational fisheries may range from about $2,200 per acre along the Pacific Coast, to almost $10,000 per acre along parts of the Florida coast (Bell, 1989).

In addition to wetland loss, rising development costs and the demand for waterfront property promote increased competition for limited space in estuarine and coastal areas. This, combined with industrial pressures and natural stresses, makes wetland preservation a more important issue than ever before.

Recognizing the need to preserve coastal ecosystems, private and nonprofit conservation organizations have been active in coastal land acquisition and management. However, these acquisitions represent only a fraction of the privately-owned land base. For every square mile of privately-owned coastal conservation land, another 200 square miles of privately-owned land remain unprotected, either being used or available for development (NOAA, 1990b).

Fisheries. Estuaries provide food, refuge from predation, and habitat for a wide variety of fishes and invertebrates. Many of these species are economically important and use various estuarine habitats to complete their life cycle. Estuaries are especially important as nursery areas for many species during their early and juvenile life stages. As a result, the economic viability of many of the Nation's commercial and recreational fisheries is also estuarine dependent.

Table 2. *Economic Value of Selected, Commercially Important Estuarine-Dependent Fisheries, 1989 (millions of dollars)*

	FISHES			INVERTEBRATES						
Region	Pacific Salmon	Menhaden	Summer Flounder	Penaeid Shrimp	Blue Crab	Oyster (meat)	Hard Clam (meat)	Dungeness Crab	Soft Clam (meat)	All Commercial Fisheries
North Atlantic	0	<1	4	8	0	1	3	0	13	250[a]
Rank	-	*40*	*18*	*13*	-	*28*	*19*	-	*8*	-
Middle Atlantic	0	1	18	0	42	22	26	0	7	500[a]
Rank	-	*31*	*9*	-	*2*	*7*	*6*	-	*14*	-
South Atlantic	0	2	11	54	18	3	12	0	0	169
Rank	-	*16*	*6*	*1*	*2*	*12*	*5*	-	-	-
Gulf of Mexico	0	52	<1	374	24	41	<1	0	0	648
Rank	-	*2*	*26*	*1*	*4*	*3*	*30*	-	-	-
Pacific[b]	84	0	0	0	0	16	4	37	0	337
Rank	*1*	-	-	-	-	*5*	*14*	*2*	-	-
Total	**84**	**55**	**33**	**436**	**84**	**83**	**45**	**37**	**20**	**1,904**

Note: All values are rounded. Rank indicates rank among all commercial fisheries in region.
a. Values are estimated.
b. Does not include Alaska fisheries values.
Source: NOAA, 1990f, and unpublished 1989 statistics

Table 2 shows the value and rank of commercially important "estuarine-dependent" species by region. Estuarine-dependent fisheries are among the most valuable within regions and across the Nation. For example, the species comprising the top four fisheries in the Gulf of Mexico (shrimp, menhaden, oyster, and blue crab) use estuaries extensively. The first, second, fifth, and sixth most valuable South Atlantic fisheries (shrimp, blue crab, hard clam, and summer flounder) are also estuarine dependent. In the North Atlantic, the eighth most valuable fishery (soft clam) is found only in estuaries. The Pacific region's first, second, and fifth most valuable fisheries (salmon, dungeness crab, and oyster) are estuarine dependent. The Nation's second most valuable fishery is for the penaeid shrimp along the Gulf of Mexico, South and North Atlantic coasts. In total, estuarine-dependent fisheries generated most of the Nation's seafood landings income in 1989 (NOAA, 1990f).

Shellfishing. Molluscan shellfish fisheries are of special concern because these bottom-dwelling organisms complete their entire life cycle within estuaries. Because of their bottom-dwelling nature, they may be affected more directly by human impacts than other estuarine-dependent marine organisms.

Molluscan shellfish are filter-feeders, capable of pumping large volumes of water through their bodies and accumulating particles and pollutants. The bacterial or viral pathogens that accumulate in shellfish tissue in heavily polluted areas may be passed on to humans who consume raw or partially cooked shellfish. The *National Shellfish Register of Classified Estuarine Waters* conducted by NOAA indicates that urban stormwater runoff, sewage treatment plant effluent, agricultural runoff, and increased boating activity are the primary causes of harvest restrictions in most areas of the Nation (NOAA,1990c).

In 1985, almost 22,000 square miles of estuarine waters were classified as shellfish harvest areas (Broutman and Leonard, 1988; Leonard et al.,1989; Leonard and Slaughter, 1990). However, many areas were restricted for harvesting at certain times of the year due to public health threats from bacterial or viral contamination. About 15,000 square miles were approved for shellfishing without restriction, a decline of about six percent from 1980.

Despite the continued harvest of shellfish in the Gulf of Mexico and Middle Atlantic regions, degradation of harvest areas remains a national concern. Rapid development has placed increased environmental stress on many estuarine resources. Shellfish are indicators of such changing conditions. Once waters are closed to shellfish harvest, they soon become unavailable for recreation and the support of other recreational and commercial species.

Human Uses

In addition to their ecological importance, estuaries are valuable sources of food, recreation, housing, and aesthetic pleasure. Continued modification of their ecosystems seems probable. Consequently, understanding the distribution and extent of human activities affecting the Nation's estuaries is fundamental to improving and maintaining their environmental quality.

Population Growth. Estuarine and coastal regions include some of the Nation's most densely populated areas, where growth rates and population concentrations are highest. Current population patterns reflect historical development and population pressures, location relative to transportation networks, and the characteristics and natural resources of the coastal areas themselves.

Population in these areas has increased by about 30 million people over the last three decades (almost half the total U.S. population increase), and is expected to continue to increase, although at reduced levels (Culliton et al., 1990). Population densities in estuarine drainage areas are greatest in the Middle Atlantic and Pacific regions, reflecting the major population corridors extending from New York to Washington, Los Angeles to San Diego, and within the San Francisco Bay metropolitan area.

The pattern of population growth in estuarine areas ranges from the traditional growth outward from an inner city, characteristic of the older urban centers in the North Atlantic and Middle Atlantic regions, to the suburban sprawl along narrow coastal strips characteristic of sections of the South Atlantic and Gulf of Mexico regions.

Evidence is mounting that increasing development pressures are at the heart of many environmental quality problems affecting the Nation's estuaries. Problems associated with population growth and development include changing and conflicting land uses; the growing infrastructure needed to support increased population; pressures and demands for services; pollutant discharges from urban, industrial, and agricultural land uses; and restricted access to outdoor recreation opportunities.

Land Use. The use of land in estuarine drainage areas is a function of historical development. The type and extent of certain land uses are a partial indicator of the pollutants entering estuarine waters and the extent to which the environment of the surrounding drainage basin has been altered. Land use may also be indicative of the economic value placed on estuarine areas.

The development of urban and agricultural lands and the activities associated with them alter the landscape and generate most of the pollution entering estuaries from human activities. Stormwater runoff from urban areas and agricultural runoff contribute significantly to the discharge of sediments, nutrients, pesticides, and other pollutants into estuarine waters. Industrial, commercial, residential, and municipal activities in urban areas are major dischargers in most estuarine drainage areas.

Urban or agricultural land uses are significant (accounting for 25 percent or more of land use in an estuarine drainage area) in almost half (50 of 102) of the estuaries in the inventory. Almost 20,000 square miles are classified urban and 52,000 square miles as agricultural. As population patterns indicate, urban land use in estuarine drainage areas is concentrated in the Middle Atlantic and southern portion of the Pacific region.

In the Pacific region, although large urban expanses surround San Francisco and extend from Los Angeles to San Diego, urban land use in many EDAs is

overshadowed by large areas of agricultural and forested land. Estuaries with extensive agricultural lands are concentrated in the Gulf of Mexico and South Atlantic regions.

Demands for Recreation. With a growing population and continued urbanization of coastal areas, the Nation is experiencing an ever-growing demand for open space, wilderness areas, and other places for recreating that are close to population centers. Between 1972 and 1984, public recreation lands in estuarine and coastal areas increased by about 27 percent (NOAA, 1988). Given the large populations surrounding estuaries, the increasing demand for estuary-based recreation opportunities is not surprising.

With over 50,000 miles of estuarine and coastal shoreline (Outdoor Recreation Resources Review Commission, 1962) and almost 44,000 square miles of outdoor public recreation area along the Atlantic, Pacific, and Gulf of Mexico coasts offer a wide variety of marine-based outdoor recreation opportunities. They also provide other recreation activities that are enhanced by their proximity to the coast. Although only nine to 14 percent of the outdoor public recreation sites (e.g., parks, boat ramps, fishing piers, beaches, picnic areas) in coastal areas provide access to estuarine waters, they provide increasingly important recreational opportunities (NOAA, 1988).

Privately provided outdoor recreation opportunities also are increasingly important to the public. Private enterprises offer a wide variety of outdoor recreation choices and promote economic growth and stability in most coastal communities. However, private outdoor recreation sites and activities also place added stress on coastal and estuarine resources. Over 3,800 private marinas and over 4,500 private charter boats are located within the Nation's coastal areas (NOAA, 1990d).

While the ability of estuaries to sustain recreational activities at current levels of quality is uncertain, recent public reaction to beach closures and coastal pollution underscores the high value our society places on coastal and estuarine recreation. In economic terms, this reflects the fact that recreation resources might well be undervalued, particularly with respect to other commercial uses.

Estuaries in the Middle Atlantic region contain the greatest number of public outdoor recreation sites (over 10,000) and the largest number of private marinas, over 42 percent of the national total (NOAA, 1990d). However, the amount of land area available for recreation is significantly less than in all other regions (less than 3,000 square miles), except the North Atlantic. Pacific estuaries have the second largest number of outdoor public recreation sites (over 6,500) and contain the most land area set aside for recreation in EDAs (over 14,500 square miles) (NOAA, 1988).

Pollution Stresses. Many of the environmental quality problems affecting the Nation's estuaries stem from natural and human-induced pollution produced both within and upstream of EDAs. Both can affect dramatically the biological productivity of estuarine waters, as well as reduce the appeal of these environments for living and recreating. Beach

closures, fish consumption advisories, and evidence of toxic substances in sediments and fish tissue are all indications of pollution-related declines in the quality of estuarine and coastal waters (NOAA, 1989a).

Industrial facilities and *municipal wastewater treatment plants (MWTPs)* are the major point sources of pollution discharging directly into the Nation's estuaries. Over 9,000 EPA-permitted point sources are located within the EDAs of the 102 estuaries in the inventory; 17 percent of these are considered "major" point sources. Estuaries in the Gulf of Mexico region contain the greatest number of point sources among the regions, 41 percent of the national total. The Middle Atlantic region contains the second most, approximately 31 percent of all point source dischargers located in estuaries. This concentration of dischargers has a direct impact upon water quality, shellfishing, recreation, and estuarine quality in general.

Several estuarine areas (EDAs) contain significant concentrations of industrial and municipal point sources:

Galveston Bay contains 747 industrial point sources, the largest concentration in any EDA nationwide. It also contains 566 MWTPs, or 45 percent of all those located in the Gulf of Mexico region.

Almost two-thirds (63 percent) of all industrial facilities and 61 percent of all MWTPs in the Middle Atlantic are located in the *Hudson River/Raritan Bay* or *Chesapeake Bay* EDAs.

Puget Sound contains one-quarter of the industrial and municipal point sources in the Pacific region.

Albemarle/Pamlico Sounds contains one quarter of the industrial facilities in the South Atlantic region, 40 percent of all MWTPs in the region are located in the *St. Johns River* estuary.

Power plants, as sources of pollution, are of concern mostly in the Gulf of Mexico, where 436 facilities are located. This represents approximately 12 percent of all point source discharges into EDAs in the region. Both the Mississippi River and Mississippi Sound estuaries contain over 100 power plants. The Middle Atlantic region contains 89 facilities, the second largest number of power plants among regions.

Agriculturally applied nutrients and pesticides may also have an impact on the productivity and health of the Nation's estuaries. Nutrients are essential for the productivity of an estuary. However, an overabundance of nitrogen and phosphorus entering a system from sources such as agricultural runoff and wastewater treatment plants can cause nutrient enrichment problems. For example, lowered oxygen levels and decreased light penetration caused by algal blooms degrade the environmental quality of an estuary. A number of coastal areas, including Chesapeake Bay, New York Bight, and the Louisiana coast, have experienced eutrophication and/or hypoxia in recent years.

Fertilizers applied to agricultural lands contribute to nutrient loadings in estuaries and coastal rivers. The highest regional application of nitrogen and

phosphorus fertilizers in coastal areas occurs in the Gulf Coast. Over 800,000 tons of fertilizers were applied in 1982. The South Atlantic was the second highest, with over 160,000 tons of fertilizer applied. The North Atlantic was the lowest, with only 5,000 tons of fertilizer applied in 1982 (NOAA, 1990e).

Pesticides can enter an estuary from runoff, atmospheric deposition, or groundwater discharge. The amount of pesticides that run off from agricultural land with precipitation ranges from one to five percent. While not enough is known to state that pesticides are a major cause of degradation in the Nation's estuaries, they may be a factor in individual estuarine systems. Agricultural pesticide use decreased slightly in the U.S. during the 1980s (NOAA, 1990e).

Large quantities of pesticides are applied to agricultural lands in the drainage basins of several estuaries in the Middle Atlantic and South Atlantic regions. The Chesapeake Bay EDA, for example, led the Nation's EDAs with approximately 5.3 million pounds applied in 1982, followed by Albemarle/ Pamlico sounds (4.1 million pounds) and Winyah Bay (3.2 million pounds). In the Gulf of Mexico, large quantities of pesticides are applied in the estuarine drainage area of both Upper and Lower Laguna Madre (1.9 million pounds) (Pait et al., 1989).

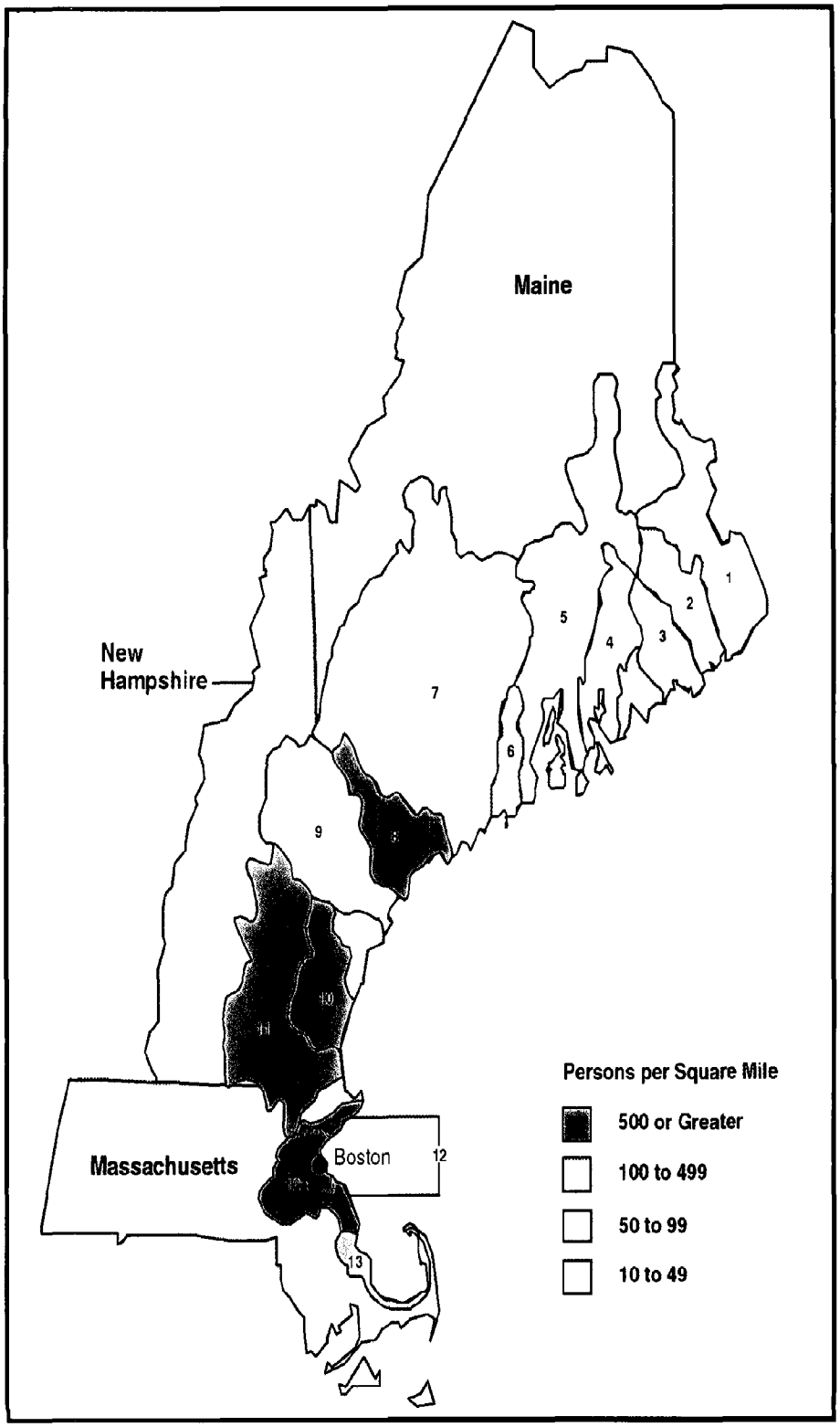
* * *

The sections that follow present additional information on the estuaries in each region. Appendix B presents summary information on selected characteristics by estuary and region. Maps depicting all counties intersecting estuarine drainage areas are contained in Appendix C.

Near infra-red LANDSAT image of Galveston Bay showing a coastal portion of its estuarine drainage area.

Courtesy of NASA

Figure 2. *Population Density in North Atlantic EDAs, 1980*



The North Atlantic region extends from the U.S.-Canada border in Maine to the tip of Cape Cod in Massachusetts. The 13 estuaries and one subestuary shown in Figure 2 account for more than 23,000 square miles of estuarine drainage along the North Atlantic coast.

North Atlantic Estuaries

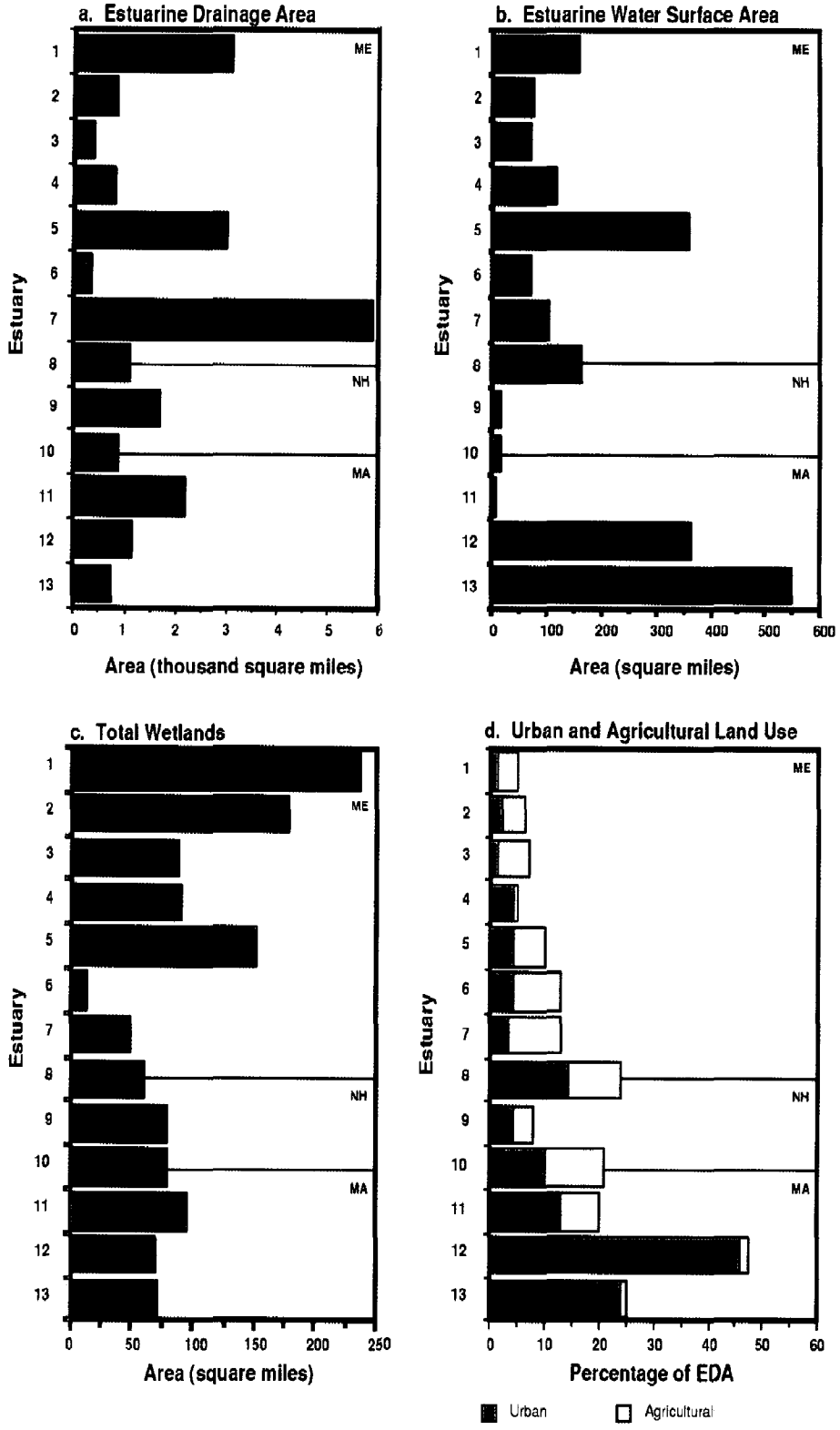
1 Passamaquoddy Bay
2 Englishman Bay
3 Narraguagus Bay
4 Blue Hill Bay
5 Penobscot Bay
6 Muscongus Bay
7 Sheepscot Bay
8 Casco Bay
9 Saco Bay
10 Great Bay
11 Merrimack River
12 Massachusetts Bay
12a Boston Bay
13 Cape Cod Bay

Physical Features. Estuaries in this region were formed by glaciers that removed soil cover, leaving rocky shorelines and steep-sided river channels. Estuarine drainage areas (EDAs) in the region range from about 300 (Muscongus Bay) to about 6,200 square miles (Sheepscot Bay). EDAs in the region are smaller on average than in other regions, except for the Pacific. EDAs account for about two-thirds of total drainage into estuaries in the region, suggesting that activities occurring within EDAs may impact estuaries the most. Sheepscot Bay has both the largest fluvial drainage area (over 10,000 square miles) and EDA. Total water surface area of the estuaries in the region (about 2,000 square miles) is the smallest among regions. Cape Cod Bay has the largest water surface area (548 square miles) followed by Massachusetts and Penobscot bays, 364 and 361 square miles, respectively.

