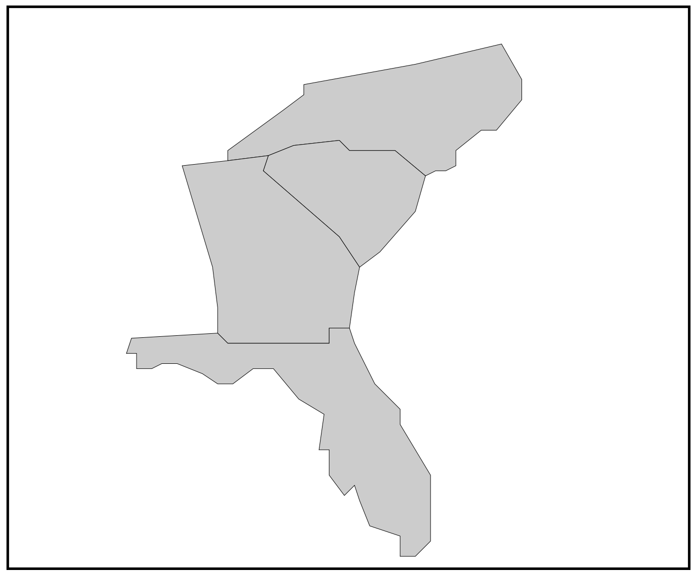
NOAA's Estuarine Eutrophication Survey

Volume 1: South Atlantic Region



September 1996

Office of Ocean Resources Conservation and Assessment
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

The National Estuarine Inventory

The National Estuarine Inventory (NEI) represents a series of activities conducted by NOAA's Office of Ocean Resources Conservation and Assessment (ORCA) since the early 1980s to define the nation's estuarine resource base and develop a national assessment capability. Over 120 estuaries are included (Appendix 3), representing over 90 percent of the estuarine surface water and freshwater inflow to the coastal regions of the contiguous United States. Each estuary is defined spatially by an estuarine drainage area (EDA)—the land and water area of a watershed that directly affects the estuary. The EDAs provide a framework for organizing information and for conducting analyses between and among systems.

To date, ORCA has compiled a broad base of descriptive and analytical information for the NEI. Descriptive topics include physical and hydrologic characteristics, distribution and abundance of selected fishes and invertebrates, trends in human population, building permits, coastal recreation, coastal wetlands, classified shellfish growing waters, organic and inorganic pollutants in fish tissues and sediments, point and nonpoint pollution for selected parameters, and pesticide use. Analytical topics include relative susceptibility to nutrient discharges, structure and variability of salinity, habitat suitability modeling, and socioeconomic assessments.

For a list of publications or more information about the NEI, contact C. John Klein, Chief, Physical Environments Characterization Branch, at the address below.

The Estuarine Eutrophication Survey

ORCA initiated the Estuarine Eutrophication Survey in October 1992. The goal is to comprehensively assess the scale and scope of nutrient enrichment and eutrophication in the NEI estuaries (see above) and to provide an information base for formulating a national response that may include future research and monitoring. The Survey is based, in part, upon a series of workshops conducted by ORCA in 1991-92 to facilitate the exchange of ideas on eutrophication in U.S. estuaries and to develop recommendations for conducting a nationwide survey. The survey process involves the systematic acquisition of a consistent and detailed set of qualitative data from the existing expert knowledge base (i.e., coastal and estuarine scientists) through a series of surveys, site visits, and regional workshops.

The original survey forms were mailed to over 400 experts in 1993. The methods and initial results were evaluated in May 1994 by a panel of NOAA, state, and academic experts. The panel recommended that ORCA proceed with a regional approach for completing data collection, including site visits with selected experts to fill data gaps, regional workshops to finalize and reach consensus on the responses to each question, and regional reports on the results. The Mid-Atlantic regional workshop was held in January 1995 and a draft regional report has been completed. The South Atlantic regional workshop was held in February 1996 and this document is the regional report.

Site visits, regional workshops, and regional reports will be completed for the Gulf of Mexico, North Atlantic, and West Coast in the next six to eight months. A national assessment report of the status and health of the nation's estuaries will be developed from the survey results. In addition, an "indicator" of ecosystem health will also be published. Both national products will require one or more workshops to discuss and reach consensus on the methods proposed for conducting these analyses. ORCA also expects to recommend a series of follow-up activities that may include additional and/or improved water quality monitoring, and case studies in specific estuaries for further characterization and analysis.

For publications or additional information, contact Suzanne Bricker, Project Manager, at the address below.

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ORCA Organization

The Office of Ocean Resources Conservation and Assessment (ORCA) is one of four major line offices of the National Oceanic and Atmospheric Administration's (NOAA) National Ocean Service. ORCA provides data, information, and knowledge for decisions that affect the quality of natural resources in the nation's coastal, estuarine, and marine areas. It also manages NOAA's marine pollution programs. ORCA consists of three divisions and a center: the Strategic Environmental Assessments Division (SEA), the Coastal Monitoring and Bioeffects Assessment Division (CMBAD), the Hazardous Materials Response and Assessment Division (HAZMAT), and the Damage Assessment Center (DAC), part of NOAA's Damage Assessment and Restoration Program.

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Contents

Introduction

This section presents an overview of how the Estuarine Eutrophication Survey is being conducted. It includes a statement of the problem, a summary of the project objectives, and a discussion of the project origins and methods. A diagram illustrates the project process and a table details the data being collected. The section closes with a brief description of the remaining tasks. For additional information, please see inside the front cover of this report.

About This Report

This report presents the results of ORCA's Estuarine Eutrophication Survey for 21 estuaries of the South Atlantic region of the United States. It is the first in what is expected to be a series of five regional summaries (South Atlantic, Mid-Atlantic, Gulf of Mexico, North Atlantic, and West Coast). A national report on the overall project results is also expected. The Survey is a component of ORCA's National Estuarine Inventory (NEI) - an ongoing series of activities to provide a better understanding of the nation's estuaries and their attendant resources (see inside front cover).

The report is organized into five sections: Introduction, Regional Overview, References, Estuary Summaries and Regional Summary. It also includes three appendices. The Introduction provides background information on project objectives, process, and methods. The Regional Overview presents a summary of findings for each parameter and includes a regional map and maps illustrating the results for selected parameters. Next are the Estuary Summaries—one-page summaries of Survey results for each of 21 South Atlantic estuaries. Each page includes a narrative summary, a salinity map, a table of key physical and hydrologic information, and a matrix summary of data results. The Regional Summary displays existing parameter conditions and their spatial coverage across the region. Appendix 1 lists the regional experts who participated in the survey. Appendix 2 presents the references suggested by workshop participants for understanding better the status and trends of nutrient enrichment in South Atlantic estuaries. Appendix 3 presents a complete list of NEI estuaries.

The Problem

Between 1960-2010, U.S. population has increased, and it is projected to continue to increase, most significantly in coastal states (Culliton et al., 1990). This steady influx of people is placing unprecedented stress on the Nation's coastal and estuarine ecosystems. Ironically, these changes threaten the quality of life that many new coastal residents seek. One of the most prominent barometers of coastal environmental stress is estuarine water quality, particularly with respect to the inputs of nutrients.

Coastal and estuarine waters are now among the most heavily fertilized environments in the world (Nixon et al., 1986). Nutrient sources include point (e.g. wastewater treatment plants) and nonpoint (e.g. agriculture, lawns, gardens) discharges. These inputs are known to have direct effects on water quality. For example, in extreme conditions, excess nutrients can stimulate excessive algal blooms that can lead to increased metabolism and turbidity, decreased dissolved oxygen, and changes in community structure—a condition described by ecologists as eutrophication (Day et al., 1989; Nixon, 1995; NOAA, 1989). Indirect effects can include impacts to commercial fisheries, recreation, and even public health (e.g. Boyton et al., 1982; Rabalais and Harper, 1992; Rabalais, 1992; Paerl, 1988; Whitledge and Pulich, 1991; NOAA, 1992; Burholder et al., 1992; Cooper, 1995; Lowe et al., 1991; Orth and Moore, 1984; Kemp et al., 1983; Stevenson et al., 1993; Burkholder et al., 1992a, Ryther and Dunstun, 1971; Smayda, 1989; Whitledge, 1985; Nixon, 1983).

Reports and papers from workshops, panels, and commissions have consistently identified nutrient enrichment and eutrophication as increasingly serious problems in U.S. estuaries (National Academy of Science, 1969; Ryther and Dunstan, 1971; Likens, 1972; NOAA, 1991; Frithsen, 1989; Jaworski, 1981). These conclusions are based on numerous local and regional investigations into the location and severity of nutrient problems, and into the specific causes. However, evaluating this problem on a national scale and formulating a meaningful strategy for improvements requires a different approach.

Objectives

The Estuarine Eutrophication Survey will provide the first comprehensive assessment of the temporal scale, scope, and severity of nutrient enrichment and eutrophication-related phenomena in the Nation's major estuaries. The goal is not necessarily to define one or more estuaries as eutrophic. Rather, it is to systematically and accurately characterize the scale and scope of eutrophication related, water-quality parameters in over 100 U.S. estuaries. The project has four specific objectives:

1. To assess the existing conditions and trends, for the base period 1970 to present, of estuarine eutrophication parameters in 129 estuaries of the contiguous United States;

2. To publish results in a series of regional reports and a national assessment report;

3. To formulate a national response to identified problems; and

4. To develop a national "indicator" of estuarine health based upon the survey results.

ORCA also expects to recommend a series of follow-up activities that may include additional and/or improved water-quality monitoring, and case studies in specific estuaries for further characterization and analysis.

Methods

The topic of estuarine eutrophication has been receiving increasing attention recently in both the scientific literature (Nixon, 1995) and in the activities of coastal resource management agencies. In the United States, investigators have generated thousands of data records and dozens of reports over the past decade that document seasonal and annual changes in estuarine water quality, primary productivity, and inputs of nutrients. The operative question for this project is how to best use this knowledge and information to characterize these parameters for the contiguous United States.

Preparing for a national survey

To answer this question, ORCA conducted three workshops in 1991-92 with local and regional estuarine scientists and coastal resource managers. Two workshops held at the University of Rhode Island's Graduate School of Oceanography in January 1991 (Hinga et al., 1991) consisted of presentations by invited speakers and discussions of the measures and effects associated with nutrient problems. The purpose was to facilitate the exchange of ideas on how to best characterize eutrophication in U.S. estuaries and to consider suggestions for the design of ORCA's proposed data collection survey. A third workshop, held in April 1992 at the Airlie Conference Center in Virginia, focused specifically on developing recommendations for conducting a nationwide survey.

Given the limited resources available for this project, it was not practical to try to gather and consolidate the existing data records. Even if it were possible to do this, it would be very difficult to merge these data into a comprehensible whole due to incompatible data types, formats, time periods, and methods. Alternatively, ORCA elected to systematically acquire a consistent and detailed set of qualitative data from the existing expert knowledge base (i.e., coastal and estuarine scientists) through a series of surveys, interviews, and regional workshops.

Identifying the Parameters and Parameter Characteristics

To be included in the Survey, a parameter had to be (1) essential for accurate characterization of nutrient enrichment; (2) generally available for most estuaries; (3) comparable among estuaries; and (4) based upon existing data and/or knowledge (i.e., no new monitoring or analysis required). Based upon the workshops described above and additional meetings with experts, seventeen parameters were selected (Table 1).

The next step was to establish response ranges to ensure discrete gradients among responses. For example, the survey asks whether nitrogen is high, medium, or low based upon specific thresholds (e.g., High ≥ 1 mg/l, Medium ≥ 0.1 < 1 mg/l, low > 0 <0.1 mg/l, or unknown). The ranges were determined from nationwide data and from discussions with eutrophication experts. The thresholds used to classify ranges are designed to distinguish conditions among estuaries on a national basis and may not distinguish among estuaries within a region.

Temporal Framework: Existing Conditions and Trends

For each parameter, information is requested for existing conditions and recent trends. Existing conditions describe maximum parameter values observed over a typical annual cycle (e.g., normal freshwater inflow, average temperatures, etc.). For instance, for nutrients, ORCA collected information characterizing peak concentrations observed during the annual cycle such as those associated with the spring runoff and/or turnover. For chlorophyll *a*, ORCA collected information on peak concentrations that are typically reached during a bloom period. Ancillary information is also requested to describe the timing and duration of elevated concentrations (or low levels in the case of dissolved oxygen). This information is collected because all regions do not show the same periodicity, and, for some estuaries, high concentrations can occur at any time depending upon estuarine conditions.

For some parameters, such as nuisance and toxic blooms, there is no standard threshold concentration that causes problems. In these cases a parameter is considered a problem if it causes a detrimental impact on biological resources. Ancillary descriptive information is also collected for these parameters (Table 1).

	PARAMETERS	EXISTING CONDITIONS (predominant maximum values observed over a typical annual cycle)	TRENDS (1970 - 1995)
ALGAL CONDITIONS	**CHLOROPHYLL *A***	• Surface concentrations: Hypereutrophic (>60 µg chl-a/l) High (>20, 60 µg chl-a/l) Medium (>5, 20 µg chl-a/l) Low (>0, 5 µg chl-a/l) • Limiting factors to algal biomass (N, P, Si, light, other) • Spatial coverage[1], Months of occurrence, Frequency of occurrence[2]	• Concentrations[3,4] • Limiting factors • Contributing factors[5]
	TURBIDITY	• Secchi disk depths: High (<1m), Medium (1 m, 3m), Low (>3m), Blackwater area • Spatial coverage[1], Months of occurrence, Frequency of occurrence[2]	• Concentrations[3,4] • Contributing factors[5]
	SUSPENDED SOLIDS	• Concentrations: Problem (significant impact upon biological resources) No Problem (no significant impact) • Months of occurrence, Frequency of occurrence[2]	(no trends information requested)
	NUISANCE ALGAE **TOXIC ALGAE**	• Occurrence Problem (significant impact upon biological resources) No Problem (no significant impact) • Dominant species • Event duration (Hours, Days, Weeks, Seasonal, Other) • Months of occurrence, Frequency of occurrence[2]	• Event duration[3,4] • Frequency of occurrence[3,4] • Contributing factors[5]
	MACROALGAE **EPIPHYTES**	• Abundance Problem (significant impact upon biological resources) No Problem (no significant impact) • Months of occurrence, Frequency of occurrence[2]	• Abundance[3,4] • Contributing factors[5]
NUTRIENTS	**NITROGEN**	• Maximum dissolved surface concentration: High (1 mg/l), Medium (0.1, <1 mg/l), Low (0, < 0.1 mg/l) • Spatial coverage[1], Months of occurrence	• Concentrations[3,4] • Contributing factors[5]
	PHOSPHORUS	• Maximum dissolved surface concentration: High (0.1 mg/l), Medium (0.01, <0.1 mg/l), Low (0, < 0.01 mg/l) • Spatial coverage[1], Months of occurrence	• Concentrations[3,4] • Contributing factors[5]
DISSOLVED OXYGEN	**ANOXIA (0 mg/l)** **HYPOXIA (>0 2 mg/l)** **BIOL. STRESS (>2 5 mg/l)**	• Dissolved oxygen condition Observed No Occurrence • Stratification (degree of influence): (High, Medium, Low, Not a factor) • Water column depth: (Surface, Bottom, Throughout water column) • Spatial coverage[1], Months of occurrence, Frequency of occurrence[2]	• Min. avg. monthly bottom dissolved oxygen conc.[3,4] • Frequency of occurrence[3,4] • Event duration[3,4] • Spatial coverage[3,4] • Contributing factors[5]
ECOSYSTEM / COMMUNITY RESPONSE	**PRIMARY PRODUCTIVITY**	• Dominant primary producer: Pelagic, Benthic, Other	• Temporal shift • Contributing factors[5]
	PLANKTONIC COMMUNITY	• Dominant taxonomic group (number of cells): Diatoms, Flagellates, Blue-green algae, Diverse mixture, Other	• Temporal shift • Contributing factors[5]
	BENTHIC COMMUNITY	• Dominant taxonomic group (number of organisms): Crustaceans, Molluscs, Annelids, Diverse mixture, Other	• Temporal shift • Contributing factors[5]
	SUBMERGED AQUATIC VEG. **INTERTIDAL WETLANDS**	• Spatial coverage[1]	• Spatial coverage[3,4] • Contributing factors[5]

NOTES

(1) SPATIAL COVERAGE (% of salinity zone): High (>50, 100%), Medium (>25, 50%), Low (>10, 25%), Very Low (>0, 10%), No SAV / Wetlands in system

(2) FREQUENCY OF OCCURRENCE: Episodic (conditions occur randomly), Periodic (conditions occur annually or predictably), Persistent (conditions occur continually throughout the year)

(3) DIRECTION OF CHANGE: Increase, Decrease, No trend

(4) MAGNITUDE OF CHANGE: High (>50%, 100%), Medium (>25%, 50%), Low (>0%, 25%)

(5) POINT SOURCE(S), NONPOINT SOURCE(S), OTHER

Table 1: *Project parameters and characteristics.*

Trends information is requested for characterization of the direction, magnitude, and time period of change for the past 20 to 25 years. In cases where a trend has been observed, ancillary information is requested about the factors influencing the trend.