Hydrologic Characteristics. The strong tides and basin geometry in these estuaries result in tidally-dominated circulation patterns. Tides in the North Atlantic region are semidiurnal and range from about 19 feet in northern Maine to about nine feet at Cape Cod. Estuarine water volumes range from about two billion cubic feet in the Merrimack River to one trillion cubic feet in Cape Cod Bay, and are about average when compared to other regions. However, North Atlantic estuaries are generally deeper than those found in other regions. Figures 3a and 3b show estuarine drainage and water surface areas in the North Atlantic.

Precipitation averages 40-46 inches per year across this region. Sheepscot Bay and Penobscot Bay have, by far, the greatest freshwater inflows in the region, approximately 17,600 and 16,100 cubic feet per second, respectively. However, their inflows are lower than the mean for all U.S. estuaries (about 20,000 cubic feet per second). The timing of peak freshwater inflow to estuaries is a function of spring melting, with high-flow periods occurring from March through May. Low-flow periods occur from July through September. During low-flow periods, low precipitation and high evaporation rates result in increased salinities within estuaries. North Atlantic estuaries account for about one-sixth of the freshwater discharge to coastal waters along the Atlantic Coast.

Figure 3. *Selected Characteristics, North Atlantic Estuaries*



Notes: Sub-estuaries are not shown separately. All values are in Appendix B.

Wetlands. The amount of coastal wetlands in the region, about 1,200 square miles, is small compared to other regions (NOAA, 1989b). This is due to the rugged relief, rocky shorelines, and steep-sided river channels of the region, and incomplete data for the inland portions of most EDAs. Passamaquoddy Bay contains the most wetlands in the region, about 240 square miles. Wetlands in the North Atlantic are primarily forested and scrub-shrub, with lesser amounts of salt and fresh marsh, and tidal flats present. Figure 3c shows the wetland area in each EDA.

Land Use. Three of the largest population centers in the region (Boston, MA; Manchester, NH; and Portland, ME) are located in EDAs. However, urban land use makes up only about seven percent of estuarine drainage areas in the region. Urban land is dominant only in the Boston Bay sub-estuary. Agricultural lands also account for about seven percent of land use in the region's EDAs. The remaining majority of land in the EDAs is forested. Figure 3d shows the percentage of land that is urban and agricultural in each EDA.

Population. The North Atlantic is the third most densely populated coastal region in the U.S. Figure 2 shows the population density in each of the EDAs in the North Atlantic. Population decreased in the Boston Bay estuarine drainage area by about five percent between 1970 and 1980. Even so, it is still seven times more densely populated than any other EDA in the region, and is one of the most densely populated in the Nation. Passamaquoddy and Englishman bays are the least densely populated EDAs in the region and among the least densely populated in the Nation. Population increase for the region as a whole was about four percent between 1970 and 1980. However, Cape Cod Bay was one of the fastest growing EDAs in the Nation, with a 57 percent population increase. Population in the 31 counties in this region is projected to grow by 16 percent over the next 20 years, making it the second slowest growing coastal region in the U.S. (Culliton et al., 1990) Appendix C identifies counties falling entirely or partially in EDAs in the North Atlantic region.

Pollution Sources. Despite the presence of several large cities, the North Atlantic has fewer point sources of pollution (less than 400) than any other region (NOAA, 1990e). There are almost twice as many industrial sources as municipal wastewater treatment plants. The greatest number of point sources, 69 or about one-fifth of the region's total, are found in Boston Bay. The ratio of industrial to municipal point sources is about four to one in Boston Bay. Industrial sources include chemical manufacturing, metal fabrication, and machinery and transportation equipment production. Great Bay has almost as many point sources (59) as Boston Bay, although most are small facilities. Point sources in Great Bay are evenly divided between industrial and municipal facilities.

The application and runoff of pesticides may be a concern in many estuarine drainage areas. In 1982, over one-quarter million pounds of commonly used pesticides were applied to agricultural lands in the North Atlantic region (Pait et al., 1989). The intensity (average annual application per square mile of

A salt marsh within a North Atlantic estuary. Many species of plants and animals depend on estuarine ecosystems.

Courtesy of NOAA

cropland) of pesticide application was approximately 276 pounds. This relatively low volume reflects the region's limited agricultural activity. The distribution of pesticides was: herbicides (57 percent), insecticides (13 percent), and fungicides (30 percent). Application was highest in the Cape Cod EDA (1,227 pounds per square mile).

In 1982, the application of fertilizer to agricultural lands in the region's estuarine drainage areas was the lowest among the five regions. Approximately 3,000 tons of phosphorus and 9,000 tons of nitrogen fertilizers were applied. Sheepscot, Saco, and Penobscot bays received the highest applications. Excluding nutrients from upstream fluvial sources, fertilizer runoff from agricultural land is a significant nutrient source (i.e., greater than 25 percent of the total inputs of either phosphorus or nitrogen) in Passamaquoddy, Englishman, Narraguagus, Muscongus, and Casco bays.

Fishery Resources. The estuaries and bays of this region support an array of commercially and ecologically important fish and invertebrates. Over 300 million pounds of seafood, with an estimated ex-vessel value of over 250 million dollars, were landed at ports in the region in 1989 (NOAA, 1990f). The American lobster and the sea scallop are currently the top commercial species in the region, providing more than 60 million pounds of seafood valued at more than 193 million dollars in 1989. Atlantic cod was the most commercially important fish in 1989, with nearly 74 million pounds valued at 45 million dollars (NOAA, 1990f).

Estuarine-dependent species of economic importance include the soft clam and summer flounder, whose combined landings totaled 17 million dollars in 1989 (NOAA, 1990f). Ecologically important species include sand lance and spiny dogfish. Several species which contribute to the significant Georges Bank fishery rely on North Atlantic estuaries for nursery areas (winter flounder and red hake) and seasonal foraging (bluefish and spiny dogfish).

Approved shellfish growing areas in North Atlantic estuarine waters exceed 1,000 square miles, or about 83 percent of the total area classified by state shellfish sanitation officials in the region (Leonard et al., 1989). Penobscot Bay has the greatest amount of approved and total shellfish waters in the region. The North Atlantic ranks fourth in amount of classified waters and second in percentage of waters approved for shellfish harvest among regions. The remaining 17 percent of growing waters are restricted from harvesting all or part of the year. Harvest restrictions are due to identified declines in water quality associated with: (1) municipal wastewater treatment plants and combined sewer systems, (2) increasing coastal populations resulting in increasing shoreline development and boating activities, and (3) increased monitoring and awareness of nonpoint pollution.

Recreation. The supply of public outdoor recreational resources in North Atlantic estuarine drainage areas is the lowest among coastal regions. There are more than 2,600 public outdoor recreation sites in the North Atlantic, of which almost 400 are adjacent to estuarine waters. The total area of all sites in the region is approximately 500 square miles. Most of these sites are concentrated in Massachusetts, as is most of the recreation land.

Slightly more public recreation areas are set aside for hunting than for conservation in this region. Most sites (88 percent) are managed by local governments; however, most of the land is under Federal control (40 percent), with state and local governments each controlling 30 percent (NOAA, 1988).

Privately-owned outdoor recreation sites follow the same general distribution pattern as public sites. The North Atlantic contains fewer sites in all recreation categories than the other regions (NOAA, 1990d). This is the result of many factors including population levels, climate, and the physiography of the region.

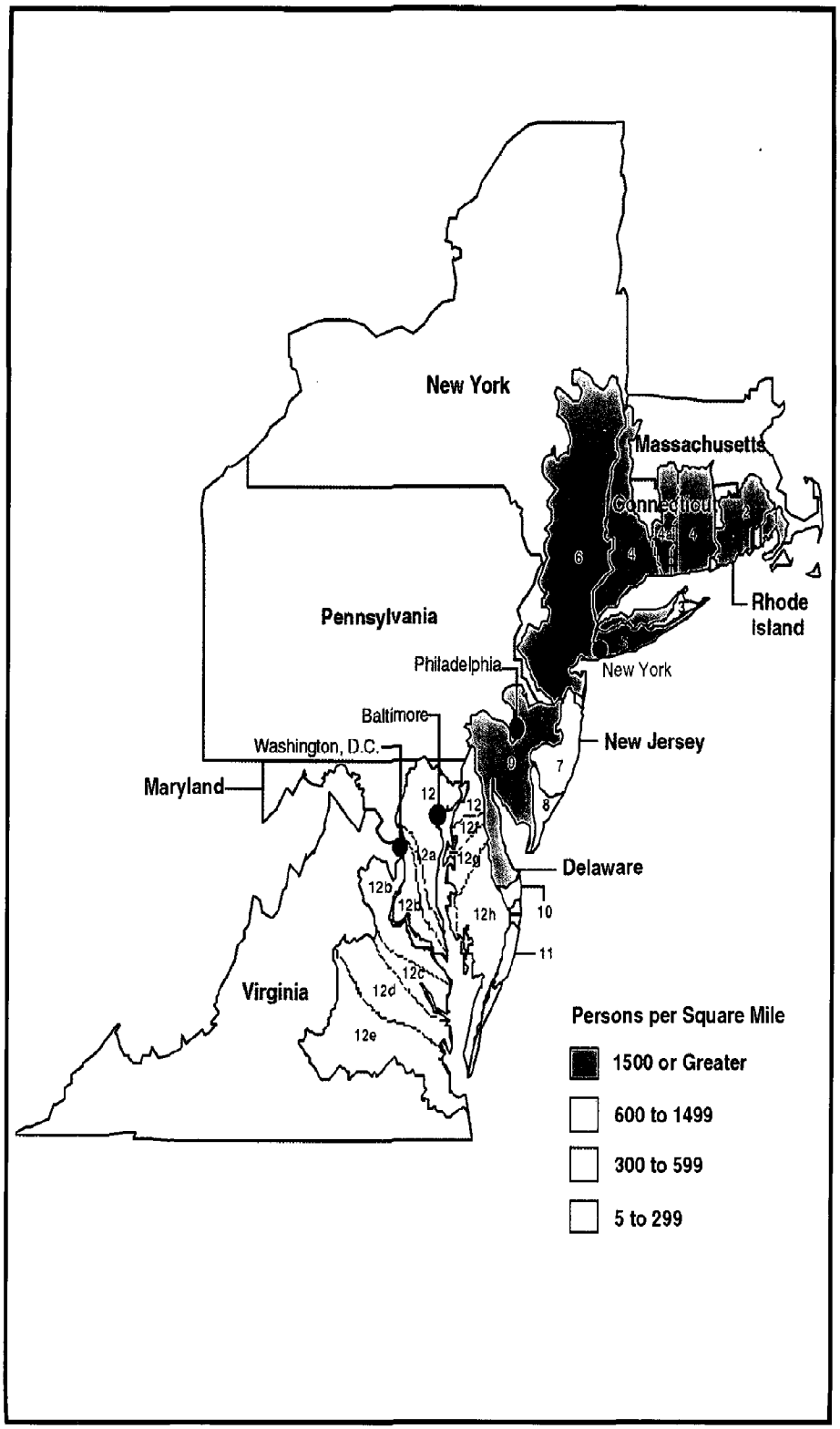
* * *

As of mid-1990, Casco Bay, Massachusetts Bay, Cape Cod Bay, and Boston Bay were included in EPA's National Estuary Program.

More detailed information on each estuary can be found in Appendix B. Maps showing the counties in each EDA are in Appendix C.

Estuaries of the Middle Atlantic

Figure 4. *Population Density in Middle Atlantic EDAs, 1980*



The Middle Atlantic region extends from Buzzards Bay in Massachusetts through Chesapeake Bay in Virginia. The 12 estuaries and nine sub-estuaries shown in Figure 4 account for more than 48,000 square miles of estuarine drainage along the Middle Atlantic coast.

Middle Atlantic Estuaries

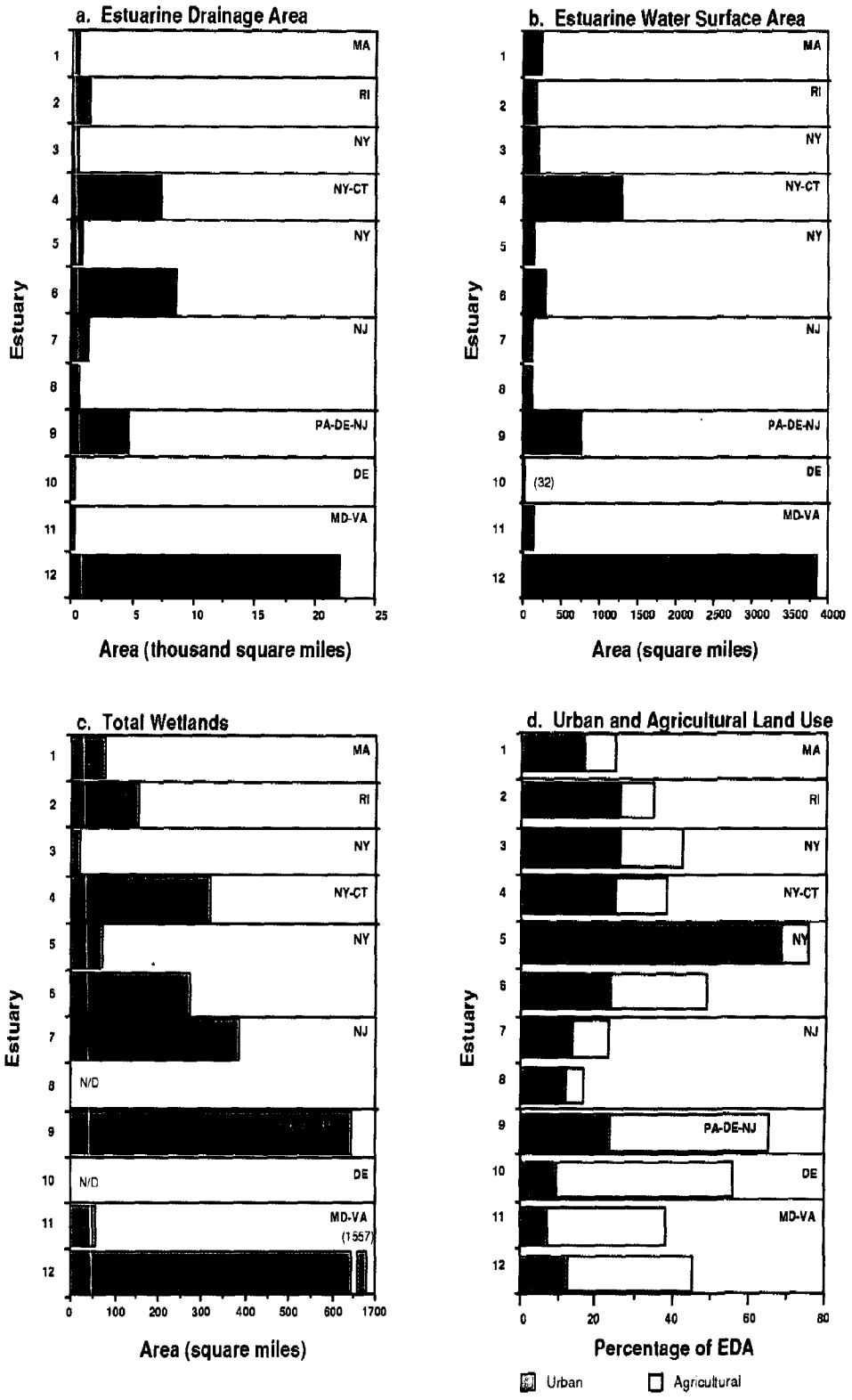
1 Buzzards Bay
2 Narragansett Bay
3 Gardiners Bay
4 Long Island Sound
4a Connecticut River
5 Great South Bay
6 Hudson River/Raritan Bay
7 Barnegat Bay
8 New Jersey Inland Bays
9 Delaware Bay
10 Delaware Inland Bays
11 Chincoteague Bay
12 Chesapeake Bay
12a Patuxent River
12b Potomac River
12c Rappahannock River
12d York River
12e James River
12f Chester River
12g Choptank River
12h Tangier/Pocomoke Sounds

Physical Features. Middle Atlantic estuaries are geomorphologically different from those in the North Atlantic region. Rising sea level, resulting from melting glaciers, drowned the mouths of ancient rivers extending across the continental shelf. The resulting coastal plain estuaries generally are restricted to temperate latitudes. Estuarine drainage areas (EDAs) range from about 300 square miles in the Delaware Inland Bays to nearly 22,000 square miles in Chesapeake Bay. EDAs account for almost 40 percent of total drainage (estuarine plus fluvial) into estuaries in the region. At almost 70,000 square miles, Chesapeake Bay has the largest total drainage area in the region. The total water surface area of Middle Atlantic estuaries (over 7,000 square miles) is exceeded only by the Gulf of Mexico region. Chesapeake Bay's water surface area (3,830 square miles) is almost three times that of Long Island Sound (1,281 square miles), the region's second largest estuary in water surface area. Figures 5a and 5b show estuarine drainage and water surface areas in the Middle Atlantic.

Hydrologic Characteristics. Tides in the Middle Atlantic are semidiurnal and range from about seven feet in Delaware Bay to one to two feet in tributaries of Chesapeake Bay. Average depths of estuaries in the Middle Atlantic rank third among regions and vary significantly, from four feet in the Delaware Inland Bays to 62 feet in Long Island Sound. Estuarine water volumes in the region range from about four billion cubic feet in the Delaware Inland Bays to more than 2.5 trillion cubic feet in Chesapeake Bay. The Middle Atlantic has the second largest estuarine volume of all regions.

Middle Atlantic estuaries account for 44 percent of the total freshwater discharge to coastal waters along the Atlantic Coast. Long-term precipitation, approximately 40-48 inches per year, increases slightly from north to south. The timing of peak freshwater inflow to estuaries is primarily a function of spring snow melt. Low freshwater inflows occur from July through September and

Figure 5. *Selected Characteristics, Middle Atlantic Estuaries*



Notes: Sub-estuaries are not shown separately. All values are in Appendix B. N/D - no data.

result in higher salinities in estuarine waters during this period. Chesapeake Bay has the greatest freshwater inflow (85,800 cubic feet per second) and accounts for almost half of all freshwater entering estuaries in the region. The Delaware Inland and Chincoteague bays have the lowest inflows. Freshwater inflow significantly affects estuarine circulation throughout the region, combining with tides to create relatively complex circulation patterns, compared to other regions where either tides or freshwater inflow predominate.

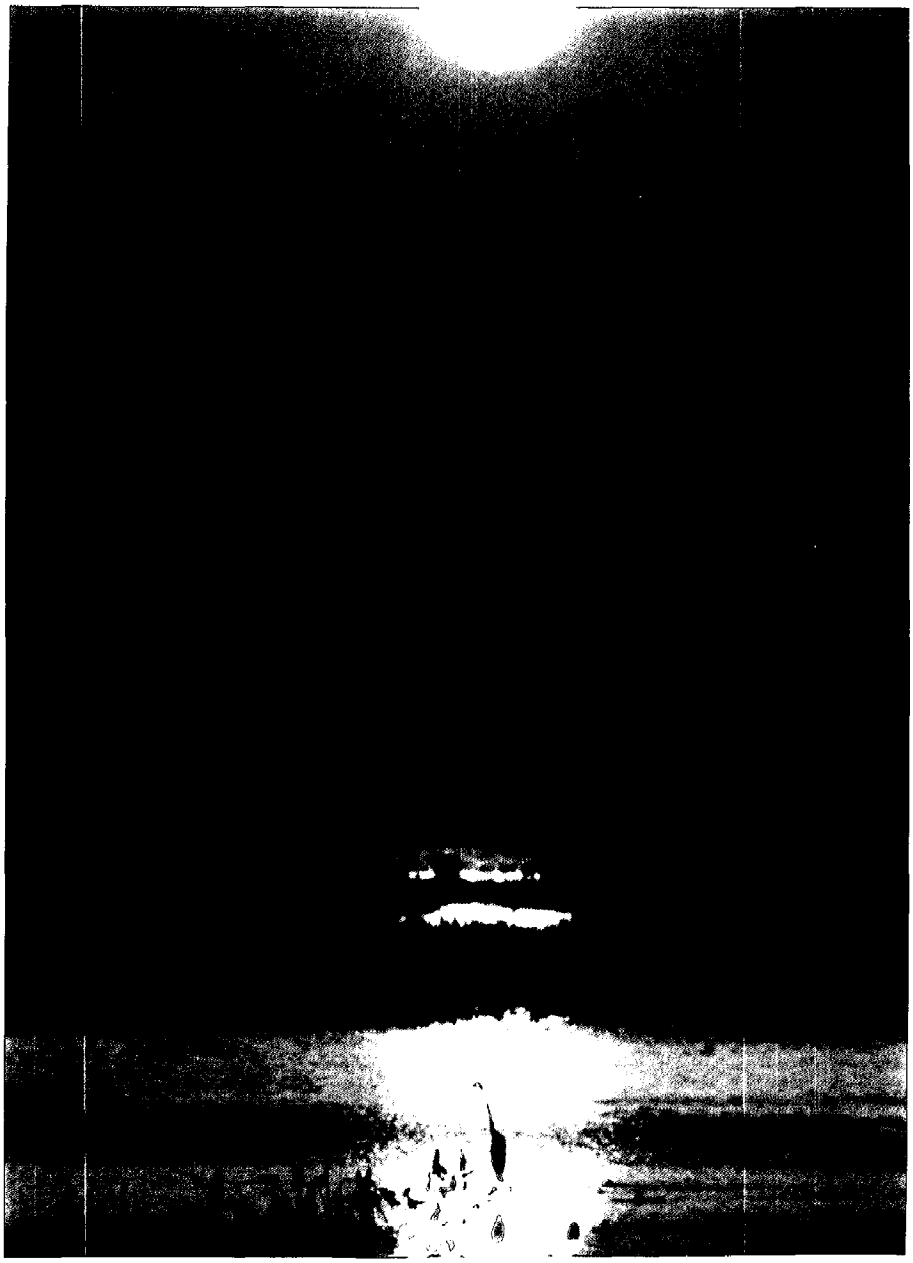
Wetlands. Despite the urbanized nature of the Middle Atlantic, it contains more than 3,500 square miles of wetlands (Reyer et al., 1990a) and ranks third behind the Gulf of Mexico and South Atlantic regions in total wetland area in EDAs (NOAA, 1990a). Figure 5c shows the amount of wetlands in each EDA in the region. The Chesapeake Bay estuarine drainage area alone contains more than 1,500 square miles of wetlands. The second largest amount of wetlands is in Delaware Bay (641 square miles). Forested wetlands are the most common, accounting for nearly 58 percent of the region's wetlands, followed by salt marsh (28 percent).

Land Use. The Middle Atlantic had a population of almost 33 million in 1980, concentrated in an urban corridor extending from Providence, RI to Norfolk, VA. The major population centers in the region are New York, Philadelphia, Baltimore, and Washington, DC. Despite the size of these metropolitan areas, urban land is the leading land use in only one EDA, Great South Bay, NY (Figure 5d). Urban land use ranks behind forest and agricultural land uses in estuarine drainage areas in the region as a whole. This is even the case in the Hudson River/Raritan Bay estuary where forest and agricultural lands account for nearly three-quarters of land use. Similar land use patterns are found in other Middle Atlantic estuaries containing large metropolitan areas, such as Narragansett and Delaware bays and the Potomac River. These are large EDAs extending inland well beyond the limits of urban growth. Nevertheless, estuaries in the Middle Atlantic contain the greatest percentage of urban land among regions. While agricultural land use is modest in the region as a whole, it occupies over 30 percent of the estuarine drainage areas of Delaware, Chincoteague, and Chesapeake bays, and the Delaware Inland Bays.

Population. The Middle Atlantic is the most densely populated coastal region in the U.S. This is shown by the large populations and amount of urban land in estuarine drainage areas. Figure 4 shows the population density in each of the EDAs. Population density is highest in Great South Bay, followed by Hudson River/Raritan Bay, Delaware Bay, Narragansett Bay, and Long Island Sound.

Although population growth for the region was relatively low between 1970 and 1980, a few areas, such as Barnegat Bay, and the York and Rappahannock rivers, had significant growth (47, 40, and 27 percent, respectively). Population decreased by about five percent in the Hudson River/Raritan Bay and Chincoteague Bay EDAs, and by about one percent in Long Island Sound and Delaware Bay. The 155 counties with land area in EDAs are projected to grow by almost 10 percent over the next 20

Sunset over a Middle Atlantic estuary. Wetland areas in this region support a wide variety of plants and animals, and provide food and cover for many migratory species of birds.



Courtesy of Art Weber, U.S. Fish and Wildlife Service

years, making it the slowest growing coastal region in the U.S. (Culliton et al., 1990). Appendix C identifies counties falling entirely or partially in EDAs in the Middle Atlantic region.

Pollution Sources. The region's large population centers have created a proliferation of major point sources of pollution. Over 2,700 point sources are contained in estuarine drainage areas, second only to the Gulf of Mexico region (NOAA, 1990e). Most of these sources are industrial facilities (almost 1,800). Municipal wastewater treatment plants (over 900) make up most of the remainder. Hudson River/Raritan Bay and Chesapeake Bay contain more point sources than any other EDA in the Nation, with the exception of Galveston Bay in Texas.

In 1982, almost nine million pounds of commonly used pesticides were applied to agricultural lands in the region (Pait et al., 1989). The distribution of pesticides was: herbicides (76 percent), insecticides (16 percent), and fungicides (seven percent). The intensity of application was relatively high in 1982, with approximately 1,148 pounds of pesticides applied per square mile of cropland. Gardiners Bay (1,636 pounds per square mile) and Great South Bay (1,468 pounds per square mile) received the highest application rates in the region. The intensity of application in the Chesapeake Bay EDA was 1,118 pounds per square mile.

In 1982, the application of fertilizer to agricultural lands in the region's estuarine drainage areas was the third highest among the five regions. Approximately 28,000 tons of phosphorus and 100,000 tons of nitrogen fertilizers were applied. Chesapeake Bay and Delaware Bay had the highest applications. Both contain a high percentage of agricultural lands. Excluding nutrients from upstream fluvial sources, fertilizer runoff from agricultural land is a significant nutrient source (i.e., greater than 25 percent of the total inputs of either phosphorus or nitrogen) in Chincoteague Bay.

Fishery Resources. About 1.1 billion pounds of seafood with an approximate ex-vessel value of 500 million dollars were landed in the region in 1989. Although the sea scallop was the leading commercial species in the region, the estuarine-dependent blue crab was the second-most valuable, worth more than 41 million dollars. Approximately half of the Nation's total blue crab catch was taken from the region, the majority from Chesapeake Bay (NOAA, 1990f).

Middle Atlantic coastal plain estuaries are characteristically shallow and subject to strong tidal circulation (NOAA, 1985), creating ideal conditions for biological productivity. Seasonal conditions can dramatically change the diversity and species compositions of these estuaries (White, 1989). Middle Atlantic estuaries provide year-round habitat for such species as white perch and bay anchovy, and attract foraging marine predators like bluefish and Atlantic croaker. They also serve as nursery areas for earlier life stages of marine species such as Atlantic menhaden, and anadromous fishes such as American shad and striped bass. Hence, Middle Atlantic estuaries are directly linked to many offshore fisheries.

Classified shellfish growing waters in the region exceed 7,300 square miles, with about 6,300 square miles approved for harvest. This is the largest amount and the highest percentage (85 percent) of growing waters approved for harvest among regions (Leonard et al., 1989). Chesapeake Bay contains more than half of the approved shellfish-growing waters in the region and about one-quarter of the waters in the contiguous U.S. Long Island Sound contains the second largest amount of approved waters (over 1,100 square miles), about one-fifth of the region's total. Hudson River/Raritan Bay has no approved shellfish-growing waters. In recent years, reductions in harvestable shellfish resources have occurred throughout the region due to disease, overharvesting, predation, and pollution.

Recreation. The concentration of population in the region has created a high demand for recreational opportunities in its estuarine areas. Of the more than 10,000 public outdoor recreation sites in the region, over 1,100 are adjacent to tidal waters, with the majority in the Long Island Sound and Hudson River/Raritan Bay EDAs (NOAA, 1988). The Middle Atlantic has more public outdoor recreation sites than any other region, encompassing approximately 2,800 square miles.

Most sites (91 percent) are managed by local governments; however, most of the land is under state control (61 percent), with Federal and local governments controlling the remainder equally (NOAA, 1988). More than half of the lands are set aside for hunting; less than one-quarter are set aside for conservation, preservation, or scenic value.

Privately-owned outdoor recreation sites are also numerous. Almost 42 percent of the Nation's coastal marinas and more than one-quarter of the charter boats and coastal golf courses are located in the region. Intense development has placed growing pressure on available land near urban populations. High land values and lack of open space make privately-owned outdoor recreation sites attractive to many users in the region (NOAA, 1990d).

* * *

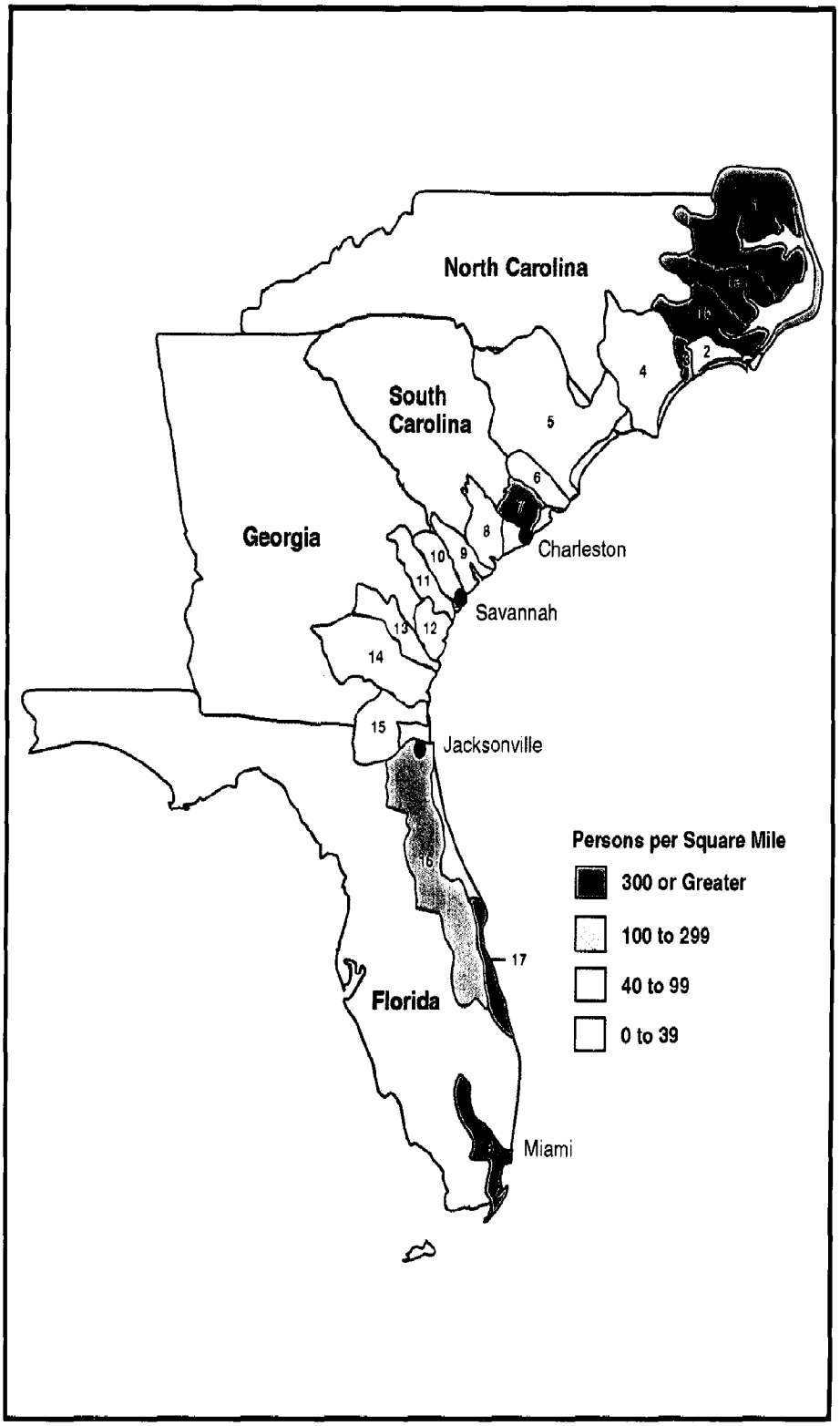
As of mid-1990, Buzzards Bay, Narragansett Bay, Long Island Sound, New York/New Jersey Harbor (part of the Hudson River/Raritan Bay estuary), Delaware Bay, and Delaware Inland Bays were included in EPA's National Estuary Program.

More detailed information on each estuary can be found in Appendix B. Maps showing the counties in each EDA are in Appendix C.

Emergent wetlands provide critical habitat for many aquatic organisms.

Courtesy of NOAA

Figure 6. *Population Density in South Atlantic EDAs, 1980*



The South Atlantic region extends from North Carolina to southern Florida. The 18 estuaries and two sub-estuaries shown in Figure 6 account for almost 56,000 square miles of estuarine drainage along the South Atlantic coast.

	South Atlantic Estuaries
1	Albemarle/Pamlico Sounds
1a	Pamlico/Pungo Rivers
1b	Neuse River
2	Bogue Sound
3	New River
4	Cape Fear River
5	Winyah Bay
6	North/South Santee Rivers
7	Charleston Harbor
8	St. Helena Sound
9	Broad River
10	Savannah River
11	Ossabaw Sound
12	St. Catherines/Sapelo Sounds
13	Altamaha River
14	St. Andrew/St. Simons Sounds
15	St. Marys River/Cumberland Sound
16	St. Johns River
17	Indian River
18	Biscayne Bay

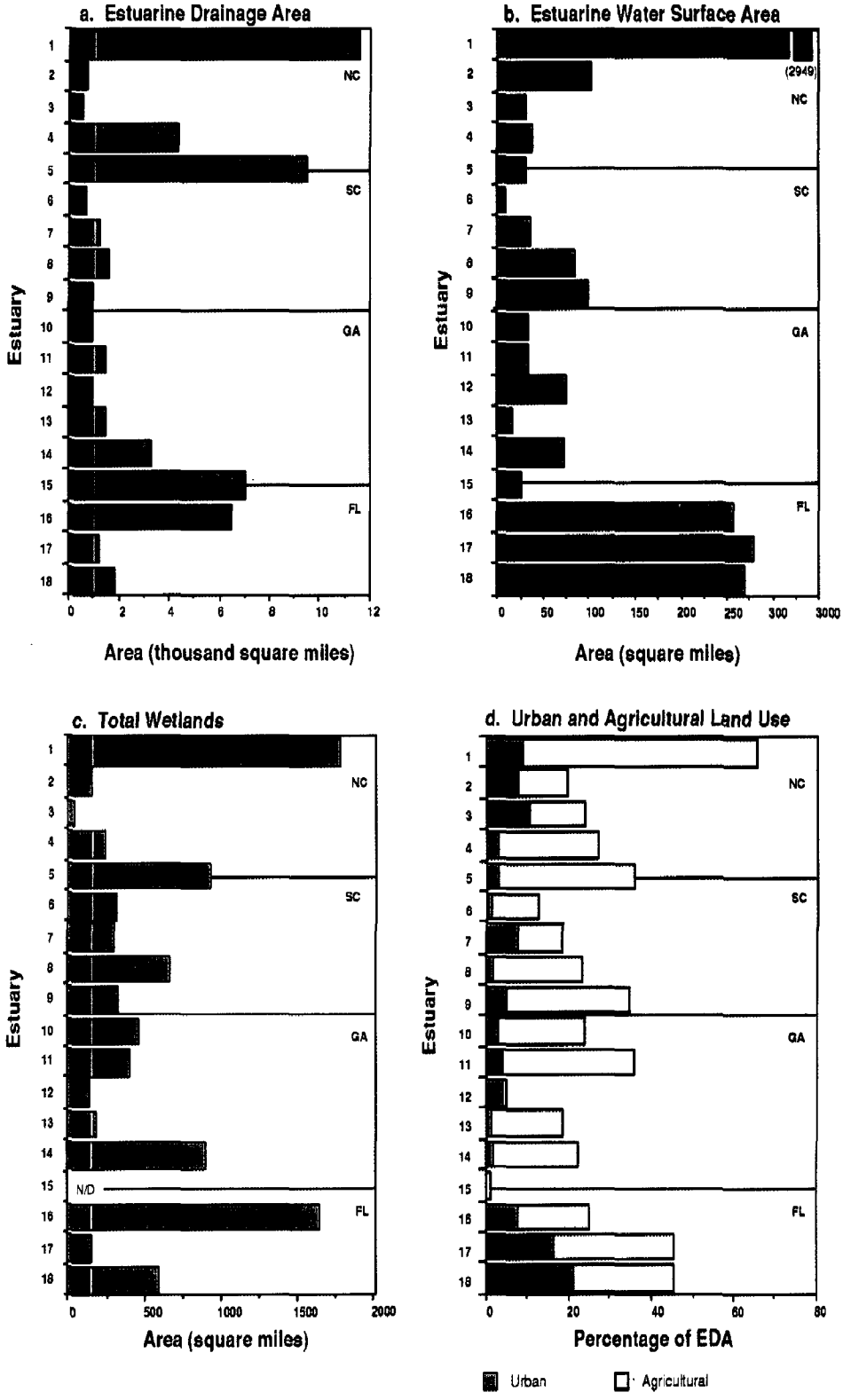
Physical Features. Estuaries in the South Atlantic region are characterized by two general shoreline formations. The first is a low-lying, marshy shoreline with a dendritic pattern of tributaries flowing to the sea and is most prevalent along the South Carolina and Georgia coasts. The second is represented by lagoons bounded by extensive barrier island systems and is found in North Carolina and central Florida. An exception to this is the St. Johns River, a large river with limited access to the sea, but tidally influenced a considerable distance upstream.

Estuarine drainage areas (EDAs) in the region range from about 500 square miles in New River to almost 11,600 square miles in Albemarle/Pamlico Sounds. Although both Winyah Bay (9,500 square miles) and St. Marys River/Cumberland Sound (7,000 square miles) have large EDAs, each has a relatively small water surface area. New River (470 square miles), Bogue Sound (680 square miles), and North/South Santee Rivers (680 square miles) have the smallest EDAs in the region. New River and Bogue Sound are bar-built estuaries without fluvial drainage areas since they are surrounded by areas draining into Albemarle/Pamlico Sounds and Cape Fear River estuaries. In addition, the head of tide in each is relatively close to the open ocean. Figures 7a and 7b show estuarine drainage and water surface areas in the South Atlantic.

Over 4,400 square miles of estuarine water surface area make this the third largest among regions. The region's largest estuary, Albemarle/Pamlico Sounds, contains over 2,900 square miles of water surface area, second nationwide only to Chesapeake Bay. This vast estuary stretches from the North Carolina/Virginia border south to Cape Lookout, and includes the Chowan, Neuse, Pamlico, and Pungo rivers. Indian River and Biscayne Bay are physically similar to Albemarle/Pamlico Sounds and have the second and third largest estuarine water surface areas in the region, respectively.

Hydrologic Characteristics. Tides throughout the region are semidiurnal and range from about 2.5 feet in North Carolina, to about seven feet in Georgia, to two feet in Florida. The flat

Figure 7. *Selected Chatacteristics, South Atlantic Estuaries*



Notes: Sub-estuaries are not shown separately. All values are in Appendix B. N/D - no data.

coastal plain, small tidal range, and barrier islands combine to minimize tidal influence on estuarine circulation in this region. Consequently, circulation is less dynamic than in the river- or tide-dominated estuaries of other regions and is more dependent on the influence of wind.

Water volumes of South Atlantic estuaries range from about 2.1 billion cubic feet in the North and South Santee rivers to 1.1 trillion cubic feet in Albemarle/Pamlico Sounds. Because of their shallow to moderate depths, water volumes for South Atlantic estuaries are among the lowest in the Nation. Albemarle/Pamlico Sounds, for example, average only 13 feet in depth. The estuary with the highest average depth is the Broad River (24 feet).

South Atlantic estuaries account for about 40 percent of the freshwater inflow to estuaries along the East Coast. The rivers flowing into Albemarle/Pamlico Sounds discharge about 46,000 cubic feet per second, the highest in the region. The highest freshwater inflows in the region occur from January through May, except in southern Florida where peak flows occur from June through September due to summer storms. Average precipitation is about 48 inches per year in the northern portion of the region, drops slightly in the central portion, then increases to about 56 to 64 inches per year in southern Florida.

Wetlands. Wetlands cover over 9,000 square miles of the region's EDAs, the second highest among regions (NOAA, 1990a). The Albemarle/Pamlico Sounds, St. Johns River, Winyah Bay, and St. Andrew/St. Simons Sounds estuaries contain the largest amounts of wetlands in the region (Figure 7c). Forested wetlands account for three-quarters of all wetlands. Two well-known and extensive areas, the Great Dismal Swamp (Virginia and North Carolina) and the Okefenokee Swamp (Georgia and Florida), are examples of the forested wetlands of the South Atlantic. Another prominent feature is the sea islands complex of South Carolina and Georgia, a vast area of intricate estuarine channels and marshlands at the mouths of estuaries extending from St. Helena Sound to St. Andrew/St. Simons Sounds. The wetlands of Biscayne Bay are part of the huge Everglades complex of southern Florida.

Land Use. Forested lands are the dominant land use in 13 estuaries, accounting for about one-third of all land in EDAs. The region's forests constitute a significant percentage of the Nation's commercial forest lands (NOAA, 1987). Extensive forested lands are found in the St. Johns River, St. Andrew/St. Simons Sounds, and Albemarle/Pamlico Sounds estuaries. Agriculture also is a major land use, accounting for 22 percent of all EDA lands (Figure 7d). In Albemarle/Pamlico Sounds, about 59 percent of the EDA land area is in agriculture. Winyah Bay, Ossabaw Sound, Broad River, and Indian River each have over 30 percent of their EDA classified as agricultural land.

Although urban lands comprise only four percent of the region's EDAs, Florida has a heavily developed coastal corridor extending north from Miami on Biscayne Bay to Jacksonville at the mouth of the St. Johns River. Unlike most of the urban areas of the North and

Middle Atlantic regions that have developed outward from the core of cities, urban areas of east Florida have spread along the narrow coastal strip in a series of suburban, second home, and resort developments. Urban areas account for 21 and 17 percent of EDA land in the Biscayne Bay and Indian River estuaries of South Florida, respectively.

Population. The South Atlantic is the least densely populated coastal region in the U.S. St. Mary's River/Cumberland Sound (nine persons per square mile) and the North and South Santee Rivers (22 persons per square mile) are the least densely populated estuaries in the region.

The most densely populated South Atlantic estuaries are in Florida. Biscayne Bay, the most heavily populated estuary, includes the southern portions of the Miami metropolitan area. Although the population density for Biscayne Bay (1,030 persons per square mile) is the highest in the South Atlantic, it is only the tenth highest among the Nation's estuaries. Indian River has the second highest population density (327 persons per square mile) in the region, largely because of resort/retirement communities.

The region is growing rapidly, especially in Florida's Broward and Dade counties (Biscayne Bay EDA). The populations in these two counties are projected to increase by 436,000 and 366,000 people respectively over the next two decades. Population in the 126 counties in the region is projected to increase by more than about 24 percent between 1988 and 2010 (Culliton et al., 1990). The major population centers of the region include: Charleston, SC; Savannah, GA; and Jacksonville and Miami, FL. Appendix C identifies counties falling entirely or partially in EDAs in the South Atlantic region.

Pollution Sources. The South Atlantic ranks third among regions in the number of municipal wastewater treatment plants (MWTPs). About three-quarters of the industrial facilities in the region are located in EDAs north of Florida (NOAA, 1990e). However, because of Florida's much higher population density, its EDAs contain more than half of all MWTPs. Florida's most densely populated estuaries, St. Johns River, Biscayne Bay, and Indian River, contain most of the large (over one million gallons per day of discharge) MWTPs in the region.

In 1982, over 11 million pounds of commonly used pesticides were applied to agricultural lands in EDAs in the region, the second highest amount of the five coastal regions. The distribution of pesticides was: herbicides (67 percent), insecticides (20 percent), and fungicides (seven percent). The South Atlantic region had the highest intensity of application (over 1,170 pounds per square mile of cropland) among regions in 1982. Albemarle/Pamlico Sounds (1,682 pounds per square mile) and New River (1,540 pounds per square mile) were the EDAs with the highest per square mile application intensity in the region (Pait et al., 1989).

In 1982, the application of fertilizer to agricultural lands in the region's estuarine drainage areas was the second highest among regions. Approximately 30,000 tons of phosphorus and 132,000

Fort Pierce Harbor, Florida is part of the Indian River estuary. Coastal development has a direct impact on estuarine environments.

Courtesy of NOAA

tons of nitrogen fertilizers were applied. Albemarle/Pamlico Sounds and St. Johns River received the highest applications. The former contains a high percentage of agricultural lands. Excluding nutrients from upstream fluvial sources, fertilizer runoff from agricultural land is a significant nutrient source (i.e. greater than 25 percent of the total inputs of either phosphorus or nitrogen) in Albemarle/Pamlico Sounds, Bogue River, New River, Broad River, and Indian River (NOAA, 1990e).