Spatial Framework

A consistently applied spatial framework was also required. ORCA's National Estuarine Inventory (NEI) was used (see inside front cover). For the survey, each parameter is characterized for three salinity zones as defined in the NEI (tidal fresh 0-0.5 ppt, mixing 0.5-25 ppt, and seawater >25 ppt). Not all zones are present in all NEI estuaries; thus the NEI model provides a consistent basis for comparisons among these highly variable estuarine systems.

Reliability of Responses

Finally, respondents were asked to rank the reliability of their responses for each parameter as either highly certain or speculative inference, reflecting the robustness of the data the response is based on. This is especially important given that responses are based upon a range of information sources from statistically tested monitoring data to general observations. The objective is to exploit all available information that can provide insight into the existing and historic conditions in each estuary, and to understand its limitations.

The survey questions were reviewed by selected experts and then tested and revised prior to initiating the national survey. Salinity maps, based upon the NEI salinity zones, are distributed with the survey questions for orientation. Updates and/or revisions to these maps were made as appropriate.

Collecting the Data

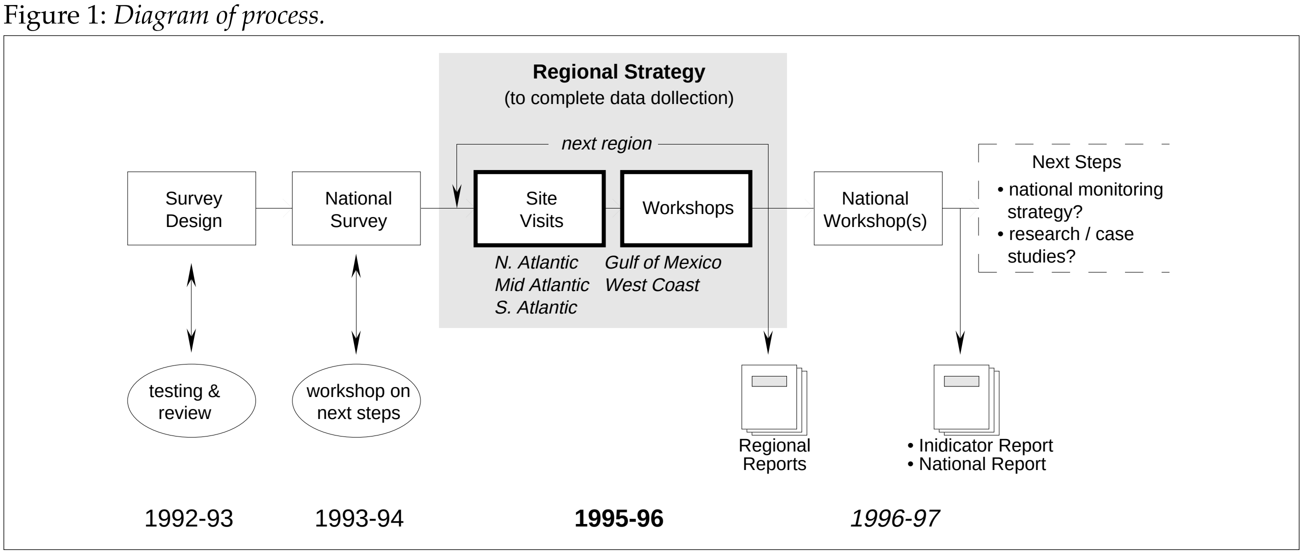
Over 400 experts and managers had agreed to participate in the survey. Survey forms were mailed to the experts, who then mailed in their responses. The response rate was approximately 25 percent with at least one response for 112 of the 129 estuaries being surveyed.

The initial survey methods and results were evaluated in May 1994 by a panel of NOAA, state, and academic eutrophication experts. The panel recommended that ORCA continue the project and adopt a regional approach for data collection involving site visits to selected experts to fill data gaps and revise salinity maps, regional workshops to finalize and reach consensus on the responses to each question (including salinity maps), and regional reports on the results. The revised strategy was implemented in the summer of 1994 starting with the 22 estuaries of the Mid-Atlantic region.

Estuaries are targeted for site visits based upon the completeness of the data received from the original mailed survey forms. The new information is incorporated into the project data base and summary materials are then prepared for a regional workshop.

Workshop participants are local and regional experts (at least one per estuary representing the group of people with the most extensive knowledge and insight about an estuary). In general, these persons have either filled out a survey form and/or participated in a site visit. Preparations include sending all regional data to participants prior to the workshop. Participants are also encouraged to bring to the workshop relevant data and reports to consult. At the workshop, at least two workgroups are established based upon geography.

Figure 1: *Diagram of process.*



The survey data and salinity maps for each estuary are then carefully reviewed. ORCA staff facilitate the discussions and record the results. At the close of the workshop, participants are asked to identify "critical" references such as reports and other publications that describe nutrient enrichment in one or more of the region's estuaries.

Workshop results are summarized for each estuary and mailed to workshop participants for review. The data are then compiled for presentation in a regional report that is also reviewed by participants prior to publication. The regional process, from site visits to publication of a regional report, takes approximately six months to complete. Some tasks are conducted concurrently.

Next Steps

Site visits, regional workshops, and regional reports are in progress for the Gulf of Mexico, North Atlantic, and West Coast (Figure 1). A national assessment report of the status and health of the nation's estuaries will be developed from the survey results. The regional results and final national data base will be available over the Internet through ORCA's Web site. Formulation of a national response to estuarine nutrient enrichment and development of a national "indicator" on coastal ecosystem health will require one or more workshops to discuss and reach consensus on the methods and products resulting from these analyses. This work is currently scheduled for 1997. ORCA is funding a series of small contracts with regional experts to provide additional technical support for these tasks.

Regional Overview

This section presents an overview of the survey results. It begins with a brief introduction to the regional geography and a summary of how the results were compiled. Narrative summaries are then presented for each parameter in four subsections; Algal Conditions, Nutrients, Dissolved Oxygen, and Ecosystem/ Community Response. Figures include a regional map showing the location of 21 South Atlantic estuaries, a summary of probable-months-of-occurrence by parameter, four maps illustrating existing conditions for selected parameters, and a summary of recent trends by estuary for selected parameters.

The Setting: Regional Geography

The South Atlantic coastal province includes 21 major estuarine systems and encompasses more than 4,440 square miles of water surface area (Figure 2). The characteristics of this region include extensive coastal and barrier features and the Atlantic Coastal Plain. This region can be subdivided into three distinct subregions: the Carolina Capes, the Sea Island Coast, and the Florida Coast. The Carolina Capes extend from Cape Hatteras, North Carolina to Cape Romain, South Carolina (approximately 50 mi. North of Charleston, SC). The Sea Island Coast includes the coastline from Cape Romain south to Cape Canaveral, Florida. The Florida Coast consists of Indian River and Biscayne Bay.

Carolina Capes

Major geomorphological features of the Carolina Capes are the extensive shoal structures and the series of barrier islands off North Carolina and South Carolina. Barrier islands are composed of beach dune ridges paralleling the present shoreline. Extensive salt marshes also predominate throughout the area. Due to the proximity of the Outer Banks region to the westward wall of the Gulf Stream, salinities tend to be higher in this area than other estuaries in the region. In the Carolina Capes, wind plays a major role in both short-term salinity structure and circulation within the estuaries. Tides are a dominant influence on water column mixing, primarily near the inlets (Orlando et

Highlights of Regional Results

Highlights include existing information only. Trends information for the 21 South Atlantic estuaries is sparse and many reported trends are based on speculative information. Refer to text and to Figure 5 for regional trends information. (Note: Tidal Fresh = 10%, Mixing = 67%, Seawater = 23% of regional surface area (4854 mi2).

Chlorophyll *a*
Concentrations of high and hypereutrophic (>20 ug/l) are observed episodically in 11 of 21 estuaries, but only in small localized areas. Concentrations of medium or greater (5 ug/l) are observed periodically in 20 estuaries, over 30-55% of the regional estuarine area. These concentrations are observed for 50% of the mixing zone area and 20% of the tidal fresh and seawater zone area. Elevated concentrations occur in the summer months.

Toxic Algal Blooms
Toxic algal blooms are reported to occur in 7 Carolina Capes and Florida estuaries (Albemarle/Pamlico Snds., Pamlico/Pungo R., Bogue Snd., Neuse R., New R., St. Johns R., Indian R.), with no occurrences in estuaries of the Sea Island Coast. Blooms occur primarily during summer months with typical durations on the order of days to weeks.

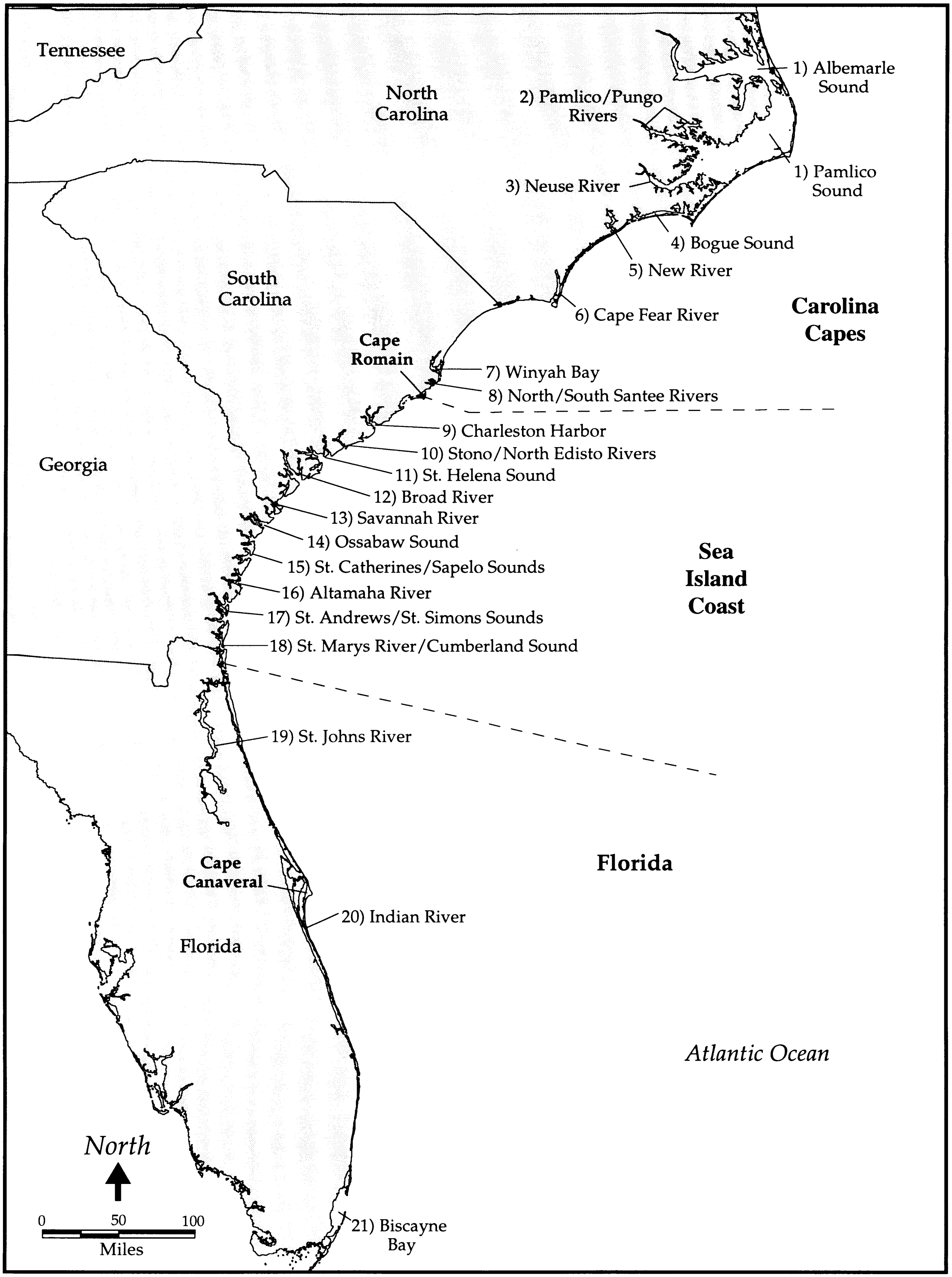
Nitrogen
Concentrations of medium or greater (0.1 mg/l) are observed in 19 estuaries, over 10-17% of the total regional estuarine area. These concentrations are observed for about 15% of the mixing and seawater zones and about 6% of the tidal fresh zone. Elevated concentrations are observed in spring in the tidal fresh zone and summer in the mixing and seawater zones.

Phosphorus
Concentrations of medium or greater (0.01 mg/l) are observed in 18 estuaries, over 12-20% of the total regional estaurine area. These concentrations are observed for 37% of tidal fresh zone, 12% and 9% of the mixing and seawater zones respectively. Elevated concentrations occur in summer in the mixing and seawater zones, and spring and summer in the tidal fresh zone.

Hypoxia
During the summer months, periodic occurrences of hypoxia are observed in 13 estuaries, over 4-11% of the regional estuarine surface area. Less than 1% of the tidal fresh area and equal percentages (about 9%) of the mixing and seawater zones reportedly become hypoxic.

Anoxia
During the summer months, periodic occurrences of anoxia in bottom waters are observed in 11 estuaries, over 3-9% of the regional estuarine area. Less than 1% of the tidal fresh zone and equal percentages of the mixing and seawater zones (about 6%) exhibit anoxia.

Figure 2: *Regional map of South Atlantic showing estuaries.*



al., 1994). Freshwater inflow into the Albemarle/Pamlico Sounds is dominated by discharge from the Roanoke, Chowan, Neuse-Trent and Tar-Pamlico river systems. Sediments are resuspended into the sounds through the main river systems and through tidal excursion within the South Atlantic Bight (Menzel, 1993).

Sea Island Coast

The Sea Island Coast consists of fluvial deposits such as dune sheets, point bars, and terrace formations in all of the major river valleys (Mathews, 1980). Low-lying sea islands are erosional remnants of Pleistocene Age sand bodies bordered by salt marshes, and relatively gently sloping marsh islands bound by tidal creeks. Marsh islands are geographically located in tidal marshes and are periodically inundated. Deltaic structures within the Sea Island Coast resemble sediment-filled drowned river valleys but formation is rather limited (Mathews, 1980). Extensive clearcutting in post-colonial times has promoted soil erosion processes and added to suspended sediments traversing the Sea Island Coast estuaries. Estuarine mixing is induced by the turbulence of semidiurnal tide fluxes. Tidal ranges are higher in this subregion than in any other portion of the South Atlantic, with Savannah, Georgia having one of the highest ranges, near 7.2 ft. The major freshwater inflow sources for the Sea Island Coast are from rivers originating in the coastal plain and from sources in the Appalachian Mountains and the Piedmont. The Black, Cooper, and Waccamaw Rivers of South Carolina, and the Satilla and St. Marys Rivers of Georgia, compose the major coastal-plain-derived riverine systems. The Pee Dee, Santee, Edisto, Savannah, Ogeechee and Altamaha Rivers originate in the Appalachian/Piedmont provinces.

Florida Coast

Florida is part of an anticlinal ridge system known as the Peninsular Arch, consisting of lakes and dissolved sinkhole formations with extensive barrier beaches along the Atlantic Coast (Hunt, 1967). As in the Carolina Capes, the shallow lagoonal estuaries of Florida are semi-enclosed by barrier island features; tidal influence is less for the Florida Coast than for the Sea Island Coast estuaries. Salinity structure and circulation in the Indian River are dominated by wind forcing and human impacts in the form of controlled stormwater releases (Zarillo et al., 1993). Water control structures located on canals leading to Biscayne Bay are managed for flood protection. Southern Biscayne Bay consists of interconnected lagoons and a complicated network of tidal inlets with narrow flow channels and water control structures (Lee et al., 1976; Markley, 1996 pers. comm.). Horizontal density gradients can occur in these estuaries as a result of freshwater inflow from drainage canals on the western side and tidal exchange through inlets on the eastern side.

About the Results

The survey results are organized into four sections: Algal Conditions, Nutrients, Dissolved Oxygen, and Ecosystem Response. Each section contains a general overview followed by more detailed summaries for each parameter. This material is based on the individual estuary summaries presented later in this report. Regional patterns and anomalies are highlighted. Existing conditions and trends are reviewed. Regional maps summarizing existing conditions for selected parameters are presented in Figure 4. A summary of recent trends for all parameters is presented in Figure 5.

Data Reliability

As described in the introduction, participants were asked to rank the reliability of their responses as either highly certain or speculative inference. Over 80 percent of the responses are highly certain. Where relevant, speculative inferences are noted in the narrative below and on the estuary summaries that follow. A highly certain response is based upon temporally and spatially representative data from long-term monitoring, special studies, or literature. A speculative inference is based upon either very limited data or general observations. When respondents could not offer even a speculative inference, the value was recorded as "unknown".

Algal Conditions

Algal conditions were examined in the South Atlantic region by characterizing existing conditions and trends for chlorophyll *a*, turbidity, suspended solids, nuisance and toxic algae, macroalgal abundance, and epiphyte abundance (Table 1). High to hypereutrophic concentrations of chlorophyll *a* (>20 µg/l) were generally reported as occurring episodically over relatively small areas, while medium concentrations (>5 µg/l) were more widely reported and occurred more predictably. Medium or greater concentrations of chlorophyll *a* were reported for 66 percent of the region's mixing zone surface area, 35 percent of the tidal fresh zone, and 31 percent of the seawater zone. Medium or greater levels of turbidity (secchi disk depths <3 meters) also occur primarily in the mixing zone, affecting 39 percent of the region's mixing zone compared to 5 percent of the tidal fresh zone and 13 percent of the seawater zone. Nuisance and toxic algae events occur fairly evenly across all three zones but are concentrated in the Carolina Capes and Florida systems. Macroalgal and epiphyte abundance are the least problematic of the parameters examined and have had a minimum impact in this region. There was a greater amount of information available for existing conditions than for trends, and because of this, in most cases it is not very meaningful to make conclusions about regional trends.

Chlorophyll a

High to hypereutrophic concentrations (>*20* µg/l) were reported in 11 of 21 estuaries, occurring across a maximum of 11 percent of the estuarine surface area (Figure 4). These conditions were reported to occur periodically (January to late summer) in the Carolina Capes estuaries, and episodically (summer only) in the Sea Island Coast estuaries and the Indian River.

Medium or greater concentrations (>*5* µg/l) of chlorophyll *a* were reported for 19 of 21 South Atlantic estuaries, occurring in up to 55 percent of the region's estuarine surface area. The spatial extent of the medium or higher conditions was unknown in four estuaries and, therefore, the area affected could be larger. In general, these conditions were reported as occurring periodically from April to September with some winter occurrences in the Carolina Capes subregion. Episodic conditions were reported for the St. Johns River and Albemarle/Pamlico Sounds.

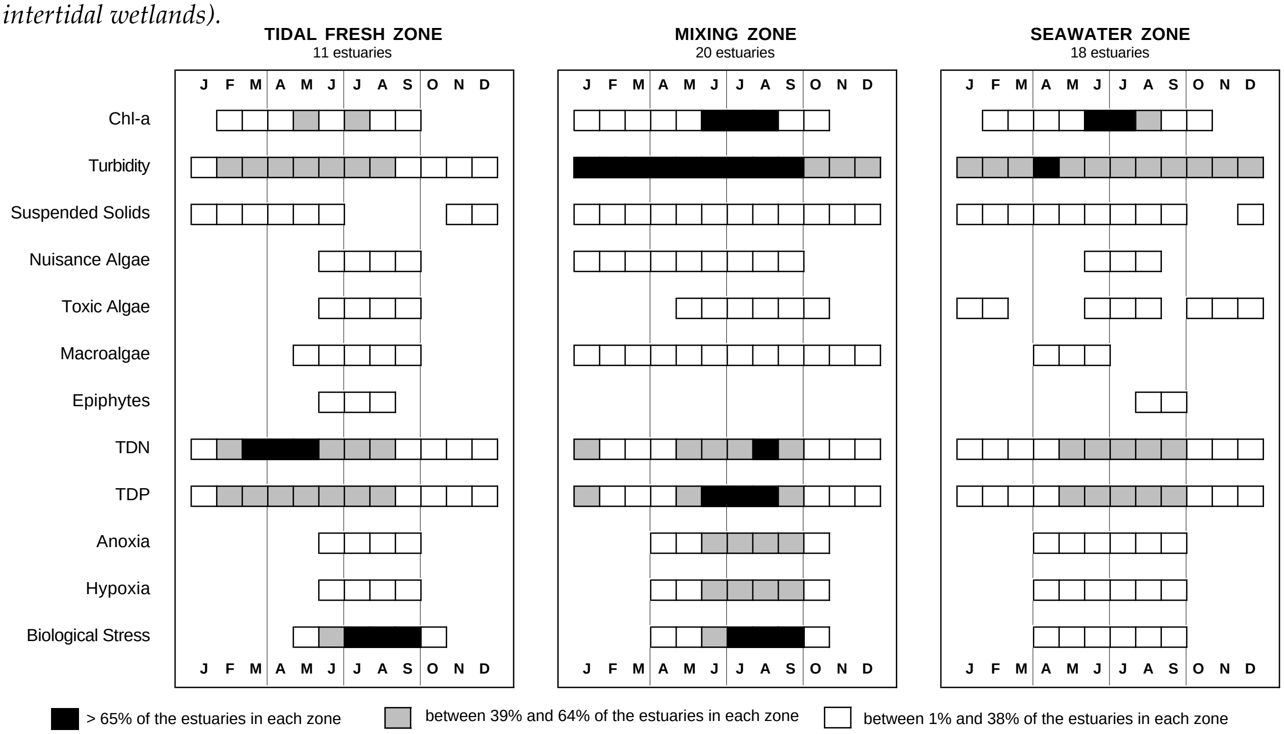
Concentrations were reported as unknown for 21 percent of the total regional area, mostly in the mixing zone. Concentrations based on speculative inferences were reported for at least one salinity zone in 10 of 21 estuaries.

Limiting factors to algal growth were reported as phosphorus and nitrogen, and sometimes light, in the tidal fresh zone. Light, or phosphorus and light, were the limiting factors in the mixing zone except in the Carolina Capes, which were reported to be nitrogen limited with silica or light sometimes co-limiting. Limiting factors in the seawater zone were reported to be nitrogen in the Carolina Capes, silica in the Sea Island Coast, and light in the Florida systems.

Trends information for the Carolina Capes and the Sea Island Coast is sparse (Figure 5): the upper Pamlico River and the Neuse River were reported to have in-

Figure 3: *Probable months of occurrence by parameter and by salinity zone (average).*

This figure illustrates the probable months, over a typical annual cycle, for which parameters are reported to occur at their maximum value. The black tone represents months where maximum values occur in at least 65 percent of South Atlantic estuaries for a particular salinity zone. For example, tidal fresh zones occur in 11 estuaries; therefore, a black tone indicates a maximum value was recorded in 7 or more estuaries. Similarly, for the mixing zone, black represents 13 or more estuaries, and for the seawater zone it represents 12 or more estuaries. Gray represents months where maximum values occur in 39 to 64 percent of the estuaries in that salinity zone, and unshaded boxes (white) represent months where maximum values occur between 1 and 38 percent of the estuaries in that zone. "Months-of-occurrence" data were not collected for Ecosystem/Community Response parameters (i.e., primary productivity, planktonic community, benthic community, SAV, and intertidal wetlands).



creasing chlorophyll *a* concentrations in the mixing zone, eight estuaries show no trend in at least one zone, and trends in the rest of the zones are unknown. The Florida systems have had no trends in concentrations with the exception of a low magnitude increase in the St. Lucie River portion of the Indian River estuary. Trends information for Albemarle Sound, Ossabaw Sound, and St. Lucie River are based on speculative inference.

Turbidity

Medium to high turbidity conditions (secchi disk depths of <3 meters) were reported for at least one salinity zone in 16 of the 21 estuaries of the South Atlantic (30 percent of the region's estuarine surface area, largely in the mixing zone). The spatial extent of these conditions was unknown for five estuaries and, therefore, the area affected could be larger. Furthermore, turbidity conditions were reported as unknown for an additional 1,126 square miles (23 percent) of the regional estuarine surface area.

In the tidal fresh and mixing zones, the medium and high turbidity conditions generally occur either all year (7 estuaries), or periodically during the winter and spring months (5 estuaries). In the seawater zone, medium to high turbidity occurs throughout the year (8 estuaries) or periodically from spring through fall (5 estuaries).

Naturally occurring blackwater areas (see sidebar) constitute 174 square miles of estuarine surface area in parts of five South Atlantic estuaries. Secchi disk depths in these waters typically are not recorded because they are not an accurate measure of turbidity conditions.

Decreases in turbidity occurred from 1980 to 1994 in the Chowan River portion of Albemarle Sound, all of the North/South Santee Rivers, and in Biscayne Bay. Increasing turbidity was reported in at least one salinity zone for five estuaries, and no trend was reported in at least one zone for ten estuaries. Turbidity trends were unknown for 75 percent of the region's estuarine surface area (Figure 5).

Blackwater Estuaries

Five estuaries in the South Atlantic region are considered blackwater systems: Neuse River, Charleston Harbor, St. Helena Sound, St. Andrew/St. Simons Sounds and St. Marys River/Cumberland Sound. Blackwater estuaries typically have clear, but coffee colored waters. The color is due to the presence of organic substances (i.e. humic acid) derived from swamp drainage. As a result, secchi disc readings are persistently low despite low suspended particle concentrations.

Suspended Solids

Suspended solids were reported as impacting biological resources (e.g. submerged aquatic vegetation, filter feeders, etc.) in at least one zone for five South Atlantic estuaries. Ten estuaries were reported to have no problem with suspended solids, although four of these also have at least one salinity zone in which suspended solids conditions are unknown. Suspended solids information was unknown in at least one zone for 11 of 21 estuaries. Trends information was not collected for suspended solids.

Nuisance/Toxic Algae

Both nuisance and toxic algae were reported as impacting biological resources in four estuaries (Albemarle/Pamlico Sounds, Neuse River, New River, and Indian River). In addition, toxic algae were reported as impacting resources in three estuaries (Pamlico/Pungo Rivers, Bogue Sound, and St. Johns River). Conversely, no impacts from nuisance or toxic algae were reported for estuaries along the Sea Island Coast.

Nuisance events were reported as mostly periodic during the summer months (except some winter months in New River), and toxic events were reported as mostly episodic during the summer (except some winter months in Bogue Sound). The duration of toxic blooms were reported as lasting days to weeks, as compared to nuisance blooms, which were reported as lasting months to seasons.

Nuisance species reported include *Anabaena portoricensis*, *Aphanizomenon flosaquae*, *Microcystis aeroginosa*, *Anabaenopsis raciborski*, various dinoflagellates, cyclotella species, and sometimes diatoms. *Pfiesteria piscicida* is the toxic species typically occurring in this region, but there are also some reported occurrences of *Phaeocystis poucheti*, and rare occurrences of *Gymnodinium breve.*

Information reported on nuisance and toxic algae was based on speculative inferences for seven estuaries. Conditions were unknown for at least one salinity zone in six estuaries.

Trends were reported only for the Neuse River, where the frequency of occurrence and event duration decreased in the tidal fresh zone, but increased in the mixing zone. Nuisance and toxic algae trends were unknown in at least one salinity zone for eleven estuaries in the South Atlantic (Figure 5).

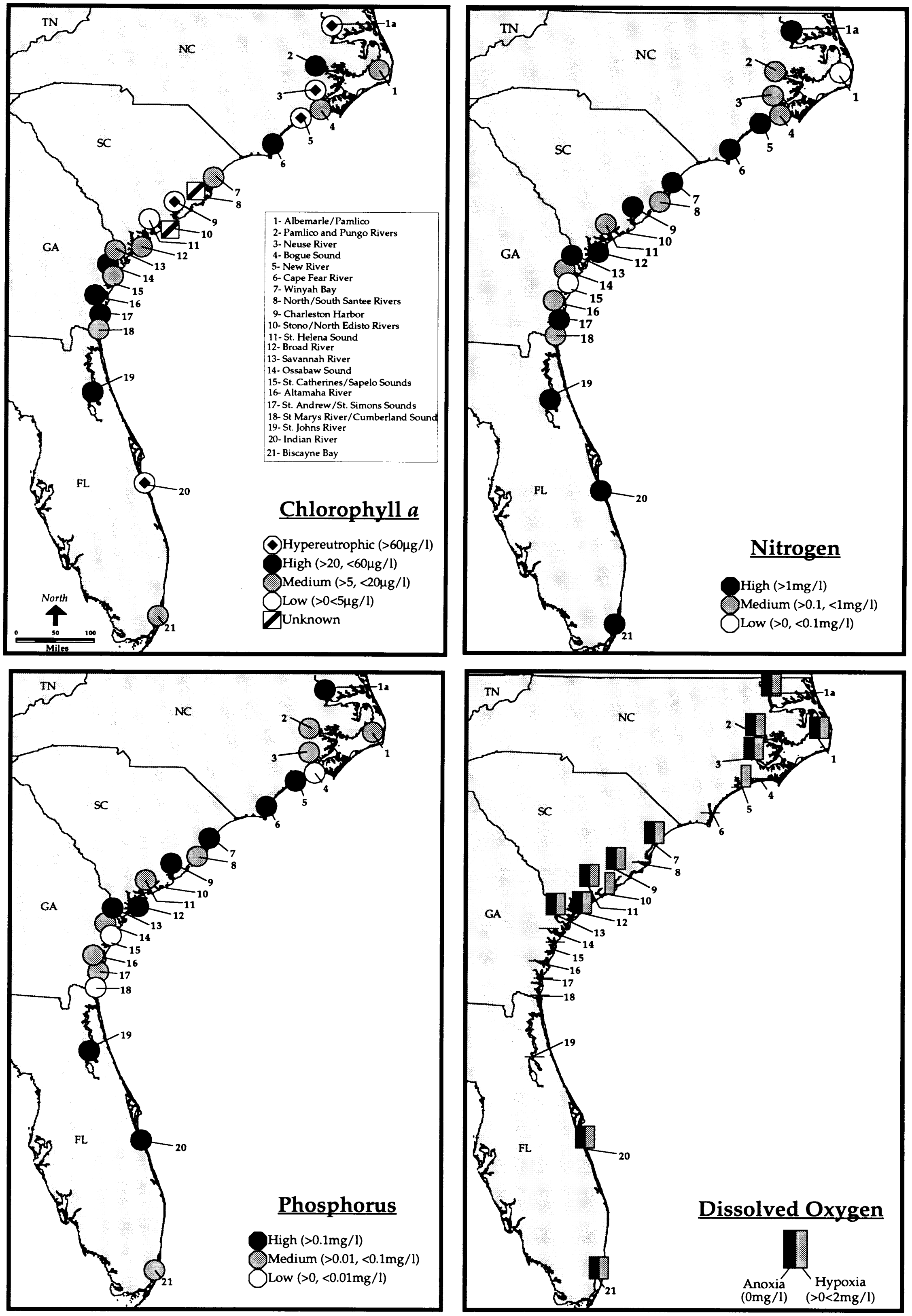


Figure 4: *Existing conditions for chlorophyll a, nitrogen, phosphorus, and dissolved oxygen. Symbols indicate that an existing condition(s) (e.g., hypereutrophic for chlorophyll a, anoxia and/or hypoxia for dissolved oxygen) was reported in at least a portion of one salinity zone of an estuary at some time during a typical annual cycle. <u>Symbols do not necessarily represent existing conditions across an entire estuary</u>. For a more complete review of individual estuaries, turn to the estuary summaries beginning on page 19.*

Macroalgal/Epiphyte Abundance

Macroalgal and epiphyte abundance were characterized by collecting information on existing conditions and trends for concentrations, months of occurrence, and frequency of occurrence. Information on contributing factors influencing trends was also recorded. Charleston Harbor and Indian River are the only estuaries reported to have impacts on biological resources from macroalgal abundance. Impacts from epiphyte abundance were reported only in the St. Johns and Indian Rivers. Reported impacts typically occur from late spring through early fall. Macroalgal and epiphyte abundance was reported as unknown in at least one salinity zone for seven estuaries.