Fishery Resources. About 250 million pounds of seafood with an approximate ex-vessel value of 169 million dollars were landed at South Atlantic ports in

1989 (NOAA, 1990f). Over half of this harvest was comprised of estuarine-dependent species, including Atlantic menhaden, Atlantic croaker, blue crab, and penaeid shrimp. Although the commercial harvest is relatively small compared to other regions, South Atlantic estuaries are nevertheless important to many species.

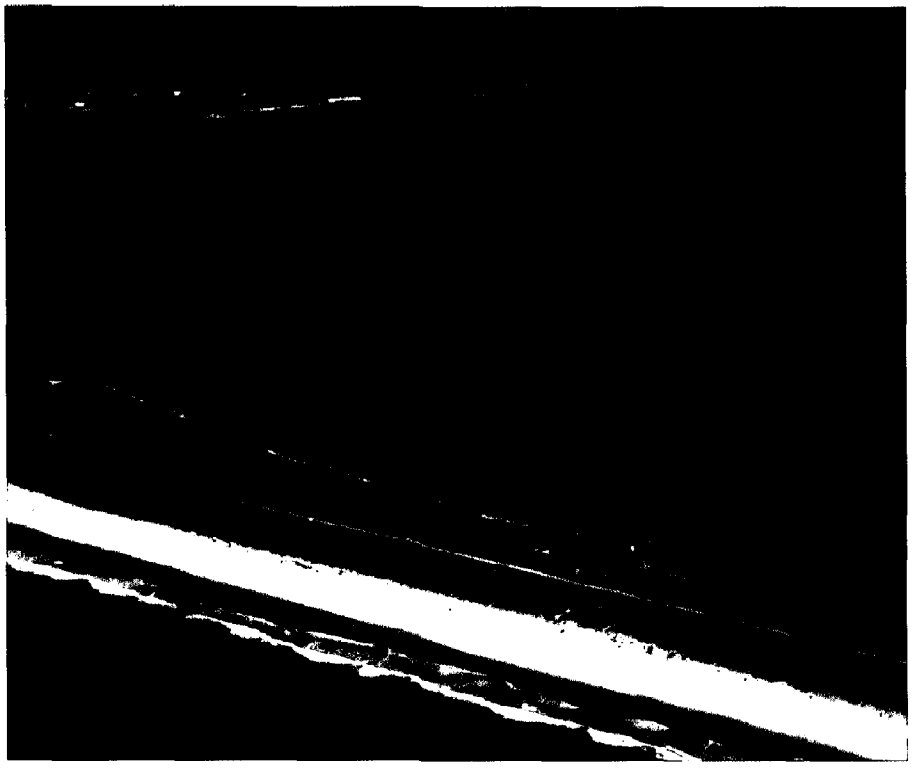
The region also supports important estuarine-dependent recreational fisheries. Some species comprising South Atlantic recreational fisheries are important commercial species in other regions. For example, red drum historically has been commercially harvested in the Gulf of Mexico, whereas it has been primarily a recreational species along the Carolina coasts (Manooch, 1984). Although a region's relative importance is often measured by commercial catch and value, many ecologically important species support these fisheries. For example, the South Atlantic region and its associated low-lying, dendritic, marshy shoreline and bar-built estuaries provide essential habitat to killifish and anchovies. These species are important links in the estuarine food chain (Stickney, 1984).

The South Atlantic accounts for about one-fifth of all classified shellfish-growing waters in all regions. Of the 4,044 square miles of classified waters, almost 75 percent are approved for harvest (Leonard et al., 1989). Agricultural runoff, septic systems, and recreational activities (e.g., boating) are the primary factors affecting the quality of shellfish waters in the region. Shellfish landings in the South Atlantic, although small compared to other regions, have increased in recent years. The region's largest estuary, Albemarle/Pamlico Sounds, contains 3,088 square miles of classified shellfishing waters. These Sounds are a commercially important source of clams and oysters, accounting for about 1.2 million pounds in 1988. St. Helena Sound (389,000 pounds) and St. Catherines/Sapelo Sounds (39,000 pounds) are also major sources of shellfish in South Atlantic estuaries.

Recreation. There are almost 2,700 public outdoor recreation sites accounting for about 5,200 square miles of land in the region's EDAs. Over 60 percent of these lands are managed for hunting, while about 32 percent are set aside for conservation, preservation, and scenic value. Most sites (90 percent) are managed by local governments; however, most of the land is under either Federal (53 percent) or state (45 percent) control. Almost 900 of the public outdoor recreation sites provide access to water. Of these, 61 percent are adjacent to estuarine waters, and 36 percent provide access to open waters of the Atlantic Ocean. Florida has about two-thirds of all sites and more than half of all recreational lands in the region (NOAA, 1988).

As with the public sites, the largest concentration of private sites (70 percent of the region's total) is in Florida (NOAA, 1990d). The South Atlantic region has fewer marinas than the Middle Atlantic and Gulf of Mexico regions. The profile of privately-owned sites in the South Atlantic is similar to that in the Gulf of Mexico region, in part because of similar physiography and climate.

The barrier islands that form the Outer Banks of North Carolina separate Albemarle/Pamlico Sounds, the region's largest estuary, from the Atlantic Ocean.



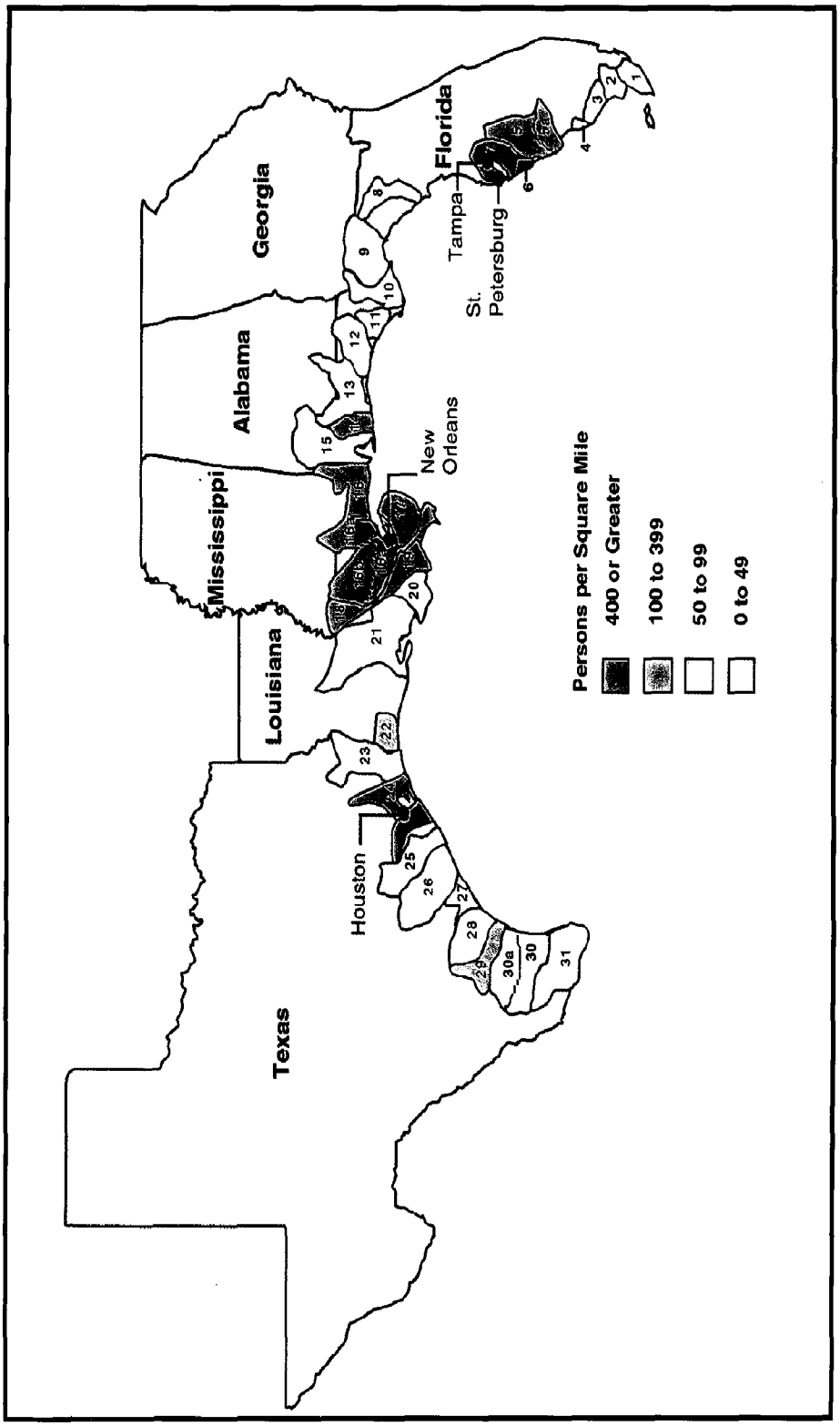
Courtesy of Timothy Goodspeed, NOAA

* * *

As of mid-1990, Albemarle-Pamlico Sounds and Indian River Lagoon (part of the Indian River estuary) were included in EPA's National Estuary Program.

More detailed information on each estuary can be found in Appendix B. Maps showing the counties in each EDA are in Appendix C.

Figure 8. *Population Density in Gulf of Mexico EDAs, 1980*



The Gulf of Mexico region extends from the southern tip of Florida west to the Texas/Mexico border. The 31 estuaries and four sub-estuaries shown account for more than 96,000 square miles of estuarine drainage along the Gulf of Mexico coast.

Gulf of Mexico Estuaries

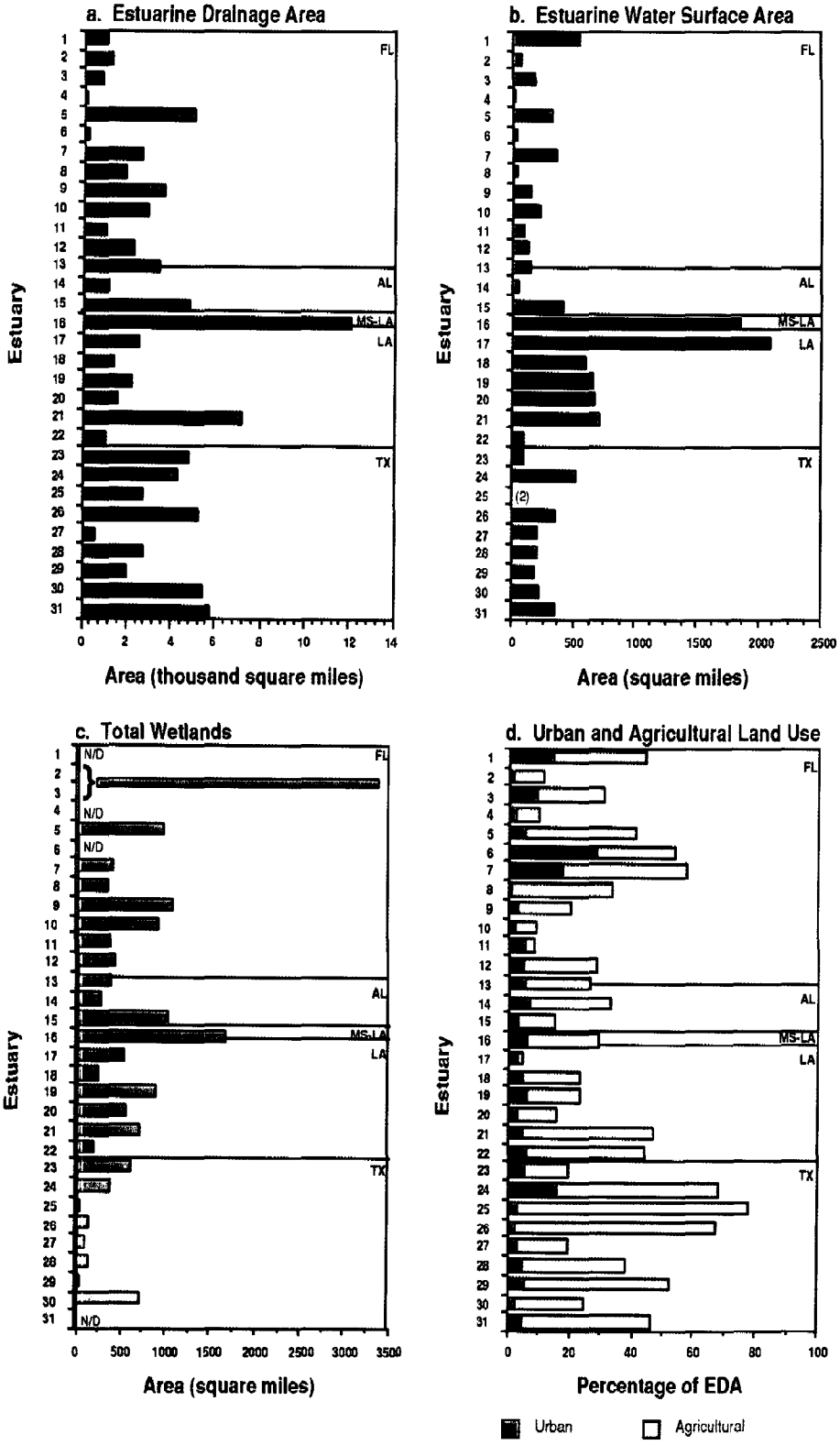
1	Florida Bay
2	South Ten Thousand Islands
3	North Ten Thousand Islands
4	Rookery Bay
5	Charlotte Harbor
5a	Caloosahatchee River
6	Sarasota Bay
7	Tampa Bay
8	Suwannee River
9	Apalachee Bay
10	Apalachicola Bay
11	St. Andrew Bay
12	Choctawhatchee Bay
13	Pensacola Bay
14	Perdido Bay
15	Mobile Bay
16	Mississippi Sound
16a	Lake Borgne
16b	Lake Pontchartrain
17	Breton/Chandeleur Sounds
18	Mississippi River
19	Barataria Bay
20	Terrebonne/Timbalier Bays
21	Atchafalaya/Vermilion Bays
22	Calcasieu Lake
23	Sabine Lake
24	Galveston Bay
25	Brazos River
26	Matagorda Bay
27	San Antonio Bay
28	Aransas Bay
29	Corpus Christi Bay
30	Upper Laguna Madre
30a	Baffin Bay
31	Lower Laguna Madre

Physical Features. Like the South Atlantic and much of the Middle Atlantic, the Gulf of Mexico is part of a vast coastal plain of sedimentary deposits. Major features include the Mississippi and Atchafalaya deltas, where large amounts of land-derived sediments have been deposited in shallow coastal waters. These deltaic environments form a complex, interconnected web of estuarine channels and extensive coastal wetlands that are important habitat for many recreational and commercial fisheries. In other areas, sediment transported and deposited by oceanic currents formed offshore bars enclosing shallow, and sometimes extensive, bodies of water. Such bar-built estuaries are common along the Texas shoreline.

Over 96,000 square miles of estuarine drainage area (EDA) make this the largest of all regions. EDAs range from about 200 square miles (Rookery Bay) to more than 12,000 square miles (Mississippi Sound). More than one-third have EDAs coinciding with their fluvial drainage areas. The notable exceptions are the Mississippi and Atchafalaya rivers, whose fluvial drainage areas extend far into the Nation's hinterland and drain more than half of the contiguous U.S. Consequently, they receive enormous amounts of runoff from outside their EDAs. Figures 9a and 9b show estuarine drainage and water surface areas in the Gulf of Mexico.

With about 11,700 square miles of water surface area, the Gulf is first among regions in total water surface area, and contains two (Breton/Chandeleur and Mississippi Sounds) of the top five estuaries with water surface areas greater than 1,000 square miles.

Figure 9. *Selected Characteristics, Gulf of Mexico Estuaries*



Notes: Sub-estuaries are not shown separately. All values are in Appendix B. N/D - no data.

Hydrologic Characteristics. Tidal cycles vary within the region. A semi-diurnal tide predominates from the Florida Keys to Apalachicola Bay and from the Mississippi Delta area west through Texas. A diurnal tide exists between these two areas. Tidal range is small throughout the region, with a maximum of 3.5 feet in Florida and a minimum of one foot in Louisiana and Texas. Hurricanes have a dramatic effect on Gulf estuaries due to accompanying storm surges and increased freshwater inflow from intense precipitation. Hurricane season extends from June through October; the probability of one hurricane per year making landfall ranges from 20 percent in Florida to five percent in Texas (NOAA, 1985).

Gulf estuaries generally are the most shallow among the regions. They also have less volume on average than most other U.S. estuaries, despite their large water surface areas. Mississippi Sound, for example, has the largest water volume in the Gulf (568 billion cubic feet); however, at least nine estuaries in other regions are larger. The combination of shallow depths and large surface areas with minimal tidal range, geomorphology, and sediment deposition has generated abundant wetlands throughout most Gulf estuaries.

The Gulf of Mexico region's vast drainage system creates tremendous freshwater inflow into estuaries. About half of all the water discharged to estuaries in the NEI is found in this region. The Mississippi River (464,400 cubic feet per second) and Atchafalaya/Vermilion Bays (223,800 cubic feet per second) dominate the inflow of water into the Gulf of Mexico, accounting for almost three-quarters of the freshwater inflow into the region's estuaries. Long-term precipitation, approximately 48 inches per year in western Florida, increases to 56 inches per year in coastal Alabama, Mississippi, and Louisiana, then decreases dramatically westward through Texas to about 24 inches per year in Laguna Madre. Periods of high freshwater inflow vary with precipitation patterns in the region. Central and southern Florida receive their heaviest precipitation from June through October. Freshwater inflow into Texas estuaries is particularly variable by season.

Wetlands. The greatest amount of coastal wetlands of any region is found in the Gulf of Mexico, more than 16,600 square miles. Wetlands are most heavily concentrated in the Mississippi Delta region and southwestern Florida (Figure 9c). Forested wetlands and fresh marsh are important along the Gulf coast of Florida; forested wetlands dominate from the Florida Panhandle to Mississippi Sound. Salt marsh dominates in the western Gulf, from Mississippi Sound westward (Reyer et al., 1988).

Wetlands provide important habitat in the life cycle of shrimp and menhaden, the two most important commercial fishery resources in the Gulf, especially in the area around the Mississippi Delta. However, an estimated 50 square miles of these wetlands have been lost per year between the mid-1950s and late 1970s (Day and Craig, 1981). This has resulted from a rise in sea level, land subsidence, and human alterations such as channelization of estuaries, canal dredging through wetlands to accommodate oil and gas production, and impoundments.

Land Use. Early settlement of the region was associated with ports such as New Orleans, situated on the Mississippi River, that provided access to the interior of the continent. The dense swamps and marshes of much of the region restricted coastal settlement. However, draining the wetlands uncovered an immensely fertile soil that helped expand agricultural activity, particularly in the Mississippi Delta region and areas near the Florida Everglades. The subtropical climate and significant rainfall have led to the growth of dense forests, most prevalent from northern Florida to the Mississippi River. Forested lands are an important land use in this region. Pulpwood for making paper is the major forest product.

Agricultural activity accounts for 31 percent of the land use in the Gulf of Mexico (Figure 9d). The region east of Sabine Lake is one of the Nation's major producers of sugarcane, rice, vegetables, and fruits. Florida is the Nation's leading grower of citrus fruits. West of Sabine Lake, rainfall rapidly diminishes and agriculture becomes irrigation-based with vegetables, fruit, and cotton as the dominant crops.

Population. The Gulf of Mexico is the second fastest growing coastal region in the Nation. Between 1970 and 1980, the population grew by more than 30 percent. In spite of this growth, only five percent of the region is considered urban. Petroleum and natural gas activity, agricultural activities, and tourism are important components of the regional economy. Figure 8 shows population density in EDAs in the Gulf of Mexico region. Major urban areas surround port cities such as New Orleans, Houston, and Tampa. Sarasota Bay has the highest population density in the region (923 persons per square mile), followed by Galveston Bay (665 persons per square mile) and Tampa Bay (476 persons per square mile).

Population in the 159 counties in the region is expected to grow by almost 26 percent over the next 20 years, higher than any other coastal region (Culliton et al., 1990). Appendix C identifies counties falling entirely or partially in EDAs in the Gulf of Mexico region.

Pollution Sources. The Gulf of Mexico region has more point sources of pollution (over 3,700) than any other region in the Nation (NOAA, 1990e). This is a region with concentrations of industrial activity associated with oil and gas production and development. Over half of the point sources are industrial facilities, with many based on the petrochemical industry. Municipal wastewater treatment plants are also numerous and are located throughout the region. Galveston Bay has the greatest concentration of point sources, followed by Mississippi Sound.

In 1982, approximately 11.7 million pounds of commonly used pesticides were applied to agricultural lands in the Gulf of Mexico region, most among regions. The distribution of pesticides was: herbicides (70 percent), insecticides (19 percent), and fungicides (eight percent). In 1982, the average application of pesticides was 366 pounds per square mile. Apalachicola Bay had the highest intensity of application in the region (1,041 pounds per square mile), followed by Apalachee Bay (1,023 pounds per square mile) (Pait et al., 1989).

In 1982, the application of fertilizer to agricultural lands in the region's EDAs was the highest among regions. Approximately 62,000 tons of phosphorus and 758,000 tons of nitrogen fertilizers were applied. Galveston Bay, Matagorda Bay, and Lower Laguna Madre received the highest applications. All contain a high percentage of agricultural land. Excluding nutrients from upstream fluvial sources, fertilizer runoff from agricultural land is a significant nutrient source (i.e., greater than 25 percent of the total inputs of either phosphorus or nitrogen) in South Ten Thousand Islands, North Ten Thousand Islands, Charlotte Harbor, Suwannee River, Lower Laguna Madre, Apalachee, Choctawhatchee, Pensacola, Perdido, Matagorda, San Antonio, Aransas, and Corpus Christi bays (NOAA, 1990e).

Fishery Resources. The coast along the Gulf of Mexico is one of the most productive fishery areas in the world. The region produced almost 1.8 billion pounds of seafood in 1989 with an estimated ex-vessel value of 648 million dollars, making it the leading seafood producer among regions (NOAA, 1990f). Over three-quarters of this harvest comprised species dependent on estuarine waters and coastal wetlands. For example, it has been demonstrated on a Gulf-wide basis that inshore shrimp yields are related directly to the area of available estuarine intertidal vegetation (Turner, 1977). Although the harvest of brown, white, and pink shrimp is second to Gulf menhaden in terms of volume, it accounts for more than half of the value of landings in the region. Gulf estuaries support abundant populations of eco-

The Gulf of Mexico region leads the Nation with approximately 17,000 square miles of coastal wetlands.