An increasing trend in rooted macrophyte abundance was reported for the tidal fresh zone of Charleston Harbor for the time period 1988 to 1995. Decreasing abundances of rooted macrophytes were reported for the tidal fresh zone of Albemarle/Pamlico Sounds during the same time period. No other macrophyte abundance trends were reported. No increasing or decreasing epiphyte abundance trends were reported, although epiphyte trends for 12 estuaries were unknown in at least one salinity zone (Figure 5).

Nutrients

Nutrient concentrations in the South Atlantic region were characterized by collecting existing conditions and trends information for nitrogen and phosphorus. The intent was to collect information for total dissolved nutrients, since it is the dissolved forms that are available for uptake by phytoplankton. Unless specifically noted otherwise, nutrient information presented in this report refers to total dissolved nitrogen (TDN) and phosphorus (TDP), including the inorganic and organic forms.

Results indicate that medium and high concentrations of both nitrogen and phosphorus occur throughout all salinity zones in the South Atlantic region. The spatial extent of medium or greater concentrations of nitrogen range from about 6 percent in the tidal fresh zone up to 21 percent in the seawater zone. The spatial extent of these concentrations of phosphorus range from about 8 percent in the seawater zone to almost 50 percent in the tidal fresh zone.

Trends information for nutrients, although more complete than other parameters, is still limited, especially in the seawater zone. The trends information reported indicates that in most estuaries, there is no change in nutrient concentrations, especially in the mixing zone, or that there is a decreasing trend, especially in the tidal fresh and mixing zones (Figure 5).

Nitrogen

High nitrogen concentrations (≥1.0 mg/l) have been observed in 11 of 21 South Atlantic estuaries (Figure 4). These observations were recorded primarily for the tidal fresh zone (up to 70 square miles or 15 percent of the regional tidal fresh zone) and mixing zone (up to 79 square miles or 2 percent of the regional mixing zone). In the seawater zone, high nitrogen concentrations were reported only for portions of the Indian River. Medium nitrogen concentrations (≥0.1-1.0 mg/l) have been reported in 18 of 21 South Atlantic estuaries. Low nitrogen concentrations (>0-0.1 mg/l) were reported in 9 of 21 South Atlantic estuaries. For four estuaries, existing conditions were based on either Total Nitrogen (Cape Fear River and Charleston Harbor), Dissolved Inorganic Nitrogen (Bogue Sound), or ammonia plus nitrate (New River).

No trends in nitrogen concentrations were reported for all or part of 9 of the 21 estuaries (Figure 5). Speculative increases between 25 and 100 percent over the past 8 to 15 years were reported for St. Catherines/Sapelo Sounds and St. Andrews/St. Simons Sounds. Low magnitude (0 to 25 percent) increases were reported for the Neuse River and for the northern seawater portion of Biscayne Bay. Decreases of 25 to 100 percent were reported for Winyah Bay, North/South Santee Rivers, Stono/North Edisto River, and Altamaha River. Low magnitude increases were reported for Charleston Harbor. Trends for five estuaries were based on either Total Nitrogen (Cape Fear River and Charleston Harbor), Total Dissolved Nitrogen (Neuse River and Bogue Sound), or ammonia plus nitrate (New River).

Phosphorus

High phosphorus concentrations (≥0.1mg/l) were reported in 9 of 21 South Atlantic estuaries including a small portion of the region's tidal fresh zone (29-70 square miles or 6-15 percent), the mixing zones of New River, Winyah Bay, and Charleston Harbor (throughout the year) and of Cape Fear and Broad River (during the summer months), and the seawater zone of portions of the Indian River (Figure 4). Medium phosphorus concentrations (≥0.01-0.1) were reported for 16 of 21 South Atlantic estuaries. Low phosphorus concentrations (>0-0.01 mg/l) were reported for Bogue Sound, St. Catherines/Sapelo Sounds, and St. Marys/Cumberland Sounds. For three estuaries (New River, Cape Fear River and Charleston Harbor), existing conditions were based on Total Phosphorus.

No trends in phosphorus concentrations were reported for 11 of 21 estuaries (Figure 5). Low to medium magnitude decreasing trends were reported for six estuaries. Speculative increasing trends were reported for St. Catherine/Sapelo Sounds and St. Andrew/St. Simons Sounds. Trends for three estuaries (New River, Cape Fear River and Charleston Harbor) were were based on Total Phosphorus.

Dissolved Oxygen

Dissolved oxygen concentrations in the South Atlantic region were characterized by collecting information on existing conditions and trends for three conditions: anoxia (0 mg/l), hypoxia (>0 mg/l< 2 mg/l), and biological stress (>2 mg/l< 5 mg/l). The location of these conditions in the water column (surface, bottom, throughout the water column), and the influence of water column stratification (high, medium, low, not a factor) were also recorded. Spatial extent of each condition was also noted.

Highly variable concentrations of low dissolved oxygen were reported throughout the region (Figure 4). Eleven of 21 estuaries have anoxic/hypoxic levels of dissolved oxygen at some point during the year. Anoxia/hypoxia were reported as periodic, mainly during the summer months, in estuaries of the Carolina Capes and northern Sea Island Coast subregions. However, the spatial extent of these conditions was low (0 to 25 percent). Only minor incidences of low dissolved oxygen were reported for the southern estuaries of the Sea Island Coast. Periodic occurrences of anoxia/hypoxia were also reported for the Florida estuaries. Water column stratification is reported as a major factor in the expression of this condition for portions of the Carolina Capes and Florida estuaries only.

Minimum average monthly bottom concentrations of dissolved oxygen were reported as decreasing for three estuaries, increasing for one estuary, and not changing for three estuaries.

Anoxia

Anoxic conditions were reported in 11 of 21 estuaries for approximately 13 percent of the total estuarine surface area (563 square miles) (Figure 4). There was only one recorded occurrence of anoxia in the Sea Island Coast estuaries—the Savannah River estuary, where anoxia was observed in the mixing zone. If anoxia was present, the spatial extent of this condition was generally very low (0 to 10 percent) to low (10 to 25 percent) except for Neuse River, St. Helena Sound, and Indian River, where it was medium (25 to 50 percent). When anoxic conditions were reported for the mixing zone, it was also observed in the tidal fresh zone.

Water column stratification was a major factor in the expression of anoxia in the Pamlico/Pungo Rivers, Neuse River, and in Indian River. In each case, it occurred at the bottom of the water column. Anoxic events are mostly periodic, beginning in June and ending in September, though some occurrences have been reported as early as April in the Carolina Capes and Florida estuaries.

Trends were reported for six estuaries: five had no change in conditions, while one (Neuse River) reported increases in spatial extent, frequency of occurrence, and duration of anoxic conditions (Figure 5).

Hypoxia

Hypoxic conditions of dissolved oxygen (>0mg/l < 2 mg/l) were reported in 13 of 21 South Atlantic estuaries, for approximately 17 percent of the region's estuarine surface area (750 square miles) (Figure 4). The spatial extent of these conditions was reported as medium (25 to 50 percent) for 8 estuaries, and very low (0 to 10 percent) or low (10 to 25 percent) for the remainder.

Water column stratification was a major factor in the expression of hypoxic conditions within three estuaries (Pamlico/Pungo, Neuse, and Indian Rivers). Hypoxia events are mostly periodic, beginning in June and ending in September, though some occurrences have been reported as early as April in the Neuse and Indian Rivers.

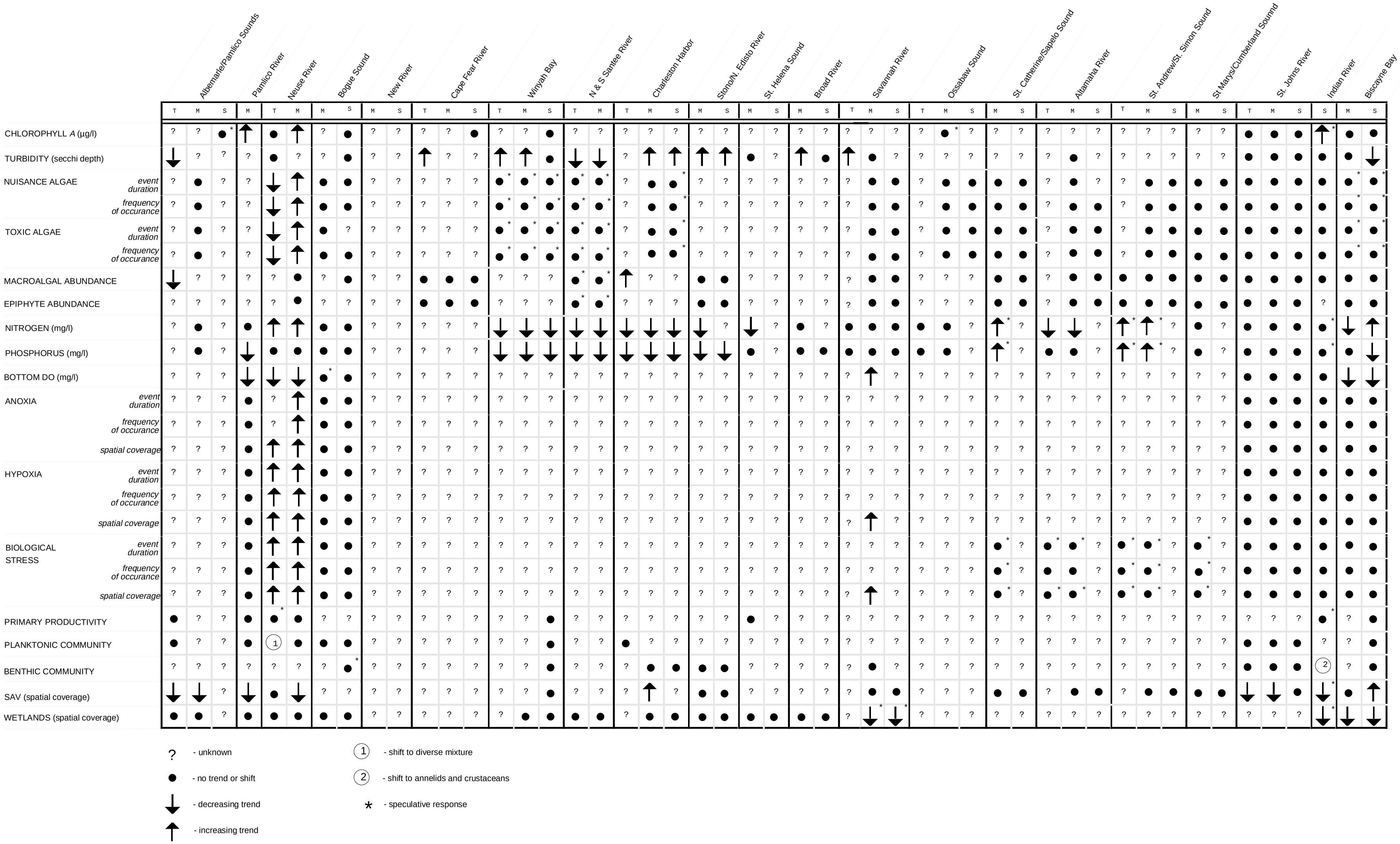
Trends were reported for seven estuaries: five reported no change in conditions, while Neuse River reported increases in spatial extent, frequency of occurrence, and duration of hypoxic conditions (Figure 5). Savannah River reported increased spatial coverage of hypoxia, but only in the mixing zone.

Biological Stress

Biologically stressful levels of dissolved oxygen (>2mg/l<5 mg/l) were reported in 20 of 21 South Atlantic Estuaries (Bogue Sound being the exception), for approximately 30 percent of the region's estuarine surface area (1,190 mi^2). A medium (25 to 50 percent) to high (50 to 100 percent) spatial extent of these conditions was predominant throughout much of the Carolina Capes and northern Sea Island Coast systems.

Water column stratification was a major factor in the expression of biologically stressed conditions within the Pamlico/Pungo, Neuse, and Indian River estuaries only. Biological stress was observed throughout the water column in 11 of 21 estuaries. Biologically stressed conditions events are mostly periodic, begin-

Figure 5: *Recent trends (1970 - present) for selected parameters by estuary by salinity zone (T, tidal fresh; M, mixing; S, seawater). All salinity zones are not present in all estuaries. Most of the 1,225 possible values are unknown (736). There are 51 decreasing trends, 47 increasing trends, and 389 no trends. Seventy-one values are based on speculative inferences. For a more complete listing of the trends parameters, see Table 1 on page 3.*



ning in June and ending in September, though some occurrences have been reported as early as April in the Neuse and Indian Rivers.

Trends were reported for eleven estuaries: nine had no change, while two (Neuse and Savannah Rivers) were reported to have increases in the spatial extent of biologically stressed levels of dissolved oxygen (Figure 5). Neuse River also observed increases in duration and frequency of occurrence of these events.

Ecosystem/Community Response

The responses of estuarine ecosystems to nutrient inputs were characterized by collecting information on the status and trends of five parameters: primary productivity, planktonic and benthic communities, submerged aquatic vegetation (SAV), and intertidal wetlands. The information reported for these parameters was limited, especially for trends, where only 18 percent of the region's estuarine surface area was characterized.

The dominant primary producer varied by estuary and salinity zone between pelagic, benthic, SAV, and intertidal wetlands. Diatoms were reported as the dominant planktonic group, followed by flagellates, and a diverse mixture of plankton groups. The dominant benthic community in the region was a diverse mixture of organisms (e.g., annelids, crustaceans, mollusks), followed by annelids and polychaetes. SAV and intertidal wetlands were each reported in approximately two-thirds of the region's estuarine area, primarily in the mixing and seawater zones. SAV was reported mostly in the Carolina Capes and Florida subregions, while wetlands were present throughout the region.

Available trends information suggests that the region's estuarine ecosystems are generally stable. Only one instance of ecosystem shifts in the planktonic community and one in the benthic community were reported. Declining trends in intertidal wetland coverage were reported in three estuaries. Declining trends for SAV were reported in five estuaries, accounting for 80 percent of the area in which SAV was reported (Figure 5).

Primary Productivity

Four biological communities were reported as the dominant primary producers in the South Atlantic region: pelagic communities in five estuaries (5 of 9 Carolina Capes estuaries); intertidal wetlands in nine (all nine Sea Island Coast systems); and benthic communities and SAV in two estuaries (Indian River and Biscayne Bay). Each of the four communities was reported as dominant across approximately eight percent of the region's estuarine surface area. The dominant primary producer was unknown for most of the remaining area.

Benthic and seagrass communities were reported as the dominant primary producer almost exclusively in the seawater zone, while intertidal wetlands were reported in both the seawater and mixing zones. Pelagic communities or a diverse mixture of pelagic, benthic and/or other communities were identified as the dominant primary producer in 3 of the region's 11 tidal fresh zones; information in the remaining tidal fresh zones was unavailable.

Temporal shifts in primary productivity, i.e., shifts in dominance from one primary producer to another, was reported as unknown in all of 13 and parts of 18 South Atlantic estuaries (80 percent of the region's estuarine surface area). Where information was reported, no shifts occurred.

Planktonic Community

Diatoms were identified as the most dominant plankton group, in terms of abundance, in 12 of 21 South Atlantic estuaries (58 percent of the region's estuarine surface area). Most of the remaining estuarine surface area was reported to be dominated by flagellates (three estuaries), or a diverse mixture of diatoms, flagellates, and/or other plankton groups (nine estuaries). An exception was blue-green algae, which was reported to be the most abundant plankton group in a portion of the tidal fresh zone in the Albemarle/Pamlico Sound. Following diatoms, a diverse mixture of plankton groups were reported to be dominant in the region's mixing zones (nine estuaries) and seawater zones (seven estuaries). In tidal fresh estuaries, diatoms were followed in abundance by flagellates.

Historical shifts in plankton dominance, from one taxonomic group to another, were reported as unknown for one or more salinity zones in 17 of 21 estuaries (78 percent of the regional estuarine surface area) and for all zones in 13 estuaries. Where information was available, no shifts were reported, with the exception of the tidal fresh zone of the Neuse River, where a shift from blue-green algae to a diverse mixture was attributed to stratification and runoff events.

Benthic Community

The dominant benthic community (with regard to abundance) reported in the South Atlantic region was a diverse mixture of annelids, crustaceans, mollusks, and/or other benthic organisms. This community occurred in at least one salinity zone in 15 of 21 estuaries, including 80 percent of the region's seawater zone, 66 percent of the mixing zone, but only 1 percent of the tidal fresh zone. Annelids were the next most abundant benthic community (reported for at least one salinity zone in eight estuaries), followed by poly-chaetes (mixing zone of Albemarle Sound). Mollusks were the dominant community in the tidal fresh zone (35 percent of the region's estuarine surface area) though they were reported only in the St. Johns River. Insects were the dominant community in the tidal fresh zone of three other estuaries.

Information regarding historical shifts in benthic dominance from one taxonomic group to another were reported in eight estuaries. Where information was available, no shifts were reported, with the exception of the seawater zone of the Indian River, where a shift from annelids to a mixture of annelids and crustaceans was attributed to nonpoint sources.

Submerged Aquatic Vegetation (SAV)

The presence of SAV was reported in 11 of 21 South Atlantic estuaries, representing 65 percent (3,221 square miles) of the region's estuarine area. SAV density (to depths of one meter below mean low water) was reported to be low (>10≤25% surface area) or very low (≤10% surface area), with the exception of medium densities (>25≤50% surface area) in Indian River and Biscayne Bay. SAV was reported in the three Florida estuaries and in 7 of 9 Carolina Cape estuaries. In contrast, no SAV was reported in North/South Santee Rivers and the entire Sea Island Coast subregion, with the exception of Charleston Harbor, where very low spatial coverage was reported for the mixing and seawater zones.

The spatial coverage of SAV was reported as declining at a low or medium magnitude in five estuaries (80 percent of the region in which it was reported to occur). Declining trends generally occurred in areas where existing spatial coverage was reported as low. A declining trend is also reported for the tidal fresh zone of Albemarle/Pamlico Sounds, suggesting that SAV has disappeared from this zone since no existing coverage was reported. Increases in coverage (of low magnitude) were reported for Charleston Harbor and Biscayne Bay (two percent of the region in which SAV was reported to occur). Trend information was reported as unknown for 15 estuaries, including 6 of the 11 estuaries in which an existing coverage of SAV was reported (Figure 5).

Intertidal Wetlands

Wetlands were recorded, in varying degrees of spatial coverage, in 14 of 21 South Atlantic estuaries. The presence of wetlands was reported as unknown for six estuaries. Seventy percent of the area in which wetlands were reported had a spatial coverage (below high water) of low to very low (≤25% surface area). Wetlands were reported in every estuary in the Carolina Capes subregion, primarily at a very low spatial coverage (≤10% surface area). Three Sea Island Coast estuaries (Charleston Harbor, St. Helena Sound, and St. Catherines/Sapelo Sounds) reported wetlands in all salinity zones at a medium or greater spatial distribution (>25% surface area). For the Florida estuaries, wetland distribution was medium (25-50% surface area) in Biscayne Bay, low in the St. Johns River, and unknown in the Indian River.

Trends in the distribution of South Atlantic intertidal wetlands were generally reported to be stable; 11 of the 14 estuaries for which wetlands were recorded were reported as having no trends (Figure 5). Decreasing trends were reported for portions of the Savannah River, Indian River, and Biscayne Bay. Trend information was reported as unknown in portions of 11 estuaries.

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Estuary Summaries

This section presents one page summaries on the status and trends of eutrophication conditions for the 21 South Atlantic estuaries. The summary information is organized into four sections; algal conditions, nutrients, dissolved oxygen, and ecosystem/community responses. Each page also includes a salinity map depicting the spatial framework for which survey information was collected, selected physical and hydrologic characteristics, and a narrative overview of the survey information.

Salinity Maps. Salinity maps depict the estuary extent, salinity zones, and subareas within the salinity zones. Salinity zones are divided into tidal fresh (0.0-0.5 ppt), mixing (0.5-25.0 ppt), and seawater (>25.0 ppt) based on average annual salinity found throughout the water column. Subareas were identified by survey participants as regions which were either better understood than the rest of a salinity zone or which behaved differently or both. Each map also has an inset showing the location of the estuary and its estuarine drainage area (EDA) (see below).

Physical and Hydrologic Data. Physical and hydrologic characteristics data are included so that readers can understand better the survey results and make meaningful comparisons among the estuaries. The EDA is the land and water component of a watershed that drains into and most directly affects estuarine waters. The average daily inflow is the estimated discharge of freshwater into the estuary. Surface area includes the area from the head of tide to the boundary with other water bodies. Average depth is the mean depth from mid-tide level. Volume is the product of the surface area and the average depth.

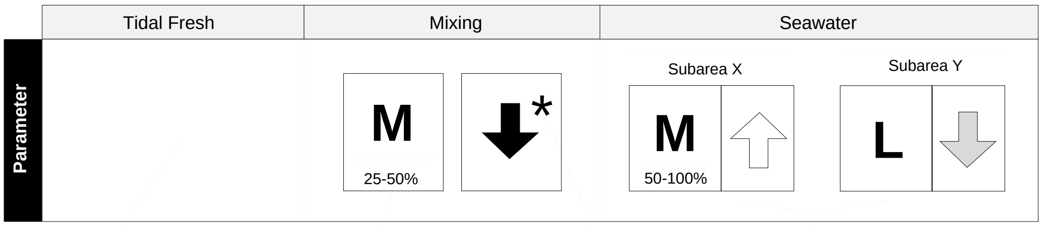
Survey Results. Selected data are presented in a unique format that is intended to highlight survey results for each estuary. The existing conditions symbols represent either the maximum conditions predominating one or more months in a typical year, or whether there are resource impacts due to bloom events. The trends (circa 1970 - 1995 unless otherwise stated) symbols indicate either the direction and magnitude of change in concentrations, or in the frequency of occurrence.

The four sections on each page include a text block to highlight additional information such as probable months of occurrence and periodicity for each parameter, limiting factors to algal biomass, nuisance and toxic algal species, nutrient forms, and degree of water column stratification.

Some parameters are not characterized by symbols on the estuary pages. These include macroalgal and epiphyte abundance, biological stress, minimum average monthly bottom dissolved oxygen trends, temporal shifts in primary productivity, benthic community shifts, intertidal wetlands, and planktonic community shifts. These parameters are described in the Regional Overview section (starting on page 5) and, where relevant, highlighted in the text blocks under each parameter section on the estuary pages.

A key is provided below that explains the symbols used on the summary pages. See Table 1 on page 3 for complete details about the characteristics of each parameter.

Key to Symbols Used on Estuary Summaries

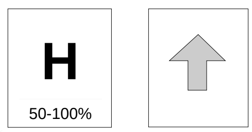


Salinity Zone Absent: if the salinity zone is not present in the estuary the entire box is left blank

Spatial Coverage: surface area over which condition occurs (not listed for nuisance/toxic algae or low/not observed conditions)

Reliability: indicates assessment made from speculative inferences

Salinity Zone Divided: salinity zones are often divided into subareas to account for unique characteristics



Existing Conditions

Concentrations

(Chl-a, Turbidity, Nutrients, SAV)

E hypereutrophic
- chl-a: >60 µg/l

H high
- chl-a: >20, ≤60 µg/l
- turbidity: secchi <1m
- TDN: ≥1 mg/l
- TDP: ≥0.1 mg/l
- SAV >50, ≤100 % coverage

M medium
- chl-a: >5, ≤20 µg/l
- turbidity: secchi ≥1m, ≤3m
- TDN: ≥0.1, <1 mg/l
- TDP: ≥0.01, <0.1 mg/l
- SAV >25, ≤ 50 % coverage

L low
- chl-a: >0, ≤5 µg/l
- turbidity: secchi >3m
- TDN: >0, <0.1 mg/l
- TDP: >0, <0.01 mg/l
- SAV >10, ≤ 25 % coverage

VL very low
- SAV >0, ≤10 % coverage

NS no SAV in zone

B blackwater area

? unknown

Event Occurrences

(Nuisance/Toxic Algae, d.o.)

Y impacts on resources
- nuisance algae: impacts occur
- toxic algae: impacts occur

or

low d.o. is observed
- anoxia: 0 mg/l
- hypoxia: >0, ≤2 mg/l

N no resource impacts
- no nuisance algae impacts
- no toxic algae impacts

or

low d.o. not observed
- no anoxic events
- no hypoxic events

? unknown

Trends (circa 1970-1995)

(Concentrations or Frequency of Event Occurrences)

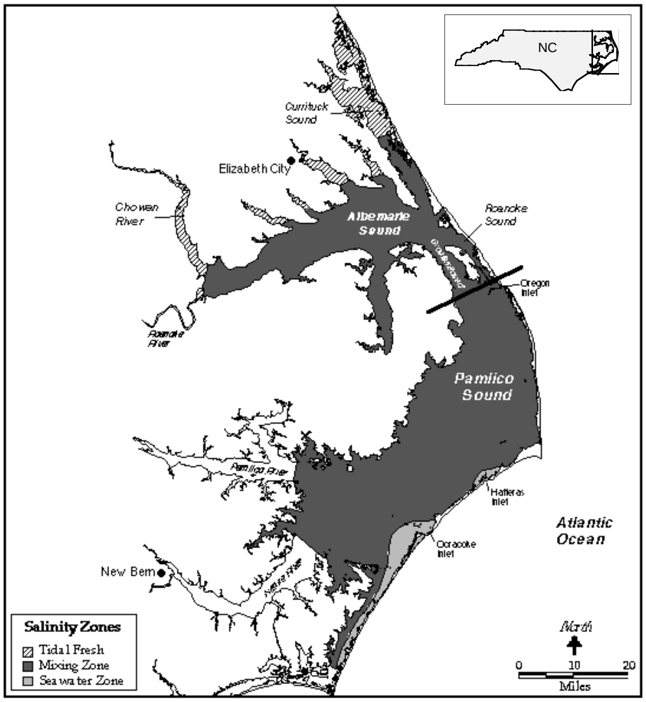
Direction of Change

- increase
- decrease
- – – – no trend
- ? unknown

Magnitude of Change

- high >50%, ≤100%
- medium >25%, ≤50%
- low >0%, ≤25%
- magnitude unknown

Albemarle/Pamlico Sounds



Albemarle/Pamlico Sounds are characterized as having moderate to hypereutrophic levels of chlorophyll-*a* and moderate to high turbidity levels. Periodic occurrences of nuisance algae and episodic occurrences of toxic algae are reported during late summer months. Nitrogen and phosphorus levels are moderate to high and anoxia and hypoxia are reported for limited bottom areas.

Extreme conditions are generally observed in the Chowan River with more moderate conditions reported for Pamlico Sound. Conditions in much of the remainder of the estuary are unknown. Trends are generally unknown throughout the estuary except for a decrease in turbidity in the Chowan River. SAV decreased significantly in the tidal fresh zone and to a lesser degree in the mixing zone of Pamlico Sound.

Physical and Hydrologic Characteristics

Estuarine Drainage Area (*mi²*) **12,781** Avg. Daily Inflow (*cfs*) **46,000**

	Estuary	Tidal Fresh		Mixing		Seawater
		In General	Chowan River	Albemarle Snd.	Pamlico Snd.	
Surface Area (*mi²*)	2,7686	183	48	765	1670	101
Average Depth (*ft*)	13.5	6.4	18	15.6	13.9	5.8
Volume (*billion cu ft*)	1063	33	24	350	640	16

A large, bar-built lagoonal system bordered on the east side by barrier beaches forming the Outer Banks. Roanoke and Chowan rivers are the major freshwater inputs to Albemarle Sound. Tides range 2 ft near the inlets but are dampened to 0.6 ft within Pamlico Sound. Salinity variability and water-column mixing in the sounds is dominated by prevailing wind-driven circulation and currents.

Algal Conditions

	Tidal Fresh				Mixing				Seawater	
	In General		Chowan River		Albemarle Snd.		Pamlico Snd.			
Chlorophyll-a	?	?	E 50-100%	?	?	?	M 50-100%	?	M* 50-100%	--- *
Turbidity	?	?	H 50-100%	⇩ ?	?	?	M 25-50%	?	?	?
Nuisance Algae	N	?	Y	?	?	?	Y	---	?	?
Toxic Algae	N	?	Y	?	?	?	Y	---	?	?

Chl-a conditions occur in summer in all zones and winter in mixing and seawater zones. Occurrences are periodic in tidal fresh and mixing and episodic in seawater zone. Limiting factors are nitrogen, phosphorus, and light in Chowan R.; nitrogen in mixing and seawater zones.Turbidity conditions occur periodically Feb. to Sept. in Chowan R. and all year in Pamlico Sound. Nuisance/toxic *Anabaena portoricensis, Aphanizomenon flosaquae, and Microcystis aeroginsoa* occur periodically June to Sept. in Chowan R. In Pamlico Sound nuisance *Anabaena raciborski* occurs July to Sept.; toxic *Pfiesteria piscicida* occurred once in 1992.

Ecosystem/Community Responses

	Tidal Fresh				Mixing				Seawater	
	In General		Chowan River		Albemarle Snd.		Pamlico Snd.			
SAV	NS*	↓	NS	---	?	?	L	⇩	L	?

Planktonic community dominated by blue-green algae in Chowan R.; diatoms in Pamlico Sound and seawater zone. Polychaetes and mollusks dominate benthic community in mixing and seawater zones. Contributing sources to SAV decline were not reported.