Courtesy of Dorothy Leonard, NOAA

logically important species such as bay anchovy and sheepshead minnow. Dominant estuarine-dependent demersal species in the region include spot and croaker (Stickney, 1984). Spot, croaker, and many other species use Gulf estuaries primarily as nursery areas for larval and juvenile life stages (Williams et al., 1990).

The Gulf of Mexico region contains the most classified shellfish-growing waters (almost 9,000 square miles) of all the regions. About 3,800 square miles of these are approved for harvesting. However, more than half (about 55 percent) of all classified waters in the region have regulatory limitations on harvest (Broutman and Leonard, 1988).

Almost 15 million pounds of oyster meats were harvested in Gulf waters in 1989 (NOAA, 1990f). Commercial harvest occurs throughout the region, from Charlotte Harbor to Laguna Madre, and is especially significant in Apalachicola Bay and Breton/Chandeleur Sounds. Most harvest limitations are on a conditional basis, depending on freshwater inflow from highly variable rainfall events. Most of the region's productive reefs are in these conditional areas.

Recreation. The supply of public outdoor recreational resources in estuarine areas is third highest among regions. There are more than 3,700 public outdoor recreation sites in the region, of which 564 are adjacent to estuarine waters. The total area of all sites is almost 8,700 square miles. The majority of these sites and most of the area are located in the Mississippi Delta region. Over half of the recreation area is managed for hunting and over one-third is set aside for conservation, preservation, or scenic value. Most sites (92 percent) are managed by local agreements; however, most of the land is under either Federal (53 percent) or state (44 percent) control (NOAA, 1988).

Private outdoor recreation sites are also numerous in the region, second only to the Middle Atlantic region in total numbers (NOAA, 1990d). The region contains almost one-third of the Nation's private charter boats and private campgrounds. Almost one-quarter of the Nation's marinas are found in the region. Because tourism is a growing industry in the Gulf, private outdoor recreation sites are likely to remain important, and the number of sites may increase in the future.

* * *

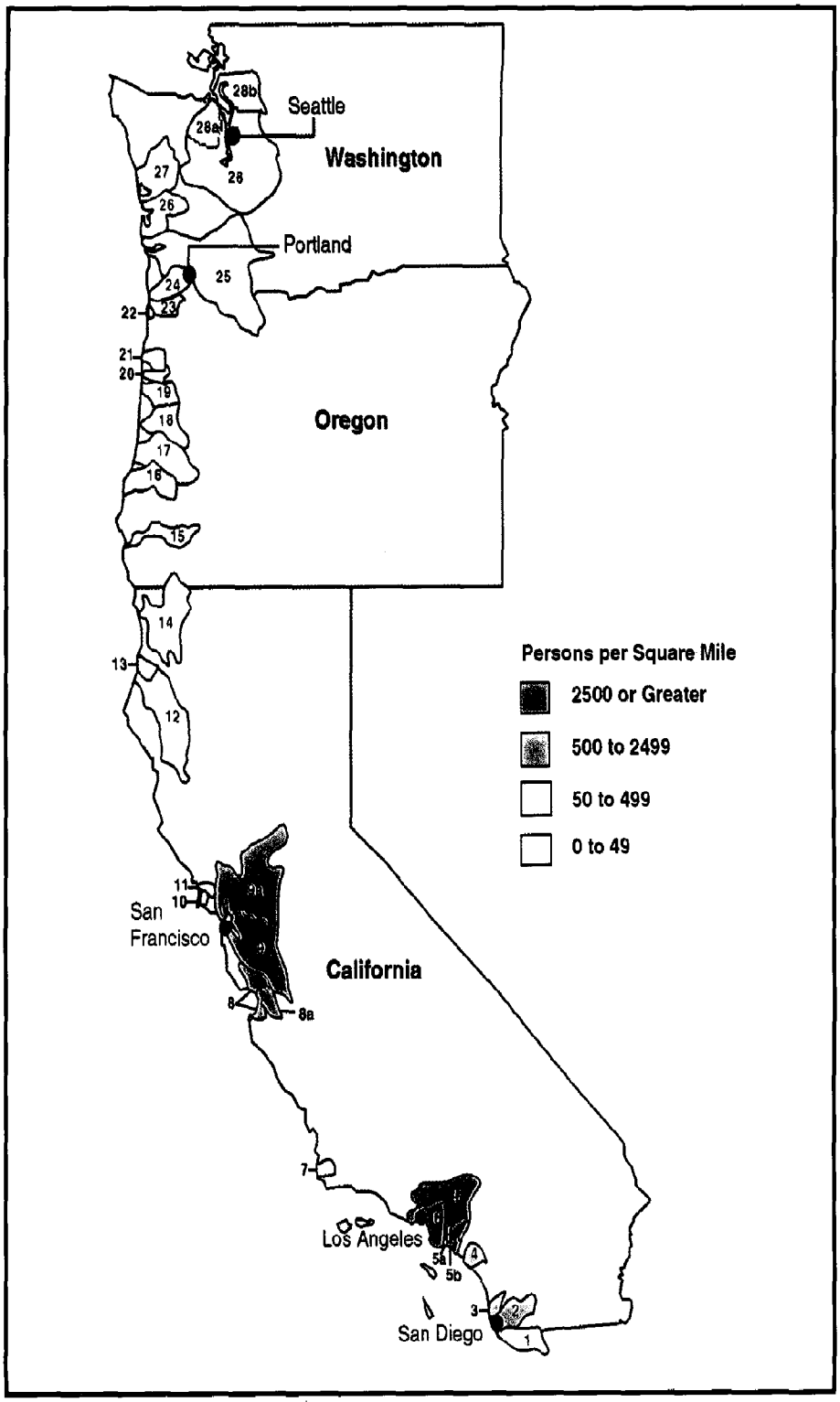
As of mid-1990, Sarasota Bay, Tampa Bay, Galveston Bay, and the Barataria/Terrebonne Estuarine Complex were included in EPA's National Estuary Program.

More detailed information on each estuary can be found in Appendix B. Maps showing the counties in each EDA are in Appendix C.

Wading birds, such as the egret, feed in the shallow waters of many Gulf estuaries.

Courtesy of NOAA

Figure 10. *Population Density in Pacific EDAs, 1980*



The Pacific region extends from Tijuana Estuary to Puget Sound. The 28 estuaries and six sub-estuaries shown in Figure 10 account for almost 38,000 square miles of estuarine drainage along the Pacific coast.

Pacific Estuaries

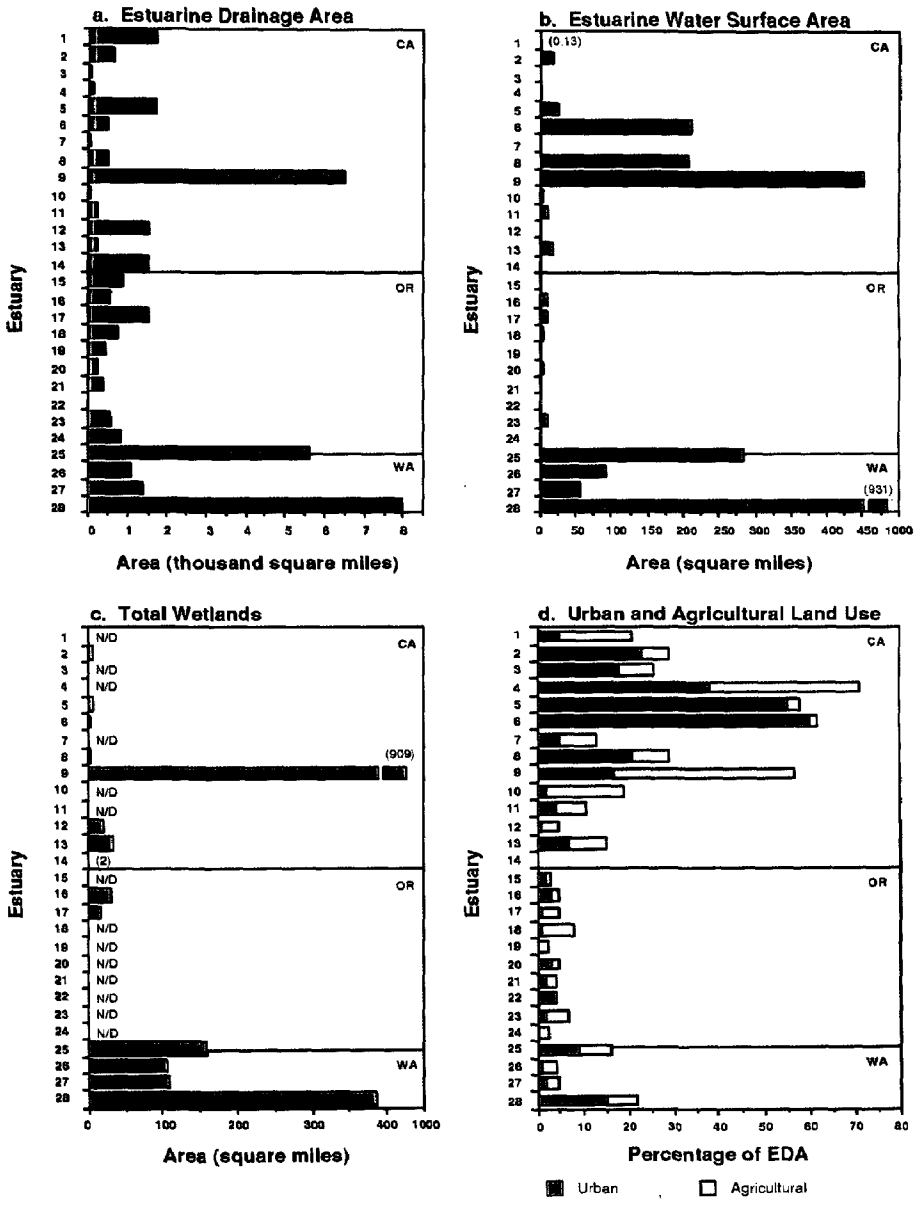
1 Tijuana Estuary
2 San Diego Bay
3 Mission Bay
4 Newport Bay
5 San Pedro Bay
5a Alamitos Bay
5b Anaheim Bay
6 Santa Monica Bay
7 Morro Bay
8 Monterey Bay
8a Elkhorn Slough
9 San Francisco Bay
9a Central San Francisco/ San Pablo/Suisun Bays
10 Drakes Estero
11 Tomales Bay
12 Eel River
13 Humboldt Bay
14 Klamath River
15 Rogue River
16 Coos Bay
17 Umpqua River
18 Siuslaw River
19 Alsea River
20 Yaquina Bay
21 Siletz Bay
22 Netarts Bay
23 Tillamook Bay
24 Nehalem River
25 Columbia River
26 Willapa Bay
27 Grays Harbor
28 Puget Sound
28a Hood Canal
28b Skagit Bay

Physical Features. The size and distribution of estuaries along the Pacific Coast are directly related to the region's geomorphology. The Pacific Coast is characterized by uniformly uplifted, resistant rock, except for coastal flats and islands along parts of the Washington coast. Coastal mountain formations have restricted the area of low-lying coastal plains and rivers that flow toward the sea. This has resulted in narrow, deep, and steep-sided estuaries. The large estuaries of San Francisco Bay and Puget Sound formed when sections of the continent containing former river valleys sank below sea level due to active mountain building. In Puget Sound, additional deepening and elongation occurred due to glacial activity.

Estuarine drainage areas (EDAs) in the region range from 14 square miles in Netarts Bay to about 8,000 square miles in Puget Sound (Figure 11a). Nineteen of the 28 estuaries in the region have EDAs coinciding with their fluvial drainage areas. The fluvial drainage areas for Puget Sound, Columbia River, and San Francisco Bay extend great distances inland. These three estuaries account for about 53 percent of the estuarine drainage along the Pacific coast.

Because of the geomorphology of the region, estuaries along the Pacific Coast generally have small water surface areas. Half of the region's estuaries have water surface areas less than or equal to five square miles (Figure 11b). Although Puget Sound contains over one-third of the estuarine water surface area in the region, it contains only one-quarter the water surface area of Chesapeake Bay.

Figure 11. *Selected Characteristics, Pacific Estuaries*



Notes: Sub-estuaries are not shown separately. All values are in Appendix B. N/D - no data.

Hydrologic Characteristics. Tides throughout the region are semidiurnal and range from about seven feet in Washington to less than four feet in Southern California. Circulation in large estuaries such as San Francisco Bay and Puget Sound tends to be dominated by tides, while circulation patterns in the smaller estuaries are directly effected by freshwater inflow. For example, estuaries such as Eel River and Humboldt Bay are influenced heavily by river discharge. During high-flow periods, these estuaries are composed almost entirely of freshwater. During low-flow periods, discharge is not sufficient to maintain a good connection with the ocean, and long-shore processes tend to cut off the entrances to these estuaries.

Because of the unique geomorphology of the Pacific region, characterized by deep submarine canyons (depths to 3,000 feet) in Southern California bays and shallow coastal estuaries in Oregon, the average depth and volume of the bays and estuaries vary considerably. Santa Monica Bay, Monterey Bay, and Puget Sound are among the deepest in the Nation, whereas Oregon estuaries are among the most shallow.

Although most estuaries along the Pacific coast are relatively small, freshwater inflow to them can be quite large. For example, the average daily freshwater discharge of the Columbia River is over 270,000 cubic feet per second, the second highest in the Nation behind the Mississippi River. Puget Sound, San Francisco Bay, and the Klamath River estuaries also receive some of the highest freshwater inflows in the Nation. The large freshwater inflows into the estuaries in the northern portion of the region are a function of the size of their drainage areas and the climate of the Pacific Northwest. Freshwater inflows are highest in estuaries north of San Francisco Bay, with peak inflows occurring from December through April. Runoff and freshwater inflow into Southern California estuaries are intermittent from May through October when the flow of some coastal streams disappears. Long-term precipitation is highly variable within the region, ranging from over 100 inches per year in northern Washington, to less than 16 inches in Southern California.

Wetlands. The estuarine drainage areas of the Pacific contain the least coastal wetlands (1,792 square miles) among regions (Reyer et al., 1990b). San Francisco Bay contains over half of all wetlands in this region (909 square miles) (Figure 11c), even though it is estimated to have lost almost 95 percent of its wetlands since the time of settlement (Josselyn, 1983). Wetlands in San Francisco Bay include extensive tidal flats and salt ponds along the southern shores of the Bay, tidal flats and salt marshes in San Pablo and Suisun bays, and vast areas of rice fields where the San Joaquin and Sacramento rivers empty into Suisun Bay. California has lost approximately 90 percent of its wetlands since being settled (Gosselink and Baumann, 1980).

Puget Sound contains the second largest amount of wetlands (387 square miles), almost half of which are tidal flats. The Columbia River EDA, third with 158 square miles, is comprised mostly of forested wetlands and

marshlands. Wetland loss in Pacific estuaries historically can be attributed to human activities such as agriculture, urbanization, and diking (Gosselink and Baumann, 1980). Because of diking by settlers and recent human pressures, 11 major deltas surveyed in Puget Sound lost about 30 square miles of wetlands from the late 1800s to 1980 (Bartleson et al., 1980).

Land Use. Although California is the most populous state in the U.S., urban land dominates only two relatively small drainage areas: San Pedro and Santa Monica bays. Other land uses, especially forest land, dominate the region's estuaries due to the large inland extent of their drainage areas. Forest land, for example, is the major land use in estuaries north of San Francisco Bay. The cool, moist climate of the Pacific Northwest has encouraged the growth of the most productive forest land in the Nation (NOAA, 1987). Puget Sound and Columbia River, the two largest EDAs, each have more than three-quarters of their land in this category. In San Francisco Bay, however, agricultural land dominates due to the inclusion of a large portion of the Central Valley along the Sacramento and San Joaquin rivers. Newport Bay also has a relatively large percentage of agricultural land use. The Pacific has the second highest percentage of urban land (12 percent) and the fourth highest percentage of agricultural land (11 percent) among the regions. Figure 11d shows the distribution of urban and agricultural land in the region.

Population. The region contains about one-quarter of the Nation's population residing in estuarine drainage areas, as well as the most densely populated estuaries in the Nation: San Pedro and Santa Monica bays. The estuarine drainage areas of both these estuaries are within the Los Angeles metropolitan area (Figure 10). *Although its drainage area is small, the population of San Pedro Bay (over six million in 1980) is greater than the total population of either the North or South Atlantic regions.* San Francisco Bay, another densely populated estuary, includes the cities of San Francisco, Oakland, Sacramento, and San Jose. Population densities decrease dramatically in Northern California, Oregon, and Washington, and are among the lowest in the Nation.

The population in the 62 counties with land in EDAs in California, Oregon, and Washington is expected to increase by about 22 percent over the next two decades (Culliton et al., 1990). Appendix C identifies counties falling entirely or partially in EDAs in the region.

Pollution Sources. There are almost 1,000 point sources of pollution in EDAs in the Pacific region, the second fewest among regions (NOAA, 1990e). Almost 70 percent of these sources are industrial facilities. Three-quarters of these industrial sources are concentrated in Puget Sound, Columbia River, San Francisco Bay, and San Pedro Bay. The largest industrial dischargers are concentrated in Columbia River and Puget Sound. Three of the region's five largest facilities are pulp and paper mills located along the Columbia River. These mills discharge at least 30 million gallons per day of process wastewater. Municipal wastewater treatment plants, including the region's largest, are concentrated in San Pedro, Santa Monica, and San Francisco bays, Columbia

River, and Puget Sound estuarine drainage areas. Puget Sound has the most point sources, followed by Columbia River.

In 1982, 1.5 million pounds of commonly used pesticides were applied to agricultural lands in the EDAs in the region. The distribution of pesticides was: herbicides (69 percent), insecticides (26 percent), and fungicides (5 percent). The Pacific region had a pesticide application of about 250 pounds per square mile of cropland in 1982, making it the region with the lowest average intensity of application. San Pedro Bay (612 pounds per square mile) and San Francisco Bay (346 pounds per square mile) were the EDAs with the highest application intensity in the region (Pait et al., 1989).

In 1982, the application of fertilizers to agricultural lands in estuarine drainage areas was the fourth highest among the five regions. Approximately 19,000 tons of phosphorus and 128,000 tons of nitrogen fertilizers were applied. San Francisco Bay, Monterey Bay, and Puget Sound received the highest applications. San Francisco Bay also contains a high percentage of agricultural lands. Excluding nutrients from upstream fluvial sources, fertilizer runoff from agricultural land is a significant nutrient source (i.e., greater than 25 percent of the total inputs of either phosphorus or nitrogen) only in Monterey Bay.

Fishery Resources. About 750 million pounds of seafood with an approximate ex-vessel value of 337 million dollars were landed at the region's ports in 1989 (NOAA, 1990f). Although only one-fifth of this harvest was from estuarine-dependent species, over half of the dollar value was associated with this catch. This was primarily due to the high price per pound of the anadromous Pacific salmon.

The estuaries and bays of the Pacific region support a wide diversity of fishes and invertebrates, including over 400 species of adult and juvenile fishes (NOAA, 1990f). The northern portion of the region provides stream and lake spawning habitats for many species, including salmon. The small but highly saline estuaries in the southern portion of the region support populations of ecologically important fishes, such as smelts and anchovies. The region's large marine bays are home to many species, including abundant populations of white croaker and kelp bass (Monaco et al., 1990).

The Pacific contains the least amount of shellfish-growing waters (about 455 square miles), two percent of the total for all regions. More than 70 percent of these growing waters are in harvest-limited status. Shellfish-growing water quality is affected most by industrial discharges, followed by urban runoff, sewage treatment plants, and agriculture. Over 80 percent of the region's approved waters are in Washington. Washington's clam and oyster industry leads the region and is concentrated in southern Puget Sound and Willapa Bay. Oregon's clam and oyster industry is centered in Tillamook, Yaquina, and Coos bays. Commercial shellfish harvest in California is based on aquaculture and occurs in only five estuaries (Leonard and Slaughter, 1990).

Recreation. There are over 6,500 public outdoor recreation sites accounting for almost 14,500 square miles in Pacific EDAs. Total public outdoor recreation land in Pacific EDAs is the largest among regions. About 43 percent of public recreation land is managed for hunting, while almost 37 percent has been set aside for conservation, preservation, or scenic value. Most sites (88 percent) are managed by local governments; however, most of the land is under either Federal (83 percent) or state (12 percent) control (NOAA, 1988). Of the 1,769 sites providing access to water, almost half were adjacent to water under tidal influence. The greatest concentration of sites is in San Francisco Bay, followed by San Pedro and Santa Monica bays, and Puget Sound. Large tracts of recreation land are found in Oregon and Washington EDAs.

Private outdoor recreation sites in the region exceed only the North Atlantic in number. However, the Pacific region does contains over one-quarter of the private campgrounds in all regions (NOAA, 1988). The large area of land under public ownership and the region's physical characteristics may account for the relatively small number of private recreation sites. California has the most privately-owned outdoor recreation sites in the region.

* * *

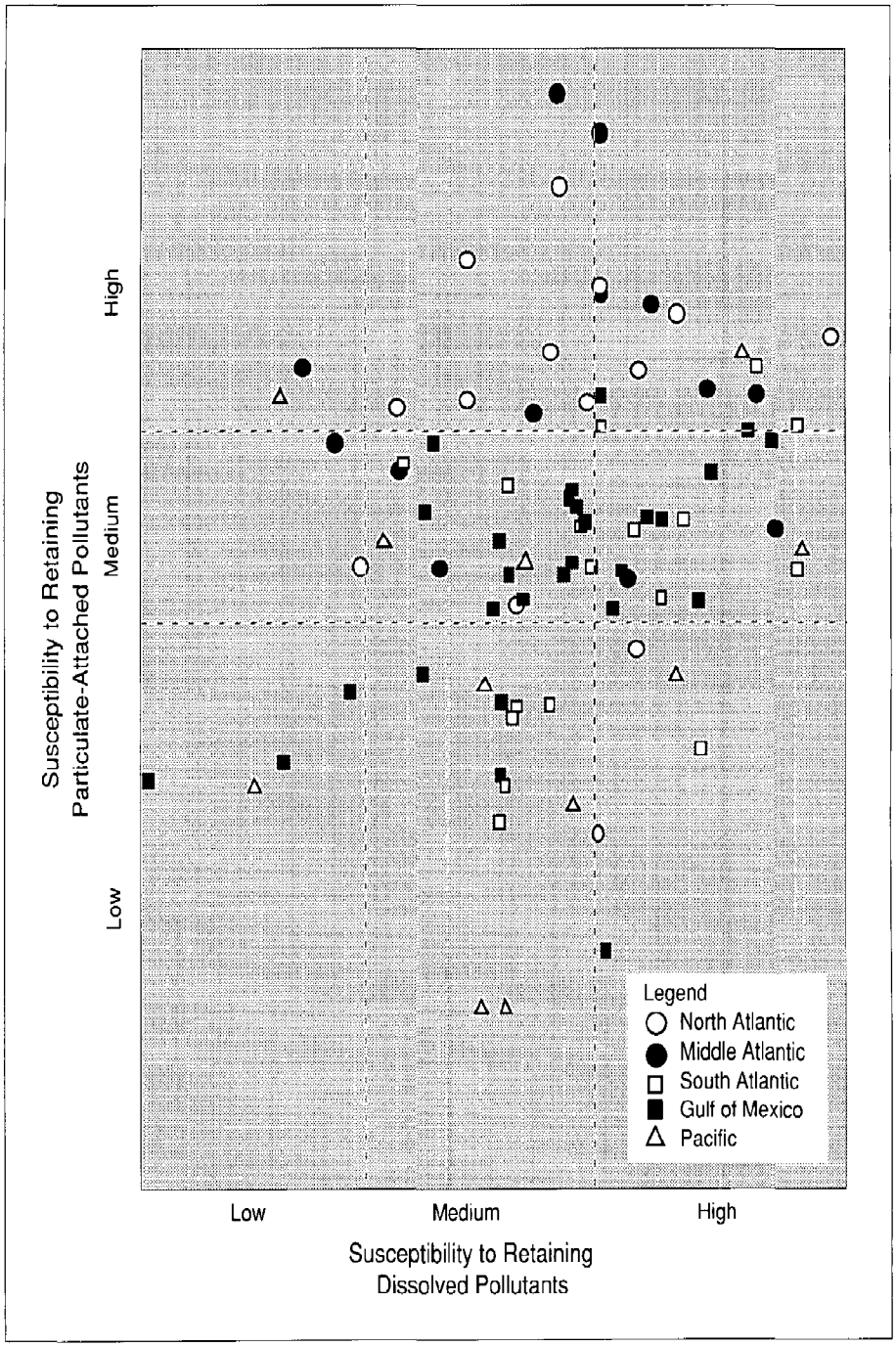
As of mid-1990, Puget Sound, San Francisco Bay, and Santa Monica Bay were included in EPA's National Estuary Program.

More detailed information on each estuary can be found in Appendix B. Maps showing the counties in each EDA are in Appendix C.

Puget Sound, an estuary formed by tectonic and glacial processes, is typical of the mountainous terrain of north pacific coast estuaries.

Courtesy of J. J. McDonough III, NOAA

Figure 12. *Relative Susceptibility Index for the Nation's Estuaries*



One measure of the susceptibility of an estuary to pollution is its ability to flush and/or dilute pollutants. The index shown takes into account the physical characteristics of an estuary (including volume, freshwater inflow, and tidal exchange) to approximate the extent to which an estuary may retain pollutants relative to other estuaries. Properly used, such indices help provide a "yardstick" against which nationwide policies affecting pollution entering estuaries can be assessed. Appendix B shows the relative susceptibility levels of each estuary.

Susceptibility of Estuaries to Pollutant Effects

One measure of an estuary's susceptibility to pollution is its ability to flush and/or dilute pollutants. Pollutants may enter an estuary either in dissolved form or attached to suspended particles in water, such as silt or clay. In general, the lower an estuary's flushing rate to the open ocean and the smaller its volume for diluting pollutants, the greater is its susceptibility to retain dissolved pollutants.

Some portion of the pollutants adsorbed onto suspended particles entering an estuary settle and become incorporated into its bottom sediments. These sediments and their attached pollutants accumulate according to the rate at which water travels through an estuary. The greater the water residence time, the greater the retention of these particles and the higher the potential for them to affect bottom-dwelling organisms and habitats.

NOAA has developed a relative classification index to approximate the ability of an estuary to retain dissolved and particulate-attached pollutants. The index is based on the "basic" physical and hydrologic characteristics of each estuary (NOAA, 1985). Figure 12 presents a relative rating scale of high, medium, or low. The ratings represent ten-fold incremental changes in the susceptibility of an estuary to retain either dissolved or sediment-attached pollutants. A high rating on either axis indicates an estuary having relatively high sensitivity to a reduction or increase in pollutant input.

Based on this index, estuaries in the North and Middle Atlantic regions exhibit the highest sensitivities to both dissolved and particulate-attached pollutants. In the North Atlantic, this is primarily due to the relatively sluggish nature of its tidally-flushed estuaries. Freshwater inflows play a minor role in estuarine circulation in this region. Muscongus and Narraguagus bays are examples of tidally-flushed estuaries in the region. By contrast, the high sensitivities of many Middle Atlantic estuaries are due to limited flushing caused primarily by narrow inlets that restrict exchange with the open ocean. These narrow inlets are a feature of lagoonal bar-built estuaries, such as Chincoteague and Barnegat bays.

Lower sensitivities are generally exhibited by estuaries throughout the South Atlantic and Gulf of Mexico, except in the lagoonal bar-built estuaries of Texas, e.g., Corpus Christi Bay, Laguna Madre, and San Antonio Bay. In the estuaries with low sensitivities, freshwater inflow to volume ratios are high. Consequently, freshwater inflow significantly affects circulation and flushing in these systems.

Pollution-retention sensitivity varies greatly in the Pacific region because of the many types of estuaries (river dominated, coastal bays, and fjords) found in the region. For example, Columbia River, a river-dominated system, has a low sensitivity while San Pedro Bay, a coastal bay, has a high sensitivity rating.

The index has been used with estimates of nitrogen and phosphorus loadings from NOAA's National Coastal Pollutant Discharge Inventory to identify estuaries that may be most sensitive to changes

in nutrient inputs (NOAA and EPA 1989a, 1989b, 1989c). Used in this way, the index helps provide a basis for determining which estuaries may be experiencing nutrient enrichment problems, and an indication of the extent to which reductions in nutrient inputs may affect an estuary. The index will be evaluated further in the coming year as part of a nationwide survey of nutrient enrichment in estuaries, sponsored jointly by NOAA and EPA.

Summary

This report shows that the Nation's estuaries are an important "national resource base," especially in terms of fish and shellfish, habitat and wildlife, and recreational values. It also shows that estuaries have been asked to meet many societal demands, directly or indirectly. Throughout our history, by developing shorelines, draining wetlands, dredging channels, and dumping pollutants, we have taken far more from our estuaries than we have given back. Like humans, some estuaries can respond to these demands; others cannot withstand the stress without developing symptoms of poor health. Each estuary is unique, described by its own set of vital statistics that define its natural processes and the level and impact of human uses.

If, as a Nation, we expect to sustain the health of this important resource, actions are needed for responsible stewardship, including continued monitoring and periodic examinations, planning preventative actions, and taking remedial or restorative actions where possible. *An important and fundamental step is to develop and maintain accurate and up-to-date information about the Nation's estuaries for use as a basis for setting national policy and program priorities.*

The information in this report and other efforts by NOAA are beginning to provide this valuable service. With this information, we have a factual basis for comparing estuaries, placing them in a regional or national context, assessing their condition, and approaching management of the Nation's estuaries on a comprehensive rather than a case-by-case basis.

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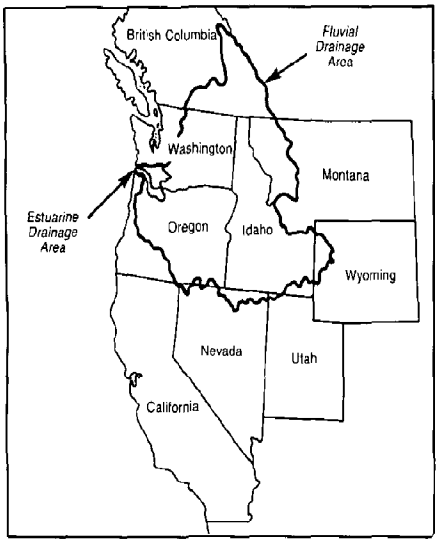
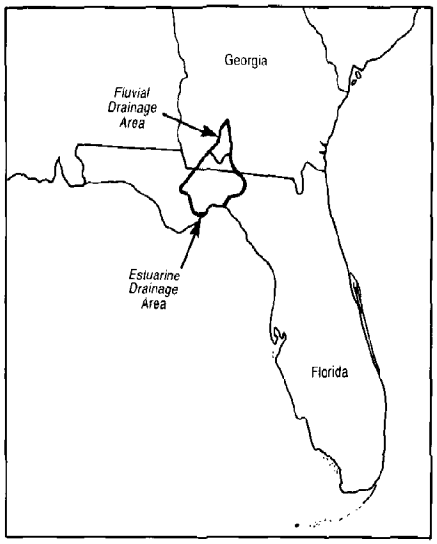
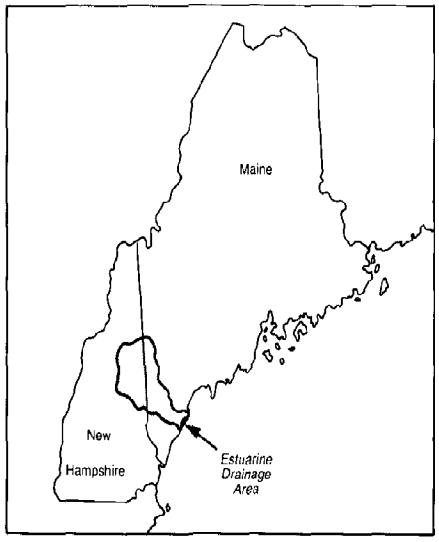
Columbia River:
Small Estuarine Drainage Area
Large Fluvial Drainage Area



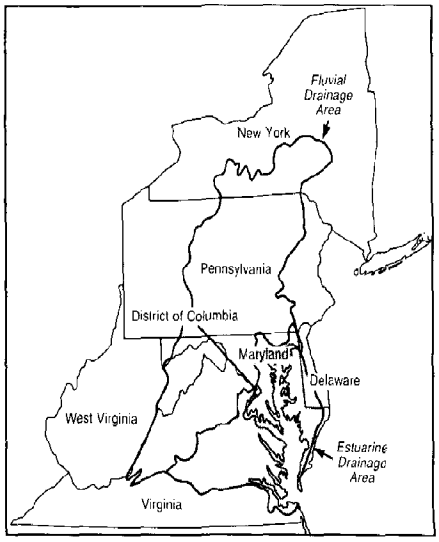
Apalachee Bay:
Large Estuarine Drainage Area
Small Fluvial Drainage Area



Saco Bay:
No Fluvial Drainage Area



Chesapeake Bay:
Large Estuarine Drainage Area
Large Fluvial Drainage Area



			PHYSICAL and HYDROLOGIC FEATURES							NATURAL RESOURCES			ECONOMIC ACTIVITIES					Susceptibility to Pollution	
											Classified Shellfish Waters (sq. mi.)			Land Use (% of EDA)		Point Sources[b] of Pollution			
Map ID#	NOAA Code	ESTUARY	Estuarine Drainage Area (100 sq. mi.)	Total Drainage Area (100 sq. mi.)	Water Surface Area (sq. mi.)	Average Depth (ft.)	Avg. Daily Freshwater Inflow (100 cfs)	Volume (billion cu. ft.)	Wetlands (sq. mi.)[a]	Approved	Total	Population Density, 1980 (per sq. mi.)	Urban	Agriculture	Industrial	MWTP	Dissolved Con. Potential	Particle Retention Efficiency
		NORTH ATLANTIC																
1	N010	Passamaquoddy Bay	32	32	157	72	62	315	238	52	62	11	1	4	8	5	M	H
2	N020	Englishman Bay	9	9	76	38	16	80	178	88	93	12	2	4	9	4	M	H
3	N030	Narraguagus Bay	4	4	70	32	9	63	89	87	89	17	1	6	2	1	H	H
4	N040	Blue Hill Bay	8	8	115	75	13	241	90	111	117	28	4	1	15	8	H	H
5	N050	Penobscot Bay	32	94	361	72	161	725	153	309	362	58	4	6	29	16	M	H
6	*N060*	*Muscongus Bay*	3	3	72	43	6	85	14	66	72	67	4	9	1	7	H	H
7	N070	Sheepscot Bay	62	101	103	41	176	118	49	56	99	66	3	10	8	12	L	M
8	N080	Casco Bay[c]	12	12	164	42	21	191	61	144	168	172	14	10	40	10	M	H
9	N090	Saco Bay	18	18	17	32	36	15	78	15	20	71	4	4	8	9	M	M
10	N100	Great Bay	10	10	15	11	20	5	80	6	20	243	10	11	29	30	H	L
11	N110	Merrimack River	23	50	6	12	84	2	96	0	4	423	13	7	29	7	H	L
12	N120	Massachusetts Bay[c]	12	12	364	77	29	786	N/D	7	40	2,228	45	3	56	16	M	H
12a	*N120a*	*Boston Bay*[d]	*7*	*7*	*69*	*26*	*18*	*50*	*69*	*0*	*24*	*2,789*	*53*	*2*	*55*	*14*	*H*	*M*
13	*N130*	*Cape Cod Bay*[c]	8	8	548	77	18	1,178	72	72	77	392	24	1	4	4	M	H
		Total	**233**	**361**	**2,068**	**48**	**651**	**3,804**	**1,198**	**1,013**	**1,223**	**211**	**7**	**7**	**238**	**129**	-	-
		MIDDLE ATLANTIC																
1	M010	Buzzards Bay[c]	6	6	228	34	12	215	75	184	199	780	13	6	7	5	H	H
2	M020	Narragansett Bay[c]	13	18	165	30	32	139	155	110	165	1,065	26	9	113	24	M	H
3	M030	Gardiners Bay	4	4	197	20	7	111	22	194	198	227	26	17	5	3	H	H
4	M040	Long Island Sound[c]	72	172	1,281	62	300	2,192	315	1,122	1,342	1,008	25	14	226	87	L	H
4a	*M040a*	*Connecticut River*	*11*	*111*	*20*	*13*	*210*	*7*	*57*	*0*	*8*	*744*	*26*	*13*	*13*	*5*	*H*	*M*
5	M050	Great South Bay	8	8	151	9	7	37	70	118	160	2,583	69	7	49	23	H	H
6	M060	Hudson River/Raritan Bay[c]	85	165	298	21	267	172	269	0	257	1,471	24	25	582	287	M	M
7	M070	Barnegat Bay	14	14	102	5	23	13	384	98	130	343	14	9	24	28	H	M
8	M080	New Jersey Inland Bays	7	7	110	9	11	26	N/D	28	64	415	12	5	18	16	H	M
9	M090	Delaware Bay[c]	48	135	768	21	198	448	641	549	623	1,082	24	42	181	153	M	M

10	M100	Delaware Inland Bays[c]	3	3	32	4	3	4	N/D	19	30	126	10	46	9	7	H	M
11	M110	Chincoteague Bay	3	3	137	6	4	23	58	154	156	46	7	32	21	16	H	H
12	M120	Chesapeake Bay	220	693	3,830	24	858	2,510	1,557	3,715	4,043	404	13	33	540	275	L	M
12a	*M120a*	*Patuxent River*	*9*	*9*	*47*	*19*	*9*	*25*	*N/D*	*N/D*	*N/D*	*446*	*16*	*20*	*6*	*12*	*H*	*M*
12b	*M120b*	*Potomac River*	*31*	*146*	*494*	*19*	*159*	*266*	*N/D*	*395*	*407*	*942*	*26*	*24*	*59*	*58*	*H*	*M*
12c	*M120c*	*Rappahannock River*	*12*	*27*	*145*	*16*	*29*	*66*	*N/D*	*111*	*117*	*75*	*4*	*29*	*46*	*12*	*H*	*M*
12d	*M120d*	*York River*	*26*	*26*	*74*	*16*	*25*	*32*	*N/D*	*51*	*60*	*56*	*4*	*25*	*9*	*22*	*H*	*M*
12e	*M120e*	*James River*	*44*	*102*	*236*	*14*	*125*	*90*	*N/D*	*71*	*238*	*399*	*12*	*24*	*126*	*63*	*H*	*M*
12f	*M120f*	*Chester River*	*5*	*5*	*57*	*14*	*5*	*22*	*N/D*	*N/D*	*N/D*	*76*	*3*	*40*	*13*	*11*	*H*	*H*
12g	*M120g*	*Choptank River*	*9*	*9*	*110*	*13*	*10*	*40*	*N/D*	*N/D*	*N/D*	*84*	*5*	*52*	*24*	*13*	*H*	*H*
12h	*M120h*	*Tangier/Pocomoke Sounds*	*26*	*26*	*459*	*13*	*29*	*160*	*N/D*	*N/D*	*N/D*	*78*	*7*	*26*	*47*	*22*	*H*	*H*
		Total	**483**	**1,228**	**7,299**	**20**	**1,722**	**5,890**	**3,546**	**6,291**	**7,367**	**822**	**19**	**27**	**1,775**	**924**	-	-
		SOUTH ATLANTIC																
1	S010	Albemarle/Pamlico Sounds[c]	116	296	2,949	13	460	1,081	1,768	2,524	3,088	182	9	59	103	84	M	M
1a	*S010a*	*Pamlico/Pungo Rivers*	*21*	*43*	*166*	*9*	*46*	*44*	*N/D*	*82*	*177*	*72*	*4*	*39*	*21*	*4*	*H*	*M*
1b	*S010b*	*Neuse River*	*22*	*56*	*173*	*12*	*62*	*55*	*N/D*	*117*	*177*	*110*	*5*	*29*	*20*	*19*	*H*	*M*
2	S020	Bogue Sound	7	7	102	5	13	13	149	66	118	70	8	12	24	11	H	M
3	S030	New River	5	5	32	6	8	5	39	0	36	219	11	14	19	29	H	M
4	S040	Cape Fear River	43	91	38	11	101	12	234	0	42	64	3	25	45	22	M	L
5	S050	Winyah Bay	95	181	30	11	204	9	923	1	30	72	3	34	31	30	M	L
6	S060	N. Santee/S. Santee Rivers	7	153	9	8	27	2	310	0	38	21	1	12	4	69	M	L
7	S070	Charleston Harbor	12	158	37	18	161	19	299	4	10	206	8	11	42	0	H	L
8	S080	St. Helena Sound	15	48	85	13	46	31	672	80	81	34	2	22	3	14	M	M
9	S090	Broad River	10	10	100	24	9	67	330	111	125	96	5	31	6	15	H	H
10	S100	Savannah River	9	104	33	15	128	14	453	7	27	67	3	22	34	14	M	L
11	S110	Ossabaw Sound	15	47	33	14	30	13	402	12	34	77	4	33	4	4	H	M
12	S120	St. Catherines/Sapelo Sounds	10	10	75	14	8	30	136	119	178	22	4	1	5	4	H	H
13	S130	Altamaha River	15	142	15	10	149	4	178	0	4	30	1	18	0	0	M	L
14	S140	St. Andrew/St. Simons Sounds	33	40	72	14	25	29	902	68	127	49	2	21	12	4	H	M
15	S150	St. Marys River/Cumberland Sd	70	70	26	20	82	15	N/D	N/D	N/D	9	<1	1	9	8	H	L
16	S160	St. Johns River[e]	65	94	258	12	78	86	1,638	N/D	N/D	212	8	18	69	304	M	M
17	S170	Indian River[c,e]	12	12	280	7	14	51	161	34	106	327	17	30	14	54	H	H
18	S180	Biscayne Bay[e,i]	15	15	269	8	32	58	589	N/D	N/D	1,030	21	24	18	103	M	M
		Total	**554**	**1,483**	**4,443**	**12**	**1,575**	**1,539**	**9,183**	**3,026**	**4,044**	**104**	**4**	**22**	**442**	**769**	-	-

Abbreviations: sq. mi., square miles; ft., feet; avg., average; cfs, cubic feet per second; cu. ft., cubic feet; EDA, estuarine drainage area; MWTP, municipal wastewater treatment plant; con., concentration; H, high; M, medium; L, low; N/D, no data.