Nutrients

	Tidal Fresh				Mixing				Seawater	
	In General		Chowan River		Albemarle Snd.		Pamlico Snd.			
Nitrogen	?	?	H 50-100%	?	?	?	L*	---	?	?
Phosphorus	?	?	H 50-100%	?	?	?	M*	---	?	?

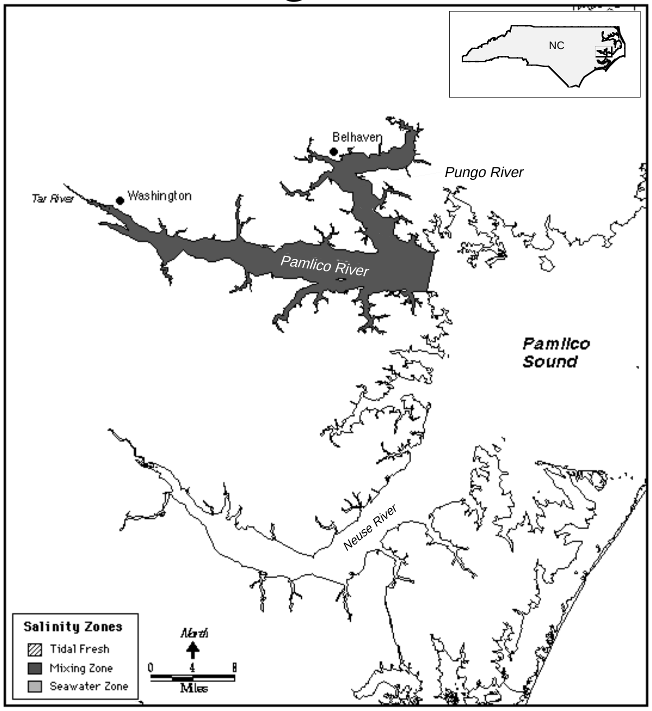
Elevated concentrations of TDN and TDP occur Feb. to April in Chowan R. TDP concentrations in Pamlico Sound occur June to Aug.

Dissolved Oxygen

	Tidal Fresh				Mixing				Seawater	
	In General		Chowan River		Albemarle Snd.		Pamlico Snd.			
Anoxia	?	?	Y* 10-25%	?	?	?	Y* 0-10%	?	?	?
Hypoxia	?	?	Y* 10-25%	?	?	?	Y* 0-10%	?	?	?

In Chowan R. and Pamlico Sound, anoxia/hypoxia occur July to Sept. at bottom of water column. Water column stratification plays moderate role in these conditions. Conditions occur periodically in Chowan R. and episodically in Pamlico Sound.

Pamlico/Pungo Rivers



Pamlico/Pungo Rivers are characterized as having periodically high levels of chlorophyll-*a* and moderate turbidity. Biological resource impacts from episodic occurrences of toxic algae are also reported. Nutrient levels are moderate and anoxia and hypoxia occur periodically in limited bottom areas.

Trends vary from a significant increase in chlorophyll-*a* to a modest decrease in phosphorus to no trends for nitrogen and dissolved oxygen. No trends were reported for the limited amount of SAV.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **2,118** Avg. Daily Inflow *(cfs)* **4,600**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	**170.6**		**170.6**	
Average Depth *(ft)*	**9.4**		**9.4**	
Volume *(billion cu ft)*	**44.7**		**44.7**	

Receives majority of freshwater from Tar River. Moderate stratification occurs especially in Feb-April during high-inflow period. Tides range 2 ft near the inlets of Outer Banks to 1 ft at mouths of Pamlico and Pungo rivers. Winds can significantly influence water elevation and circulation and tend to override tidal influences.

Algal Conditions

	Tidal Fresh	Mixing	Seawater
Chlorophyll-a		In General: H (50-100%) --- ; Upper Pamlico: H (50-100%) ↑	
Turbidity		M (50-100%) ?	
Nuisance Algae		N ?	
Toxic Algae		Y ?	

Chl-a and turbidity conditions occur periodically in winter and summer. Nitrogen and light are limiting to algal biomass. Increasing chl-a concentrations in upper Pamlico River due to best management practices leading to less light limitation. Toxic *Pfiesteria piscicida* occurs episodically mid to late summer, with durations of less than a week.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater
SAV		L ---	

Primary production is dominated by pelagic community; planktonic community dominated by flagellates; benthic community dominated by annelids and crustaceans. Intertidal wetlands coverage is low.

Nutrients

	Tidal Fresh	Mixing	Seawater
Nitrogen		M (50-100%) ---	
Phosphorus		M (50-100%) ↓	

Elevated concentrations of TDN and TDP occur January to March. Decreasing TDP is associated with point sources modifications.

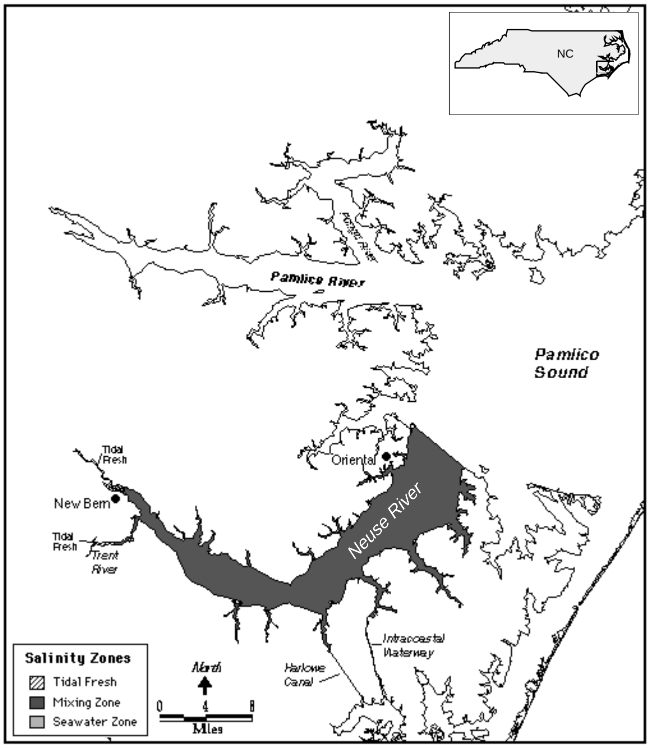
Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater
Anoxia		Y (0-10%) ---	
Hypoxia		Y (25-50%) ---	

Periodic occurrences of anoxia/hypoxia occur June to October, typically at bottom of water column. Water column stratification contributes to these conditions. Minimum average monthly bottom dissolved oxygen concentrations decreased from 1970 to 1990.

Key on page 20

Neuse River



Nuese River is characterized as having moderate to hypereutrophic chlorophyll-*a* conditions and moderate turbidity. Nuisance and toxic algae are reported as impacting biological resources during events that occur from early summer to early fall. Nitrogen and phosphorus are reported at moderate concentrations. Anoxia and hypoxia events occur periodically from June to October across a moderate portion of the estuary.

These conditions occur predominantly in the mixing zone which represents almost the entire estuary. Trends for most parameters are reported as increasing. Decreasing trends are observed for nuisance and toxic algae in the tidal fresh zone. The limited SAV in the mixing zone is also reported as decreasing.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **2,221** Avg. Daily Inflow *(cfs)* **6,200**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	177.6	1.9	175.7	
Average Depth *(ft)*	11.5	9.3	11.4	
Volume *(billion cu ft)*	56.8	0.5	56.3	

Receives majority of freshwater from both the Neuse and Trent rivers. Salinity stratification often occurs near mouth of Neuse River but is more common further upstream. Tides range 1 ft near entrance to the Pamlico Sound. Winds can significantly influence water elevation and circulation and generally override tidal influences on salinity structure.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyl-a	M 25-50%	- - -	E 25-50%	↑		
Turbidity	B	- - -	M 25-50%	?		
Nuisance Algae	Y	↓	Y	↑		
Toxic Algae	Y	↓	Y	↑		

Chl-a conditions occur periodically spring to early fall and, in mixing zone, in winter. Nitrogen and phosphorus are limiting in tidal fresh zone; nitrogen in mixing zone. Turbidity concentration maximums in mixing zone occur periodically winter to summer and episodically with high flow and algal blooms. Nuisance algae and toxic algae (*Pfiesteria piscicida*) events generally occur early summer to early fall and last a month or longer.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	NS	- - -	VL	↓ ?		

Primary production is dominated by pelagic community. Dominance shift occurred from blue green algae to diverse mixture in tidal fresh zone. Annelids are dominant benthic group. Intertidal wetlands coverage is very low.

Nutrients

	Tidal Fresh		Mixing		Seawater	
Nitrogen	M 50-100%	↑	M 25-50%	↑		
Phosphorus	M 50-100%	- - -	M 25-50%	- - -		

In tidal fresh zone, reported elevated concentrations of TDN and TDP occur February to June. In mixing zone, reported elevated concentrations occur January to April for TDN and January to April and June to August for TDP. Trends in nitrogen are for DIN over last five years.

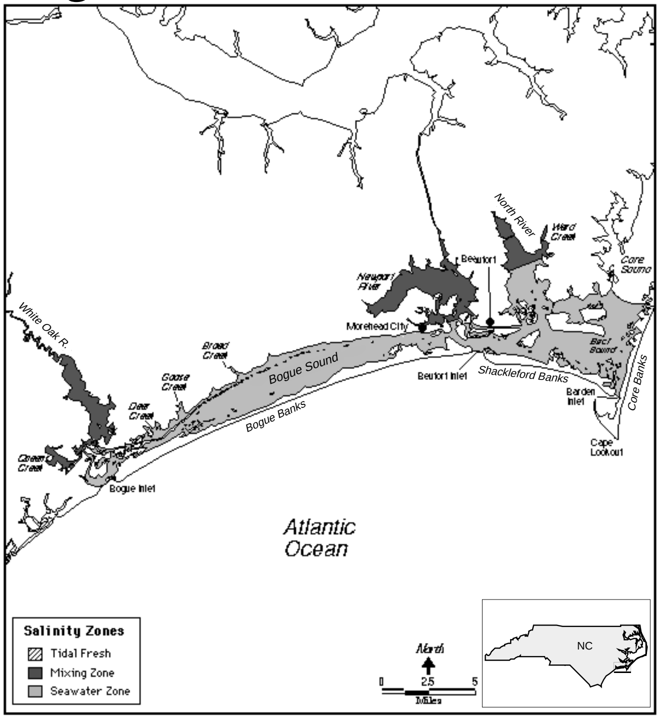
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	Y* 25-50%	?	Y 25-50%	↑		
Hypoxia	Y 25-50%	↑	Y 25-50%	↑		

Periodic occurrences of anoxia/hypoxia occur June to October; typically at bottom of water column. Water column stratification contributes significantly to these conditions. Minimum average monthly bottom dissolved oxygen concentrations have decreased and spatial coverage of anoxic/hypoxic conditions for tidal fresh and mixing zones have increased.

Key on page 20

Bogue Sound



Bogue Sound is characterized as having moderate levels of cholorophyll-*a* and moderate to high turbidity. There are no biological resource impacts associated with nuisance algae and toxic algae events are extremely rare. Moderate levels of dissolved inorganic nitrogen are reported for the seawater zone. No anoxia or hypoxia are observed.

These conditions are observed in the mixing and seawater zones. Trends are reported as either unknown or no trend. Limited SAV is present in the mixing and seawater zones.

Physical and Hydrologic Characteristics

Estuarine Drainage Area (*mi2*) **691** Avg. Daily Inflow (*cfs*) **1,300**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area (*mi2*)	104.4		27.6	76.8
Average Depth (*ft*)	4.6		2.4	5.1
Volume (*billion cu ft*)	12.9		1.9	11

A shallow, lagoonal estuarine system containing numerous shoals and disposal areas for dredged material. Tidal mixing promotes a fairly uniform seasonal salinity structure. Vertically homogeneous salinities are common in Bogue and Back sounds. White Oak, Newport, and North rivers have strong horizontal salinity gradients during late winter and spring. Moderate vertical stratification is common.

Algal Conditions

	Tidal Fresh	Mixing	Seawater
Chlorophyll-a		M (50-100%) ?	M (50-100%) - - -
Turbidity		H (50-100%) ?	M (50-100%) - - -
Nuisance Algae		N - - -	N - - -
Toxic Algae		N - - -	Y - - -

Chl-a maximums occur in spring in mixing zone and in summer in seawater zone. Nitrogen is limiting factor in mixing and seawater zones. Turbidity conditions occur continuously throughout the year. A one time event of *Gymnodinium brevis* occurred 11/87 to 2/88 due to Gulf transport. However, conditions in the estuary allowed it to sustain.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater
SAV		L ?	L ?

Planktonic community dominated by diatoms; benthic community dominated by annelids and diverse mixture. Intertidal wetlands range from low to medium coverage.

Nutrients

	Tidal Fresh	Mixing	Seawater
Nitrogen		L - - -	M (50-100%) - - -
Phosphorus		L - - -	L - - -

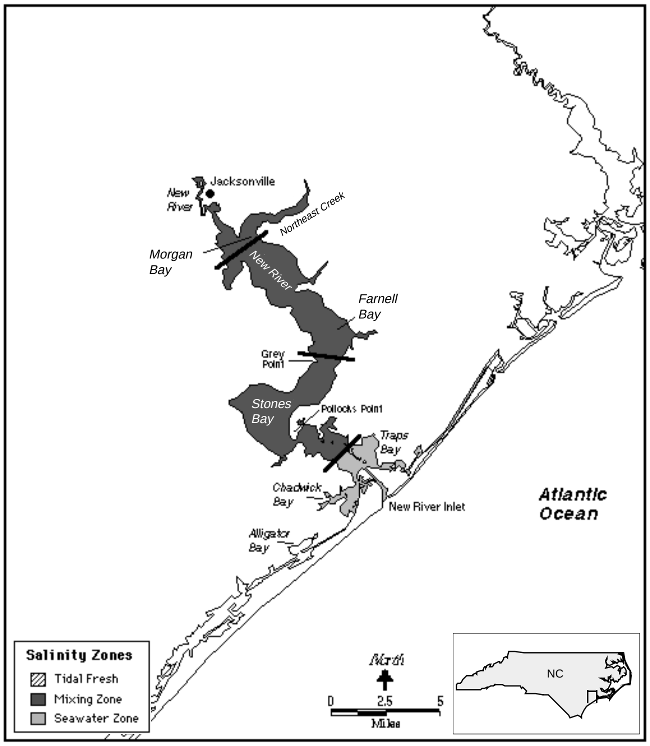
Concentrations in mixing zone for nitrogen are reported as DIN; concentration of nitrogen in seawater zone is more than 90% DON. Trends for nitrogen are for DIN.

Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater
Anoxia		N - - -	N - - -
Hypoxia		N - - -	N - - -

Key on page 20

New River



New River is characterized as having moderate to hypereutrophic levels of chlorophyll-*a* and moderate to high levels of turbidity. Biological resource impacts from periodic nuisance algae and episodic toxic algae occur in summer and winter months. Nitrogen and phosphorus are moderate to high though they occur at different times of the year. Bottom-water hypoxia in late summer months is reported.

These conditions occur primarily in the mixing zone which represents more than 80 percent of the estuary. More extreme conditions generally occur in Morgan Bay. Trends information is unknown for all parameters. SAV is present in very limited amounts in the seawater zone.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **471** Avg. Daily Inflow *(cfs)* **800**

	Estuary	Tidal Fresh	Mixing: Morgan Bay	Mixing: Farrell Bay	Mixing: Stones Bay	Seawater
Surface Area *(mi2)*	32.8		4.0	12.0	12.0	4.8
Average Depth *(ft)*	5.8		5.4	6.1	5.9	4.4
Volume *(billion cu ft)*	5.2		0.6	2.0	2.0	0.6

Consists of three major bays (Morgan, Farnell, Stones) in upper estuary, and smaller features to the south in lower or seawater portion. Freshwater from the New River is dominant influence on salinity structure, especially above Pollocks Point. Tidal influence generally restricted to lower estuary where increases in vertical mixing cause relatively stable salinities to persist. Moderate stratification is fairly common in upper portion of New River, especially during high-inflow conditions.

Algal Conditions

	Tidal Fresh	Mixing: Morgan Bay	Mixing: Farnell Bay	Mixing: Stones Bay	Mixing (zone)	Seawater
Chlorophyll-a		E (25-50%) ?	H (50-100%) ?	H (25-50%) ?		M* (?) ?
Turbidity		H (50-100%) ?	H (50-100%) ?	M (25-50%) ?		? ?
Nuisance Algae					Y ?	N* ?
Toxic Algae					Y ?	? ?

In mixing zone, maximum chl-a and turbidity concentrations occur periodically summer and winter with nitrogen and silica limiting biomass. Nuisance and toxic algae also occur during summer and winter months. Toxic algal events are episodic and are days in duration.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater
SAV		NS ?	VL ?

Primary production is dominated by pelagic community; planktonic community dominated by mixture of diatoms and flagellates; benthic community dominated by annelids in seawater zone.

Nutrients

	Tidal Fresh	Mixing: Morgan Bay	Mixing: Farnell Bay	Mixing: Stones Bay	Seawater
Nitrogen		H (25-50%) ?	M (25-50%) ?	M (25-50%) ?	L ?
Phosphorus		H (25-50%) ?	M (25-50%) ?	M (25-50%) ?	M (50-100%) ?

Concentrations of nitrogen are for ammonia and nitrate; concentrations of phosphorus are for total phosphorus and orthophosphate. In Farnell Bay and Stones Bay elevated nitrogen concentrations occur December to March; elevated phosphorus concentrations occur May to October.

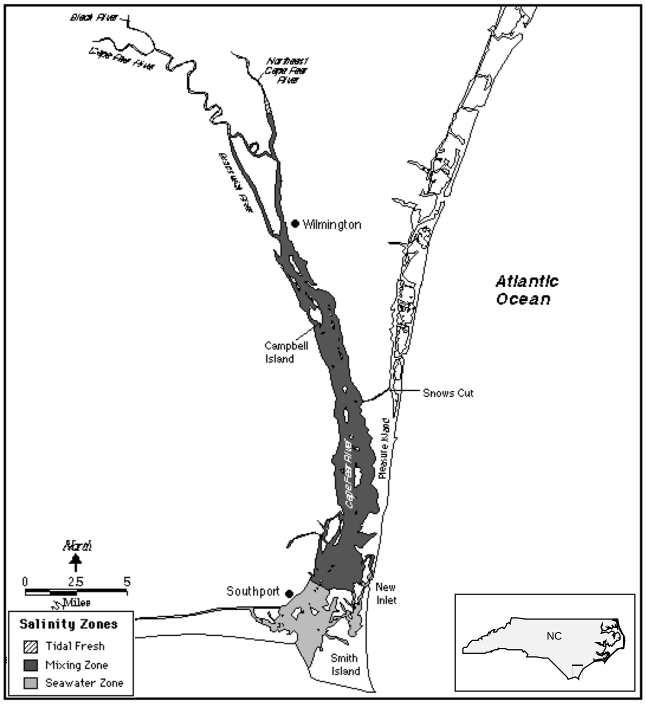
Dissolved Oxygen

	Tidal Fresh	Mixing: Morgan Bay	Mixing: Farnell Bay	Mixing: Stones Bay	Seawater
Anoxia		N ?	N ?	N ?	N ?
Hypoxia		Y (25-50%) ?	Y (25-50%) ?	N ?	N ?

Periodic, bottom-water hypoxia occurs in mixing zone June to September. Water column stratification plays a moderate role in these conditions.

Key on page 20

Cape Fear River



Cape Fear River is characterized as having moderate to high levels of chlorophyll-*a* and turbidity. Biological resource impacts from nuisance and toxic algae do not occur. Nitrogen and phosphorus are reported at moderate to high concentrations throughout most of the estuary. No anoxia or hypoxia are observed.

These conditions occur primarily in the mixing zone which represents more than 75 percent of the estuary. Trends are almost all unknown. Very low amounts of SAV are present in all salinity zones.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **4,364** Avg. Daily Inflow *(cfs)* **10,100**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	38.3	0.35	29.4	8.9
Average Depth *(ft)*	11.5	20.2	10.2	11.7
Volume *(billion cu ft)*	11.3	0.023	8.4	2.9

Receives the majority of freshwater inflow from the Cape Fear, Black, and Northeast Cape Fear rivers. Seasonal variability in freshwater inputs, governed by shifting precipitation patterns, has major effects on salinity structure. Discharge from main river systems is three times greater during early spring than in fall months. Tides are dominant influence on salinity structure and range 4.2 ft near estuary mouth. Stratification is common within navigation channels.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyll-a	M 25-50%	?	H 25-50%	?	M 50-100%	– – –
Turbidity	H 50-100%	↑ ?	H 50-100%	?	H 50-100%	?
Nuisance Algae	N	?	N	?	N	?
Toxic Algae	N	?	N	?	N	?

Maximum chl-a concentrations occur periodically April to Sept. In mixing zone; limiting factors are phosphorus, nitrogen, and light in spring, summer, and winter. In seawater zone, limiting factor is nitrogen, and light under high turbidity conditions. High turbidity concentrations occur periodically in winter in all zones and episodically with heavy rainfall or dredging activities.

Nutrients

	Tidal Fresh		Mixing		Seawater	
Nitrogen	H 50-100%	?	H 50-100%	?	M 50-100%	?
Phosphorus	H 50-100%	?	H 50-100%	?	M 50-100%	?

Concentrations are reported as total nitrogen and total phosphorus. TIN is 50-60% of total in tidal fresh zone, 40-50% in mixing zone, and 25% in seawater zone. Orthophosphate is 75% of total in tidal fresh zone, 60% in mixing zone, and 35% in seawater zone.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	VL	?	VL	?	VL	?

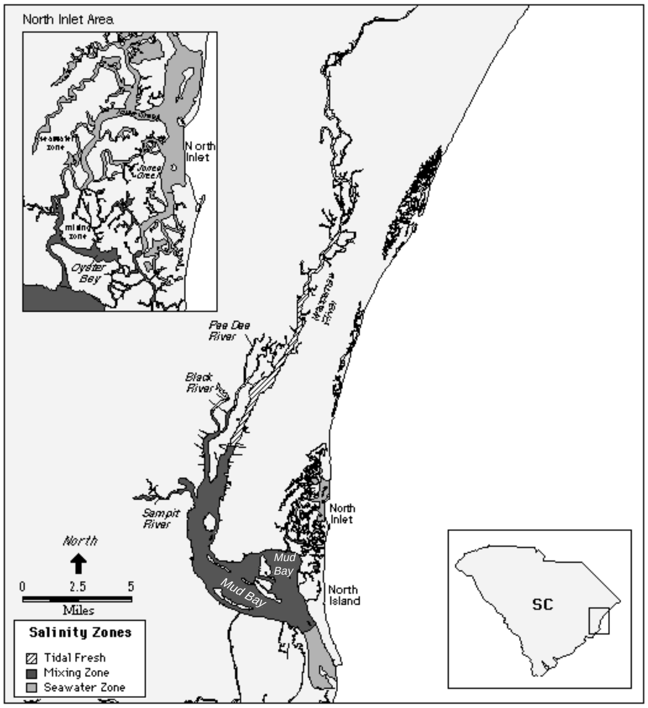
Planktonic community is dominated by mixture of diatoms and flagellates; benthic community dominated by annelids. Intertidal wetlands coverage is high in tidal fresh zone, medium in mixing zone, and low in seawater zone.

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	N	?	N	?	N	?
Hypoxia	N	?	N	?	N	?

 Key on page 20

Winyah Bay



Winyah Bay is characterized as having moderate to high levels of chlorophyll-*a* and high turbidity. Based on speculative inference, biological resource impacts from nuisance and toxic algae do not occur. Nitrogen and phosphorus are generally reported at moderate to high levels. Bottom-water anoxia and hypoxia periodically occur in the mixing zone of Winyah Bay and the seawater zone of North Inlet.

Trends reported indicate moderate increases in turbidity in the tidal fresh and mixing zones, no trends for nuisance and toxic algae, and decreasing trends for nitrogen and phosphorus. Distribution and trends for SAV are generally unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area (mi^2) **9,561** Avg. Daily Inflow (*cfs*) **20,400**

	Estuary	Tidal Fresh	Mixing: Winyah Bay	Mixing: North Inlet	Seawater: Winyah Bay	Seawater: North Inlet
Surface Area (mi^2)	41.1	12.0	22.3	0.73	3.3	2.8
Average Depth (ft)	11.0	13.9	7.4	9.4	9.7	9.3
Volume (billion cu ft)	18.5	4.7	5.4	0.2	0.9	0.7

Receives majority of freshwater inflow from Pee Dee and Little Pee Dee rivers. Seasonal inflows alter salinities approximately 10 ppt throughout most of estuary. Tides range 4.5 ft at North Inlet and salinities are generally unstratified in that area. Moderately stratified conditions are most common within mixing zone and navigation channels during early Spring but typically shift northward in Fall.

Algal Conditions

	Tidal Fresh	Mixing: Winyah Bay	Mixing: North Inlet	Seawater: Winyah Bay	Seawater: North Inlet
Chlorophyll-a	M (50-100%) / ?	M (50-100%) / ?	M (50-100%) / ?	M (50-100%) / ?	M (50-100%) / ---
Turbidity	H (50-100%) / ↑	H (50-100%) / ↑	H (50-100%) / ?	H (50-100%) / ?	H (50-100%) / ---
Nuisance Algae	N* / ---*	N* / ---*	N* / ---*	N* / ---*	N* / ---*
Toxic Algae	N* / ---*	N* / ---*	N* / ---*	N* / ---*	N* / ---*

Chl-a maximums occur periodically late spring to fall. Phosphorus is limiting in tidal fresh and mixing zone of Winyah Bay; nitrogen is limiting in North Inlet mixing zone and all of seawater zone. Light is co-limiting in all zones. Turbidity maximums occur continuously throughout the year.

Ecosystem/Community Responses

	Tidal Fresh	Mixing: Winyah Bay	Mixing: North Inlet	Seawater: Winyah Bay	Seawater: North Inlet
SAV	? / ?	? / ?	? / ?	? / ?	NS / ---

Primary production is dominated by macrophytes and diverse aquatic community in tidal fresh zone; intertidal wetlands and pelagic communities in mixing and seawater zones. Planktonic community dominated by diatoms; benthic community dominated by insects in tidal fresh zone; annelids and diverse mixture in mixing and seawater zones. Intertidal wetlands coverage high.

Nutrients

	Tidal Fresh	Mixing: Winyah Bay	Mixing: North Inlet	Seawater: Winyah Bay	Seawater: North Inlet
Nitrogen	H (50-100%) / ↓	H (50-100%) / ↓ (solid)	M (50-100%) / ?	M (50-100%) / ?	M (50-100%) / ↓
Phosphorus	H (50-100%) / ↓	H (50-100%) / ↓	L / ?	L / ?	M (50-100%) / ↓

Trends in tidal fresh zone and mixing zone are associated with best management practices, new regulations, and a phosphate ban. In seawater zone, trends are associated with drought conditions.

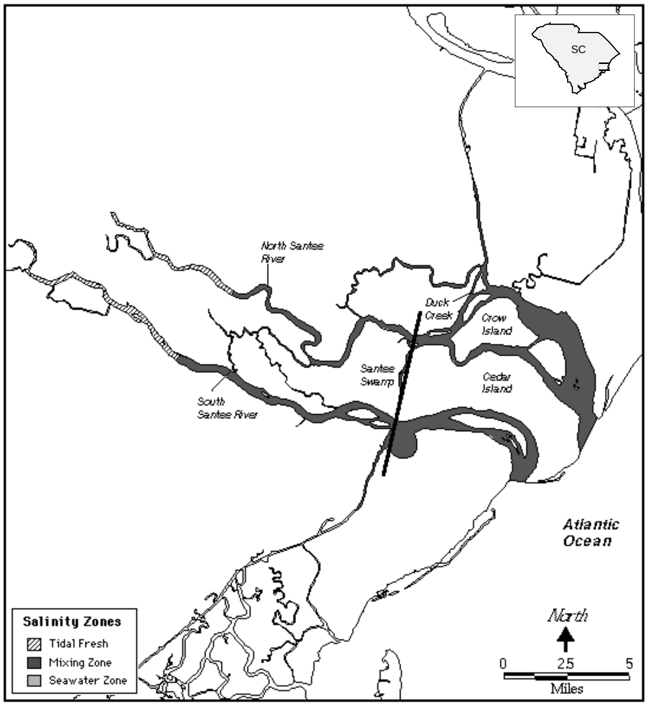
Dissolved Oxygen

	Tidal Fresh	Mixing: Winyah Bay	Mixing: North Inlet	Seawater: Winyah Bay	Seawater: North Inlet
Anoxia	N / ?	Y (10-25%) / ?	? / ?	? / ?	Y (0-10%) / ?
Hypoxia	N / ?	Y (25-50%) / ?	? / ?	? / ?	Y (10-25%) / ?

Periodic occurrences of anoxia/hypoxia have been reported May to September in mixing zone, typically at bottom of water column. In North Inlet, periodic occurrences occur August to September only. Water column stratification was not a factor.

Key on page 20

North/South Santee Rivers



North/South Santee Rivers are characterized by unknown levels of chlorophyll-*a* and turbidity and no occurrence of nuisance or toxic algae throughout the estuary. Nitrogen and phosphorus are reported at moderate concentrations during the late summer months. Anoxia and hypoxia are unknown throughout the estuary.

The conditions reported occur predominantly in the mixing zone which represents approxiately 90 percent of the estuary. Trends for turbidity, nitrogen, and phosphorus are reported as decreasing significantly due to rediversion of water in the estuary. Nuisance and toxic algae are reported as having no recent trends. The current distribution and trends for SAV are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi²)* **718** Avg. Daily Inflow *(cfs)* **12,450**

	Estuary	Tidal Fresh	Mixing: Western Half	Mixing: Eastern Half	Seawater
Surface Area *(mi²)*	9.1	0.97	4.0	5.0	
Average Depth *(ft)*	6.1	5.3	7.2	6.4	
Volume *(billion cu ft)*	2.7	1.0	0.8	0.9	

A drowned river valley system that is highly variable with regard to freshwater and salinity structure. Changes in salinity occurred following a rediversion of freshwater inflow back into Santee River system from Lake Moultrie in 1985. Currently, horizontal salinity gradients exist, mainly in lower estuary, but stratification is generally weak. Salinities in lower rivers can vary significantly between successive high and low tides, ranging 4.2 ft near estuary mouth.

Algal Conditions

	Tidal Fresh		Mixing: Western Half		Mixing: Eastern Half		Seawater
Chlorophyll-a	?	?	?	?	?	?	
Turbidity	?	↓	?	↓	?	↓	
Nuisance Algae	N*	---*	N*	---*	N*	---*	
Toxic Algae	N*	---*	N*	---*	N*	---*	

Decreasing turbidity conditions are associated with rediversion of water in the estuary.

Ecosystem/Community Responses

	Tidal Fresh		Mixing: Western Half		Mixing: Eastern Half		Seawater
SAV	?	?	?	?	?	?	

Planktonic community is dominated by diatoms; benthic community by insects in tidal fresh zone and diverse mixture and crustaceans in mixing zone. Intertidal wetlands have high spatial coverage.

Nutrients

	Tidal Fresh		Mixing: Western Half		Mixing: Eastern Half		Seawater
Nitrogen	M 50-100%	↓	M 25-50%	↓	?	?	
Phosphorus	M 50-100%	⇩	M 25-50%	⇩	?	?	