			PHYSICAL and HYDROLOGIC FEATURES							NATURAL RESOURCES		ECONOMIC ACTIVITIES					Susceptibility to Pollution	
											Classified Shellfish Waters (sq. mi.)			Land Use (% of EDA)		Point Sources [b] of Pollution		
Map ID#	NOAA Code	ESTUARY	Estuarine Drainage Area (100 sq. mi.)	Total Drainage Area (100 sq. mi.)	Water Surface Area (sq. mi.)	Average Depth (ft.)	Avg. Daily Freshwater Inflow (100 cfs)	Volume (billion cu. ft.)	Wetlands (sq. mi.) [a]	Approved	Total	Population Density, 1980 (per sq. mi.)	Urban	Agriculture	Industrial	MWTP	Dissolved Con. Potential	Particle Retention Efficiency
		GULF OF MEXICO																
1	G010	Florida Bay	11	11	538	8	N/D	110	N/D	N/D	N/D	17	14	30	0	3	-	-
2	G020	South Ten Thousand Islands [f,i]	13	13	77	7	N/D	14	3,383	43	70	29	2	9	0	0	-	-
3	G030	North Ten Thousand Islands [f,i]	9	21	192	6	N/D	31	-	-	-	3	9	22	0	3	-	-
4	G040	Rookery Bay	2	2	14	5	N/D	2	N/D	N/D	N/D	31	2	8	0	1	-	-
5	G050	Charlotte Harbor	50	50	311	8	48	73	975	86	176	105	5	36	56	22	M	M
5a	*G050a*	*Caloosahatchee River*	*14*	*14*	*26*	*5*	*19*	*3*	*N/D*	*0*	*5*	*127*	*4*	*29*	*10*	*6*	*H*	*L*
6	G060	Sarasota Bay [c]	3	3	44	6	4	8	N/D	N/D	N/D	923	28	26	6	11	H	M
7	G070	Tampa Bay [c]	26	26	346	13	24	123	394	9	88	476	17	40	69	29	H	H
8	G080	Suwannee River	19	102	42	5	112	6	358	10	26	24	1	33	3	3	M	L
9	G090	Apalachee Bay	37	46	159	10	53	45	1,087	0	33	64	3	17	21	5	M	M
10	G100	Apalachicola Bay	30	205	214	9	291	54	924	1	175	15	2	7	3	4	M	L
11	G110	St. Andrew Bay [i]	11	11	94	12	45	31	392	0	100	65	5	3	12	7	M	M
12	G120	Choctawhatchee Bay	23	54	129	14	85	51	438	0	97	42	4	24	3	8	M	M
13	G130	Pensacola Bay	35	70	143	13	116	51	382	0	147	72	5	21	6	6	M	M
14	G140	Perdido Bay	12	12	50	7	22	10	266	0	0	121	7	26	6	12	H	M
15	G150	Mobile Bay	49	446	409	10	793	113	1,023	0	407	85	3	12	101	41	L	L
16	G160	Mississippi Sound [g]	121	269	1,850	11	436	568	1,670	413	1,857	125	6	23	197	173	M	M
16a	*G160a*	*Lake Borgne*	*79*	*148*	*282*	*9*	*251*	*74*	*N/D*	*293*	*391*	*134*	*9*	*26*	*1*	*119*	*H*	*L*
16b	*G160b*	*Lake Pontchartrain*	*55*	*55*	*710*	*11*	*107*	*220*	*N/D*	*0*	*710*	*122*	*7*	*27*	*1*	*116*	*H*	*M*
17	G170	Breton/Chandeleur Sounds [h]	25	25	2,086	8	103	420	532	1,534	1,592	384	3	1	1	9	M	H
18	G180	Mississippi River [h,i]	19	11,317	600	26	4,644	386	251	0	0	326	4	19	11	16	L	L
19	G190	Barataria Bay [c,h]	22	22	646	5	55	90	897	158	199	203	6	17	1	21	H	M
20	G200	Terrebonne/Timbalier Bays [c,h]	16	16	680	6	46	110	561	465	583	67	3	13	0	30	M	M
21	G210	Atchafalaya/Vermilion Bays [i]	72	1,006	703	7	2,238	137	721	20	718	76	3	34	7	71	L	L
22	G220	Calcasieu Lake	11	43	99	9	63	26	191	39	88	117	6	38	1	8	H	M
23	G230	Sabine Lake	48	209	94	8	172	21	615	0	0	92	5	14	164	56	M	L
24	G240	Galveston Bay [c,i]	45	245	540	6	152	92	374	0	547	665	16	50	747	566	M	M

25	G250	Brazos River [f]	28	468	2	8	74	<1	31	0	2	57	5	71	40	49	H	L
26	G260	Matagorda Bay [i]	59	503	422	7	53	78	134	0	375	26	2	58	113	46	M	M
27	G270	San Antonio Bay	5	109	205	4	41	25	105	0	238	10	3	16	17	2	H	M
28	G280	Aransas Bay	28	28	208	5	10	31	152	99	212	33	4	34	104	16	H	M
29	G290	Corpus Christi Bay	20	176	192	8	12	42	46	171	225	152	5	47	183	21	H	H
30	G300	Upper Laguna Madre [j]	55	55	216	3	6	15	704	794	848	84	2	23	50	13	-	H
30a	*G300a*	*Baffin Bay*	*35*	*35*	*92*	*4*	*4*	*11*	*N/D*	*74*	*93*	*27*	*1*	*31*	*18*	*7*	*H*	*M*
31	G310	Lower Laguna Madre [j]	58	58	366	3	3	26	N/D	N/D	N/D	19	4	42	79	41	-	H
		Total	**962**	**15,621**	**11,671**	**8**	**9,701**	**2,789**	**16,606**	**3,842**	**8,803**	**122**	**5**	**30**	**2,000**	**1,293**	-	-
		PACIFIC																
1	P010	Tijuana Estuary [k]	17	17	<1	1	<1	<1	N/D	N/D	N/D	37	5	16	0	0	-	L
2	P020	San Diego Bay [l]	5	8	17	22	1	11	6	0	0	955	21	5	14	3	M	H
3	P030	Mission Bay	1	1	3	8	<1	1	N/D	N/D	N/D	1,154	18	8	1	0	-	H
4	P040	Newport Bay	2	2	2	8	<1	<1	N/D	N/D	N/D	1,662	38	33	2	2	H	M
5	P050	San Pedro Bay	17	17	25	39	3	27	7	0	0	3,677	55	3	110	18	H	H
5a	*P050a*	*Alamitos Bay*	<1	<1	1	13	<1	<1	*N/D*	*N/D*	*N/D*	*2,483*	*34*	*3*	*1*	*0*	*H*	*H*
5b	*P050b*	*Anaheim Bay*	*1*	*1*	*1*	*16*	*<1*	*<1*	*N/D*	*N/D*	*N/D*	*6,593*	*90*	*7*	*1*	*1*	-	*H*
6	P060	Santa Monica Bay [c]	5	5	211	314	9	1,844	4	0	0	4,086	60	2	*6*	*4*	M	H
7	P070	Morro Bay	1	1	3	3	<1	<1	N/D	0	0	163	5	8	1	1	H	M
8	P080	Monterey Bay	5	60	209	255	12	1,485	5	0	1	572	21	18	10	8	H	H
8a	*P080a*	*Elkhorn Slough*	*2*	*2*	*1*	*8*	*1*	*<1*	*N/D*	*0*	*0*	*395*	*15*	*37*	*6*	*2*	-	*L*
9	P090	San Francisco Bay [c]	65	441	452	21	324	261	909	0	125	802	17	40	112	53	M	M
9a	*P090a*	*Central San Francisco/ San Pablo/Suisun Bays* [l]	*46*	*422*	*264*	*21*	*46*	*151*	*N/D*	*N/D*	*N/D*	*519*	*10*	*46*	*66*	*34*	-	*H*
10	P100	Drakes Estero	<1	<1	4	3	<1	<1	N/D	3	4	68	2	17	0	0	-	M
11	P110	Tomales Bay	2	2	11	6	3	2	N/D	0	10	70	4	7	0	0	H	M
12	P120	Eel River	15	36	2	5	97	<1	20	0	0	14	1	4	8	4	M	L
13	P130	Humboldt Bay	2	2	19	11	7	6	33	0	26	272	7	8	9	7	H	M
14	P140	Klamath River	15	155	1	23	206	1	2	0	0	3	<1	<1	0	1	M	L
15	P150	Rogue River	9	51	1	5	106	<1	N/D	N/D	N/D	17	2	1	1	1	M	L
16	P160	Coos Bay	6	6	13	14	29	5	30	5	17	51	3	2	14	3	H	L
17	P170	Umpqua River [l]	15	46	10	13	93	4	16	5	9	17	1	4	13	7	M	L
18	P180	Siuslaw River	8	8	4	9	30	1	N/D	0	2	14	1	7	6	5	H	L
19	P190	Alsea River	5	5	3	7	23	<1	N/D	0	0	4	<1	2	1	1	H	L
20	P200	Yaquina Bay	3	3	5	10	10	1	N/D	3	6	46	3	2	12	3	H	L

Abbreviations: sq. mi., square miles; ft., feet; avg., average; cfs, cubic feet per second; cu. ft., cubic feet; EDA, estuarine drainage area; MWTP, municipal wastewater treatment plant; con., concentration; H, high; M, medium; L, low; N/D, no data.

Map ID#	NOAA Code	ESTUARY	PHYSICAL and HYDROLOGIC FEATURES: Estuarine Drainage Area (100 sq. mi.)	Total Drainage Area (100 sq. mi.)	Water Surface Area (sq. mi.)	Average Depth (ft.)	Avg. Daily Freshwater Inflow (100 cfs)	Volume (billion cu. ft.)	NATURAL RESOURCES: Wetlands (sq. mi.) [a]	Classified Shellfish Waters (sq. mi.): Approved	Classified Shellfish Waters (sq. mi.): Total	ECONOMIC ACTIVITIES: Population Density, 1980 (per sq. mi.)	Land Use (% of EDA): Urban	Land Use (% of EDA): Agriculture	Point Sources [b] of Pollution: Industrial	Point Sources [b] of Pollution: MWTP	Susceptibility to Pollution: Dissolved Con. Potential	Susceptibility to Pollution: Particle Retention Efficiency
21	P210	Siletz Bay	4	4	2	8	28	<1	N/D	1	2	35	2	2	1	4	H	L
22	P220	Netarts Bay	<1	<1	2	5	1	<1	N/D	4	4	16	4	<1	0	1	H	M
23	P230	Tillamook Bay	6	6	11	6	39	2	N/D	0	14	23	2	5	11	3	H	L
24	P240	Nehalem River	9	9	2	7	34	<1	N/D	3	3	6	<1	2	2	1	H	L
25	P250	Columbia River	56	2,577	284	16	2,725	124	158	0	0	189	9	7	126	68	L	L
26	P260	Willapa Bay	11	11	92	16	59	42	105	43	47	17	1	3	18	2	M	M
27	P270	Grays Harbor	14	27	58	13	135	21	110	0	94	45	2	3	28	7	M	L
28	P280	Puget Sound [c,i]	80	123	931	201	511	5,218	387	54	91	345	15	7	218	58	L	H
28a	*P280a*	*Hood Canal*	*12*	*12*	*146*	*230*	*65*	*936*	*N/D*	*13*	*13*	*26*	*4*	*1*	*5*	*1*	*H*	*M*
28b	*P280b*	*Skagit Bay*	*19*	*62*	*215*	*154*	*366*	*926*	*N/D*	*27*	*37*	*124*	*8*	*8*	*15*	*13*	*H*	*M*
		Total	**379**	**3,624**	**2,377**	**37**	**4,487**	**9,061**	**1,792**	**121**	**455**	**529**	**12**	**11**	**724**	**265**	-	-
		National Total	**2,611**	**22,317**	**27,858**	**23**	**18,136**	**23,083**	**32,325**	**14,293**	**21,892**	**309**	**9**	**23**	**5,179**	**3,380**		

Abbreviations: sq. mi., square miles; ft., feet; avg., average; cfs, cubic feet per second; cu. ft., cubic feet; EDA, estuarine drainage area; MWTP, municipal wastewater treatment plant; con., concentration; H, high; M, medium; L, low; N/D, no data.

Table Notes

a. Wetlands data (except Mississippi River) are based on estuary definitions in Volume 1 of the National Estuarine Inventory (NEI) .

b. Based on 1982-1987 data, may not represent current conditions.

c. Estuary included in the EPA National Estuarine Program. EPA boundaries may not correspond with NOAA boundaries.

d. Boston Bay was listed as an estuary in Volume 1 of the NEI. It is now a sub-estuary of Massachusetts Bay.

e. Freshwater inflow data are preliminary.

f. Listed as Ten Thousand Islands in Volume 1 of the NEI. Data for these estuaries are preliminary.

g. Lake Pontchartrain drains into Lake Borgne and is included in the Lake Borgne sub-estuary. Mississippi Sound total does not double-count Lake Pontchartrain.

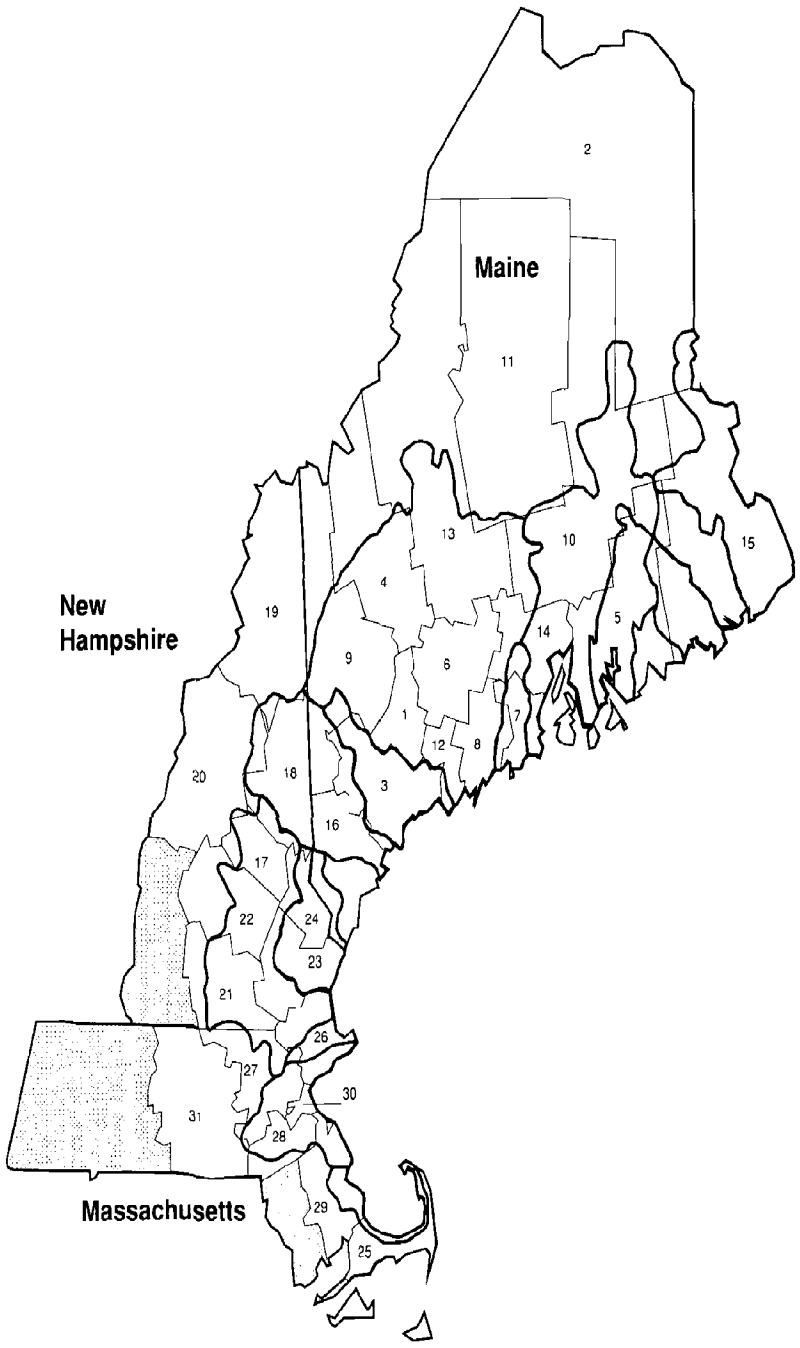
h. Listed as Mississippi Delta in Volume 1 of the NEI.

i. The area of this EDA has been revised since Volume 1 of the NEI.

j. Listed as Laguna Madre in Volume 1 of the NEI. Baffin Bay, a sub-estuary of Upper Laguna Madre, has not changed.

k. Population density and land use data are for the U.S. portion only.

l. Listed as Winchester Bay in Volume 1 of the NEI.


Maine
New Hampshire
Massachusetts
2
11
13
10
15
4
19
5
14
9
6
1
7
12
8
20
18
3
16
17
22
24
23
21
26
27
30
31
28
29
25

North Atlantic Counties*

Maine

1 Androscoggin
2 Aroostook
3 Cumberland
4 Franklin
5 Hancock
6 Kennebec
7 Knox
8 Lincoln
9 Oxford
10 Penobscot
11 Piscataquis
12 Sagadahoc
13 Somerset
14 Waldo
15 Washington
16 York

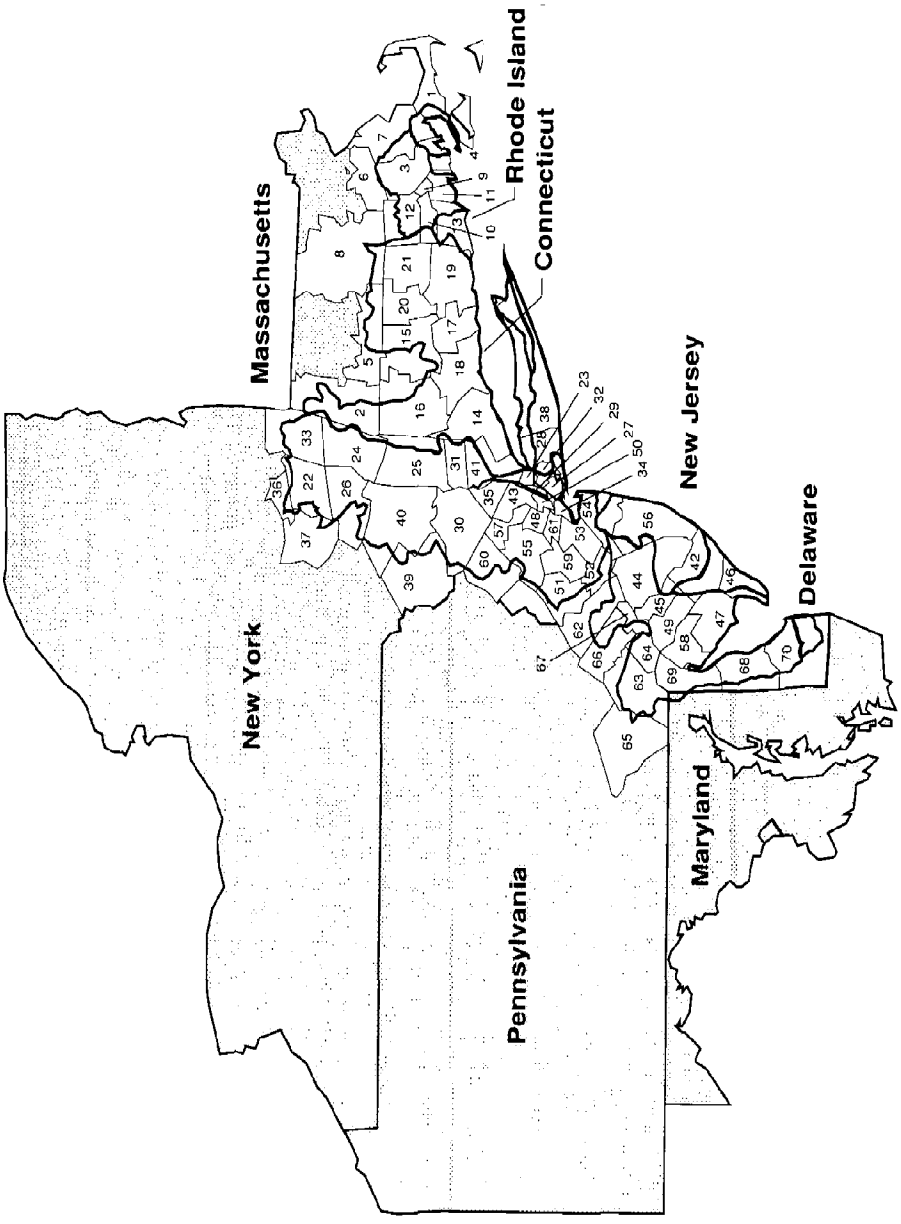
New Hampshire

17 Belknap
18 Carroll
19 Coos
20 Grafton
21 Hillsborough
22 Merrimack
23 Rockingham
24 Strafford

Massachusetts

25 Barnstable
26 Essex
27 Middlesex
28 Norfolk
29 Plymouth
30 Suffolk
31 Worcester

*Counties completely or partially in EDAs.


Massachusetts
Rhode Island
Connecticut
New Jersey
New York
Pennsylvania
Maryland
Delaware

Middle Atlantic Counties (Northern)*

Massachusetts

1 Barnstable
2 Berkshire
3 Bristol
4 Dukes
5 Hampden
6 Norfolk
7 Plymouth
8 Worcester

Rhode Island

9 Bristol
10 Kent
11 Newport
12 Providence
13 Washington

Connecticut

14 Fairfield
15 Hartford
16 Litchfield
17 Middlesex
18 New Haven
19 New London
20 Tolland
21 Windham

New York

22 Albany
23 Bronx
24 Columbia
25 Dutchess
26 Greene
27 Kings
28 Nassau
29 New York
30 Orange
31 Putnam
32 Queens
33 Rensselaer
34 Richmond
35 Rockland
36 Schenectady
37 Schoharie
38 Suffolk
39 Sullivan
40 Ulster
41 Westchester

New Jersey

42 Atlantic
43 Bergen
44 Burlington
45 Camden
46 Cape May
47 Cumberland
48 Essex
49 Gloucester
50 Hudson
51 Hunterdon
52 Mercer
53 Middlesex
54 Monmouth
55 Morris
56 Ocean
57 Passaic
58 Salem
59 Somerset
60 Sussex
61 Union

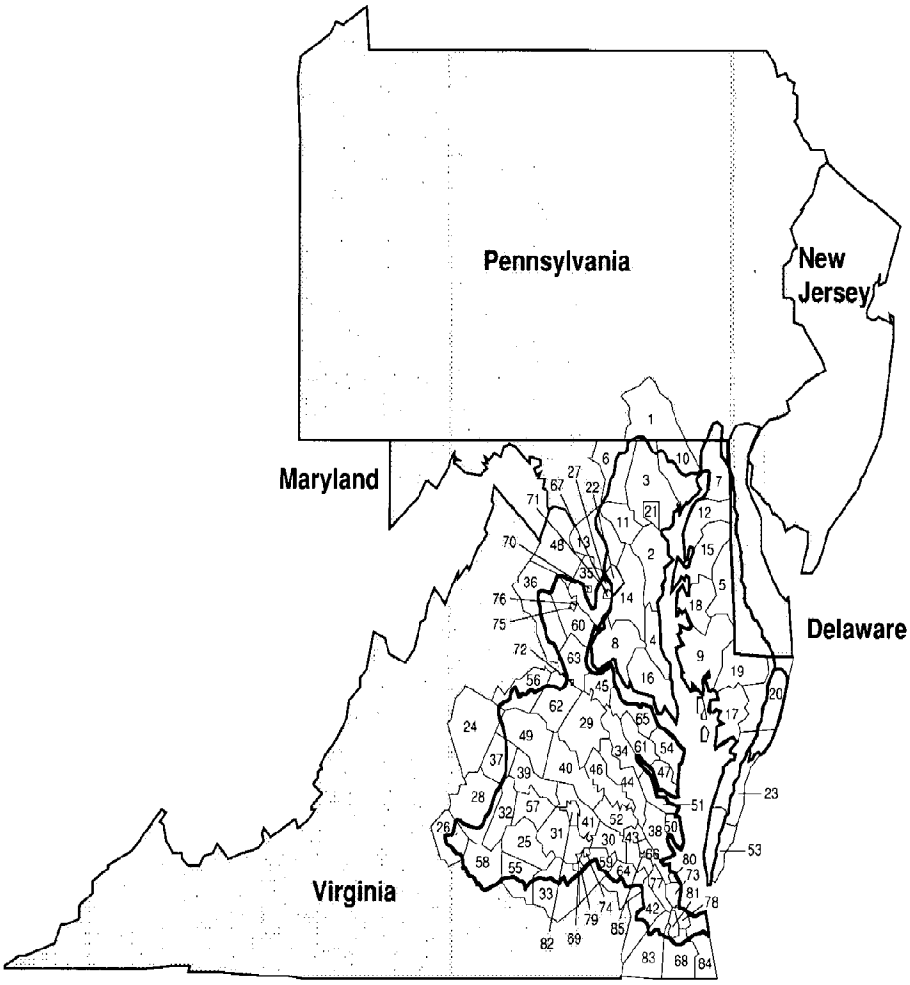
Pennsylvania

62 Bucks
63 Chester
64 Delaware
65 Lancaster
66 Montgomery
67 Philadelphia

Delaware

68 Kent
69 New Castle
70 Sussex

*Counties completely or partially in EDAs.


Pennsylvania
New Jersey
Maryland
Delaware
Virginia

Middle Atlantic Counties (Southern)*

Pennsylvania

1 York

Maryland

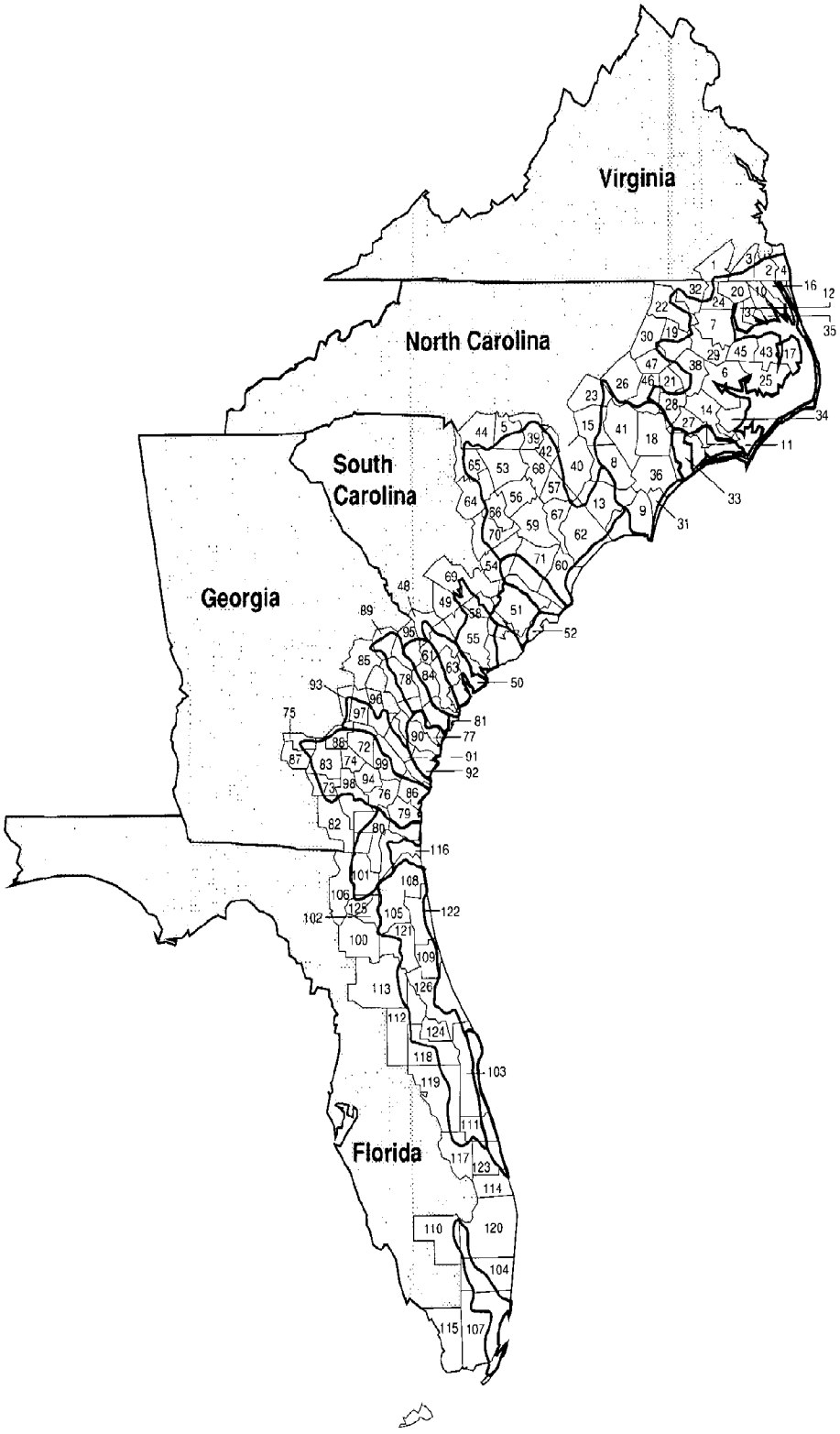
2 Anne Arundel
3 Baltimore
4 Calvert
5 Caroline
6 Carroll
7 Cecil
8 Charles
9 Dorchester
10 Harford
11 Howard
12 Kent
13 Montgomery
14 Prince George's
15 Queen Anne's
16 St. Mary's
17 Somerset
18 Talbot
19 Wicomico
20 Worcester
21 Baltimore city

22 *District of Columbia*

Virginia

23 Accomack
24 Albemarle
25 Amelia
26 Appomattox
27 Arlington
28 Buckingham
29 Caroline
30 Charles City
31 Chesterfield
32 Cumberland
33 Dinwiddie
34 Essex
35 Fairfax
36 Fauquier
37 Fluvanna
38 Gloucester
39 Goochland
40 Hanover
41 Henrico
42 Isle of Wight
43 James City
44 King and Queen
45 King George
46 King William
47 Lancaster
48 Loudoun
49 Louisa
50 Mathews
51 Middlesex
52 New Kent
53 Northampton
54 Northumberland
55 Nottoway
56 Orange
57 Powhatan
58 Prince Edward
59 Prince George
60 Prince William
61 Richmond
62 Spotsylvania
63 Stafford
64 Surry
65 Westmoreland
66 York
67 Alexandria
68 Chesapeake
69 Colonial Heights
70 Fairfax
71 Falls Church
72 Fredericksburg
73 Hampton
74 Hopewell
75 Manassas
76 Manassas Park
77 Newport News
78 Norfolk
79 Petersburg
80 Poquoson
81 Portsmouth
82 Richmond
83 Suffolk
84 Virginia Beach
85 Williamsburg

*Counties completely or partially in EDAs.


Virginia
North Carolina
South Carolina
Georgia
Florida

South Atlantic Counties*

Virginia

1 Southampton
2 Chesapeake
3 Suffolk
4 Virginia Beach

North Carolina

5 Anson
6 Beaufort
7 Bertie
8 Bladen
9 Brunswick
10 Camden
11 Carteret
12 Chowan
13 Columbus
14 Craven
15 Cumberland
16 Currituck
17 Dare
18 Duplin
19 Edgecombe
20 Gates
21 Greene
22 Halifax
23 Harnett
24 Hertford
25 Hyde
26 Johnston
27 Jones
28 Lenoir
29 Martin
30 Nash
31 New Hanover
32 Northampton
33 Onslow
34 Pamlico
35 Pasquotank
36 Pender
37 Perquimans
38 Pitt
39 Richmond
40 Robeson
41 Sampson
42 Scotland
43 Tyrrell
44 Union
45 Washington
46 Wayne
47 Wilson

South Carolina

48 Allendale
49 Bamberg
50 Beaufort
51 Berkeley
52 Charleston
53 Chesterfield
54 Clarendon
55 Colleton
56 Darlington
57 Dillon
58 Dorchester
59 Florence
60 Georgetown
61 Hampton
62 Horry
63 Jasper
64 Kershaw
65 Lancaster
66 Lee
67 Marion
68 Marlboro
69 Orangeburg
70 Sumter
71 Williamsburg

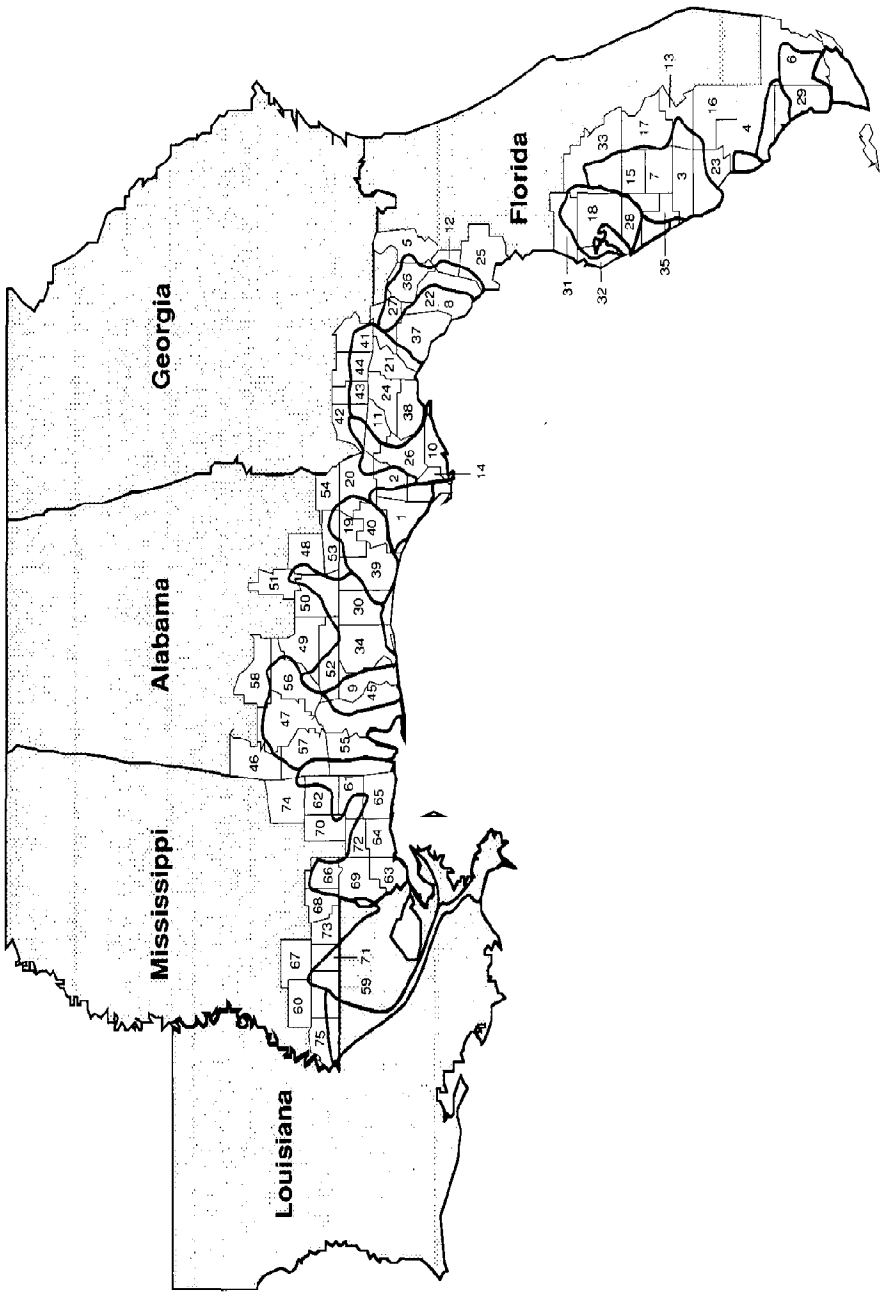
Georgia

72 Appling
73 Atkinson
74 Bacon
75 Ben Hill
76 Brantley
77 Bryan
78 Bulloch
79 Camden
80 Charlton
81 Chatham
82 Clinch
83 Coffee
84 Effingham
85 Emanuel
86 Glynn
87 Irwin
88 Jeff Davis
89 Jenkins
90 Liberty
91 Long
92 McIntosh
93 Montgomery
94 Pierce
95 Screven
96 Tattnall
97 Toombs
98 Ware
99 Wayne

Florida

100 Alachua
101 Baker
102 Bradford
103 Brevard
104 Broward
105 Clay
106 Columbia
107 Dade
108 Duval
109 Flagler
110 Hendry
111 Indian River
112 Lake
113 Marion
114 Martin
115 Monroe
116 Nassau
117 Okeechobee
118 Orange
119 Osceola
120 Palm Beach
121 Putnam
122 St. Johns
123 St. Lucie
124 Seminole
125 Union
126 Volusia

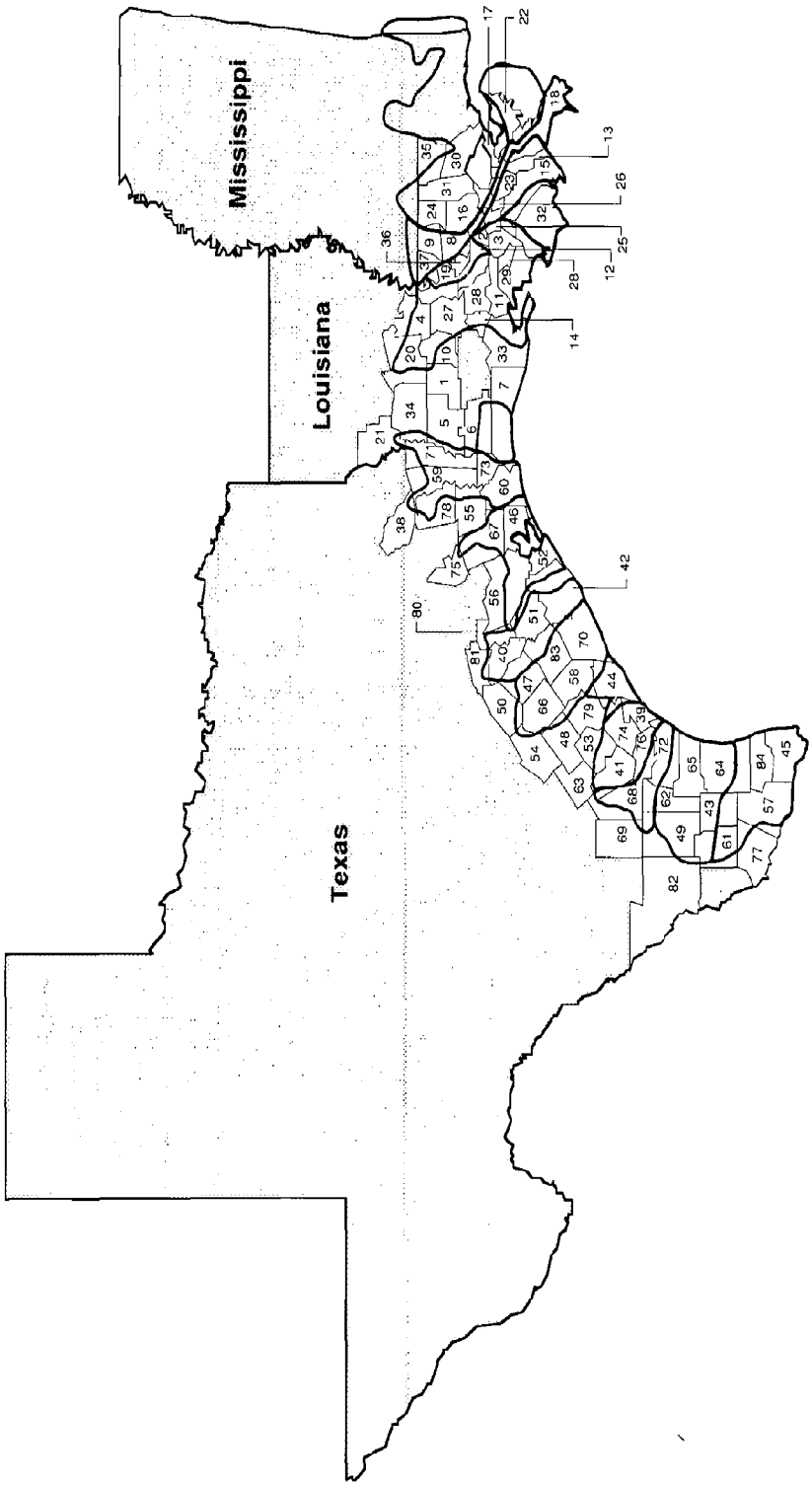
*Counties completely or partially in EDAs.


Florida
Georgia
Alabama
Mississippi
Louisiana

Gulf of Mexico Counties (Eastern)*

Florida				*Georgia*		*Alabama*		*Mississippi*	
1	Bay	20	Jackson						
2	Calhoun	21	Jefferson	41	Brooks	45	Baldwin	59	Amite
3	Charlotte	22	Lafayette	42	Decatur	46	Choctaw	60	Franklin
4	Collier	23	Lee	43	Grady	47	Clarke	61	George
5	Columbia	24	Leon	44	Thomas	48	Coffee	62	Greene
6	Dade	25	Levy			49	Conecuh	63	Hancock
7	De Soto	26	Liberty			50	Covington	64	Harrison
8	Dixie	27	Madison			51	Crenshaw	65	Jackson
9	Escambia	28	Manatee			52	Escambia	66	Lamar
10	Franklin	29	Monroe			53	Geneva	67	Lincoln
11	Gadsden	30	Okaloosa			54	Houston	68	Marion
12	Gilchrist	31	Pasco			55	Mobile	69	Pearl River
13	Glades	32	Pinellas			56	Monroe	70	Perry
14	Gulf	33	Polk			57	Washington	71	Pike
15	Hardee	34	Santa Rosa			58	Wilcox	72	Stone
16	Hendry	35	Sarasota					73	Walthall
17	Highlands	36	Suwannee					74	Wayne
18	Hillsborough	37	Taylor					75	Wilkinson
19	Holmes	38	Wakulla						
		39	Walton						
		40	Washington						

*Counties completely or partially in EDAs.


Mississippi
Louisiana
Texas

Gulf of Mexico Counties (Western)*

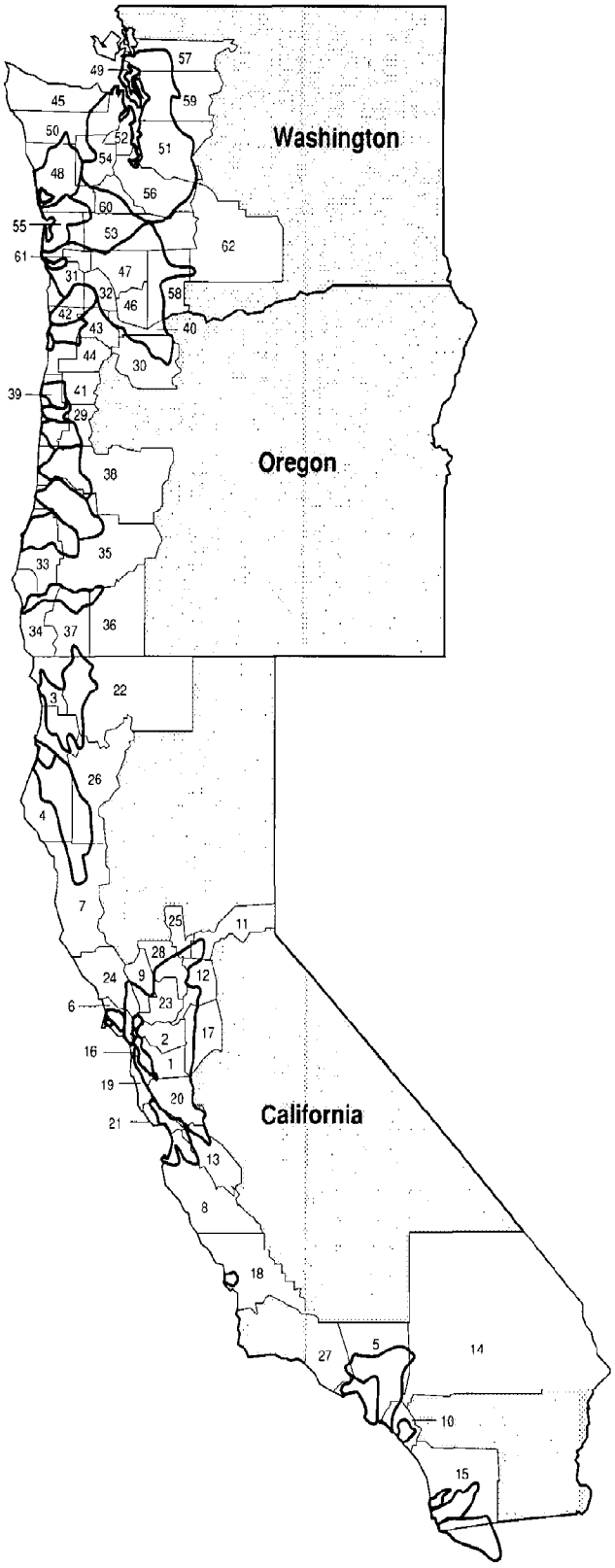
Louisiana

1 Allen
2 Ascension
3 Assumption
4 Avoyelles
5 Beauregard
6 Calcasieu
7 Cameron
8 East Baton Rouge
9 East Feliciana
10 Evangeline
11 Iberia
12 Iberville
13 Jefferson
14 Lafayette
15 Lafourche
16 Livingston
17 Orleans
18 Plaquemines
19 Point Coupee
20 Rapides
21 Sabine
22 St. Bernard
23 St. Charles
24 St. Helena
25 St. James
26 St. John the Baptist
27 St. Landry
28 St. Martin
29 St. Mary
30 St. Tammany
31 Tangipahoa
32 Terrebonne
33 Vermilion
34 Vernon
35 Washington
36 West Baton Rouge
37 West Feliciana

Texas

38 Angelina
39 Aransas
40 Austin
41 Bee
42 Brazoria
43 Brooks
44 Calhoun
45 Cameron
46 Chambers
47 Colorado
48 De Witt
49 Duval
50 Fayette
51 Fort Bend
52 Galveston
53 Goliad
54 Gonzales
55 Hardin
56 Harris
57 Hidalgo
58 Jackson
59 Jasper
60 Jefferson
61 Jim Hogg
62 Jim Wells
63 Karnes
64 Kenedy
65 Kleberg
66 Lavaca
67 Liberty
68 Live Oak
69 McMullen
70 Matagorda
71 Newton
72 Nueces
73 Orange
74 Refugio
75 San Jacinto
76 San Patricio
77 Starr
78 Tyler
79 Victoria
80 Waller
81 Washington
82 Webb
83 Wharton
84 Willacy

*Counties completely or partially in EDAs.


Washington
Oregon
California
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Pacific Counties*

California		*Oregon*		*Washington*	
1	Alameda	29	Benton	45	Clallam
2	Contra Costa	30	Clackamas	46	Clark
3	Del Norte	31	Clatsop	47	Cowlitz
4	Humboldt	32	Columbia	48	Grays Harbor
5	Los Angeles	33	Coos	49	Island
6	Marin	34	Curry	50	Jefferson
7	Mendocino	35	Douglas	51	King
8	Monterey	36	Jackson	52	Kitsap
9	Napa	37	Josephine	53	Lewis
10	Orange	38	Lane	54	Mason
11	Placer	39	Lincoln	55	Pacific
12	Sacramento	40	Multnomah	56	Pierce
13	San Benito	41	Polk	57	Skagit
14	San Bernardino	42	Tillamook	58	Skamania
15	San Diego	43	Washington	59	Snohomish
16	San Francisco	44	Yamhill	60	Thurston
17	San Joaquin			61	Wahkiakum
18	San Luis Obispo			62	Yakima
19	San Mateo				
20	Santa Clara				
21	Santa Cruz				
22	Siskiyou				
23	Solano				
24	Sonoma				
25	Sutter				
26	Trinity				
27	Ventura				
28	Yolo				

*Counties completely or partially in EDAs.

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Estuaries of the United States

Vital Statistics

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