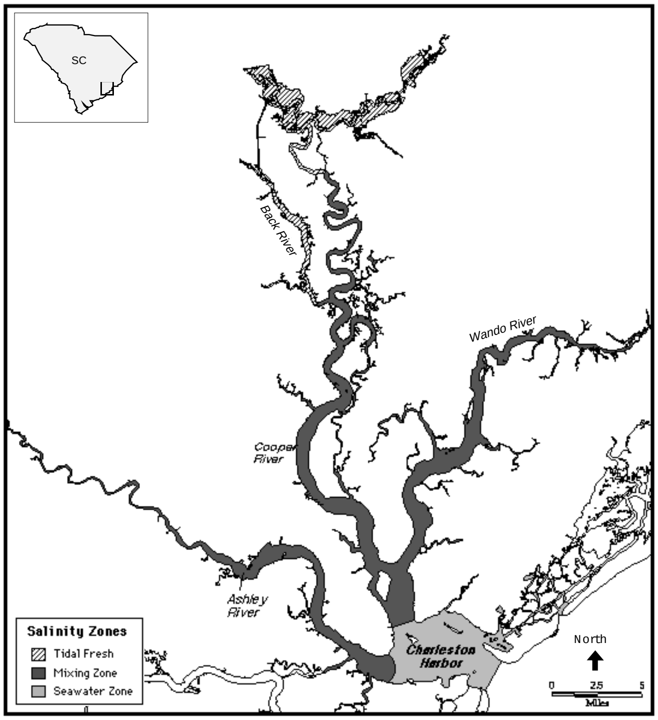
Elevated TDN concentrations occur July to September; Elevated TDP concentrations occur August to October. Trends are associated with changes in flow patterns due to water diversions.

Dissolved Oxygen

	Tidal Fresh		Mixing: Western Half		Mixing: Eastern Half		Seawater
Anoxia	?	?	?	?	?	?	
Hypoxia	?	?	?	?	?	?	

Key on page 20

Charleston Harbor



Charleston Harbor is characterized as having moderate to high levels of chlorophyll-*a* and high levels of turbidity. Biological resource impacts from nuisance and toxic algae are unknown in the tidal fresh zone and do not occur in the mixing and seawater zones. Nitrogen and phosphorus are reported at moderate levels except for high concentrations of both in the Ashley River. Anoxia and hypoxia are unknown in the tidal fresh zone and occur periodically during the late spring and summer in the mixing and seawater zones.

Trends reported indicate increasing turbidity, particularly in the Ashley River, and decreasing nutrients based upon improved wastewater treatment and a phosphate ban. Very low amounts of SAV are reported as increasing in the mixing zone.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **1,215** Avg. Daily Inflow *(cfs)* **5,996**

	Estuary	Tidal Fresh	Mixing: In General	Mixing: Ashley River	Seawater
Surface Area *(mi2)*	46.4	6.5	22.0	7.0	10.8
Average Depth *(ft)*	18.3	15.0	15.9	12.0	17.3
Volume *(billion cu ft)*	21.6	3.2	10.9	2.3	5.2

Formed at the confluence of the Cooper, Ashley, and Wando rivers. Since the rediversion of flow away from the Cooper river system in 1985, regulated flow from the Cooper and low flow from the Ashley results in small inter-annual salinity distributions. Tides range approximately 5.2 ft near harbor mouth and have dominant influence on salinity variability in upper portions of Ashley and Cooper rivers. Vertical stratification is more pronounced within Cooper River than in other parts of estuary.

Algal Conditions

	Tidal Fresh		Mixing: In General		Mixing: Ashley River		Seawater	
Chlorophyl-a	H 50-100%	?	M 50-100%	?	E 0-10%	?	M 50-100%	?
Turbidity	B	---	H 50-100%	⇧	H 50-100%	⬆	H 50-100%	⇧
Nuisance Algae	?	?	N	---	N	---	N*	---*
Toxic Algae	?	?	N	---	N	---	N*	---*

Chl-a and turbidity maximums occur periodically in summer in all zones and episodically February to March in tidal fresh zone. Algal biomass is limited by phosphorus and light in tidal fresh and mixing zones, and by nitrogen and light in seawater zone.

Ecosystem/Community Responses

	Tidal Fresh		Mixing: In General		Mixing: Ashley River		Seawater	
SAV	?	?	VL	⇧	VL	⇧	VL	?

Primary production is dominated by macrophytes and intertidal wetlands in tidal fresh and mixing zones and pelagic communities in seawater zone. Diatoms dominate planktonic community; benthic community dominated by insects in tidal fresh zone and mixture of annelids and mollusks in mixing and seawater zones. Intertidal wetlands have high spatial coverage.

Nutrients

	Tidal Fresh		Mixing: In General		Mixing: Ashley River		Seawater	
Nitrogen	M 50-100%	⇩	M 50-100%	⇩	H 10-25%	⇩	M 50-100%	⬇
Phosphorus	M 50-100%	⇩	M 50-100%	⇩	H 10-25%	⇩	M 50-100%	⬇

Concentrations are reported as total nitrogen and total phosphorus. In seawater zone, elevated TN concentrations occur May to September; elevated TP concentrations occur July to September. Trends are associated with improved wastewater treatment and a phosphate ban.

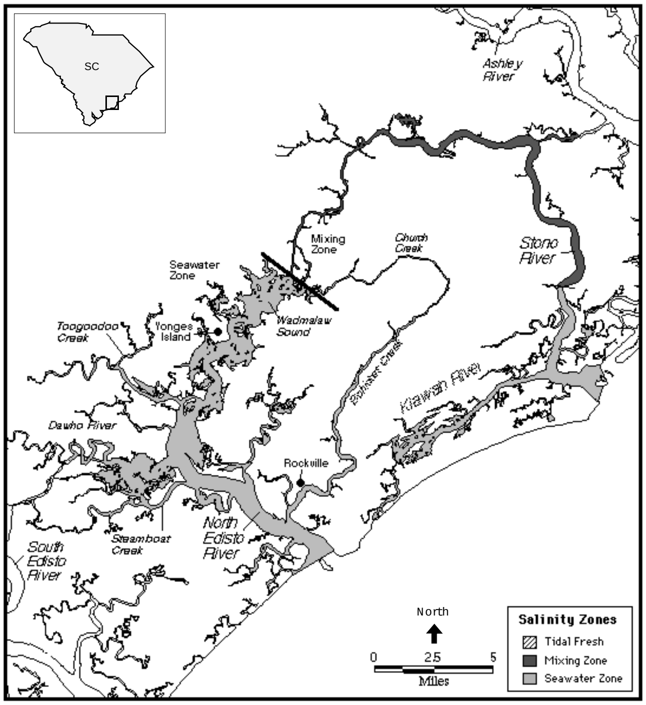
Dissolved Oxygen

	Tidal Fresh		Mixing: In General		Mixing: Ashley River		Seawater	
Anoxia	N	?	Y 10-25%	?	Y 10-25%	?	Y 0-10%	?
Hypoxia	Y 0-10%	?	Y 25-50%	?	Y 25-50%	?	Y 0-10%	?

Periodic occurrences of anoxia in mixing and seawater zones May through September. Hypoxic conditions occur in tidal fresh zone. Bottom-water occurrences were reported for anoxia; hypoxic conditions occur throughout entire water column. Water column stratification was not a factor.

Key on page 20

Stono/North Edisto Rivers



Stono/North Edisto Rivers have minimal information on existing conditions but are characterized as having slight increases in turbidity, and moderate decreases in nitrogen and phosphorus. Anoxia and hypoxia occur periodically in limited areas of the seawater zone.

The reported conditions occur primarily in the seawater zone which represents more than 80 percent of the estuary. Very low amounts of SAV are reported for the seawater zone.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **N/A** Avg. Daily Inflow *(cfs)* **N/A**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	**39.1**		**5.5**	**33.6**
Average Depth *(ft)*	**15.6**		**13.9**	**17.3**
Volume *(billion cu ft)*	**18.3**		**2.1**	**16.2**

Consists of the North Edisto River, Stono River and an intricate network of tidal creeks and tributaries. Relatively high salinities exist, especially near the mouth. Generally well mixed with low seasonal salinity variability. Freshwater inflow driven by local precipitation events and inflow from tributaries.

Algal Conditions

	Tidal Fresh	Mixing		Seawater	
Chlorophyll-a		?	?	?	?
Turbidity		?	↑ ?	?	↑ ?
Nuisance Algae		N	?	N	?
Toxic Algae		N	?	N	?

Trends are associated with nonpoint sources.

Ecosystem/Community Responses

	Tidal Fresh	Mixing		Seawater	
SAV		NS	- - -	VL	- - -

Primary producer is intertidal wetlands. Planktonic community is dominated by diatoms and benthic community by diverse mixture.

Nutrients

	Tidal Fresh	Mixing		Seawater	
Nitrogen		?	↓	?	?
Phosphorus		?	↓	?	↓

Trends are associated with improvements in point sources.

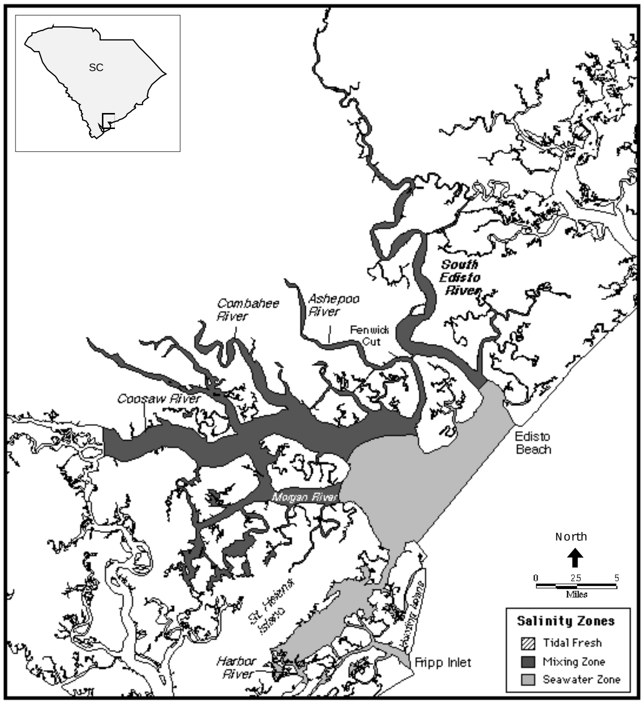
Dissolved Oxygen

	Tidal Fresh	Mixing		Seawater	
Anoxia		N	?	Y 10-25%	?
Hypoxia		N	?	Y 10-25%	?

Periodic occurrences of hypoxia occur June to October in mixing zone, and June to July in seawater zone. Conditions are mainly observed at bottom of water column. Water column stratification not a factor.

 Key on page 20

St. Helena Sound



St. Helena Sound is characterized as having low levels of chlorophyll-*a*. Turbidity is characterized as blackwater in the mixing zone and high in the seawater zone. Biological resource impacts from nuisance and toxic algae are unknown and nutrients are moderate. Anoxia and hypoxia occur periodically during the summer.

These conditions are reported primarily for the mixing zone. Trends information is generally unknown, with the exception of decreases in nitrogen in the mixing zone, and no trends for turbidity and phosphorus in the mixing zone. Distribution and trends for SAV are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi²)* **1,558** Avg. Daily Inflow *(cfs)* **4,600**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	**97.7**		**54.8**	**42.9**
Average Depth *(ft)*	**12.9**		**14.5**	**11.3**
Volume *(billion cu ft)*	**35.7**		**22.2**	**13.5**

A drowned river valley/bar built system with numerous tributaries and island formations. Major freshwater source is South Edisto River. Semi-diurnal tides range 6.9 ft near estuary mouth and are dominant forcing mechanism to salinity structure. Weak stratification of salinities and seasonal variability is common in lower Combahee and South Edisto rivers. Vertically homogeneous conditions prevail in lower St. Helena Sound.

Algal Conditions

	Tidal Fresh	Mixing	Seawater
Chlorophyll-a		L* ?	L* ?
Turbidity		B - - -	H ? ?
Nuisance Algae		? ?	? ?
Toxic Algae		? ?	? ?

The frequency and months of occurrence for high turbidity conditions are unknown.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater
SAV		? ?	? ?

Primary productivity is dominated by intertidal wetlands; planktonic community is dominated by diatoms and benthic community by mixture of annelids and crustaceans.

Nutrients

	Tidal Fresh	Mixing	Seawater
Nitrogen		M 50-100% ↓?	? ?
Phosphorus		M 50-100% - - -	? ?

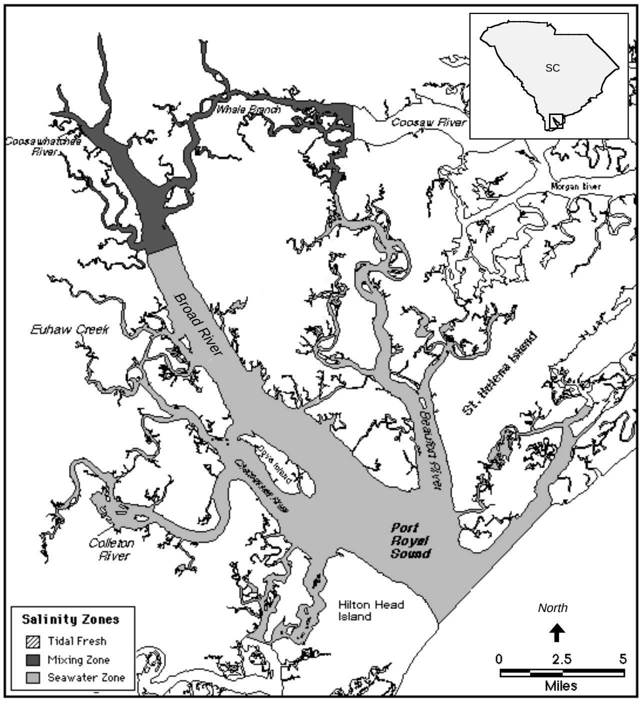
Elevated TDN concentrations occur June to September; elevated TDP concentrations occur June to October.

Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater
Anoxia		Y 25-50% ?	? ?
Hypoxia		Y 25-50% ?	? ?

Periodic occurrences of anoxia/hypoxia occur in mixing zone June to September. Bottom-water occurrences were reported for anoxia; hypoxic conditions occur throughout water column. Water column stratification not a factor.

Broad River



Broad River is characterized as having moderate levels of chlorophyll-*a* and low levels of turbidity. Based on speculative inference, biological resource impacts from nuisance and toxic algae do not occur. Nitrogen and phosphorus levels are reported at moderate to high concentrations. Bottom-water anoxia and hypoxia occur periodically during the summer.

These conditions are observed in the mixing and seawater zones. Trends are generally unknown with the exception of turbidity (increasing in the mixing zone and no trend in the seawater zone), nitrogen (no trend in the mixing zone), and phosphorus (no trend in both mixing and seawater zones). Distribution and trends for SAV are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area (*mi²*) **1,010** Avg. Daily Inflow (*cfs*) **900**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area (*mi²*)	107.5		15.5	92.0
Average Depth (*ft*)	24.0		23.7	23.2
Volume (*billion cu ft*)	69.7		10.2	59.5

A drowned river valley system with intricate tidal creeks and marsh islands. The Coosawhatchee River is major freshwater source, but little seasonal variability exists due to the relatively low discharge into estuary. Tides range an average of 6.9 ft near estuary mouth. Port Royal Sound exhibits vertically homogeneous salinity structure due to tidal mixing.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyl-a			?	?	M 10-25%	?
Turbidity			L	↑ ?	L	- - -
Nuisance Algae			N*	?	N*	?
Toxic Algae			N*	?	N*	?

Medium chl-a conentrations occur periodically in the Beaufort River portions of the seawater zone.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV			?	?	?	?

Primary productivity is dominated by intertidal wetlands; planktonic community dominated by diatoms; benthic community by mixture of annelids and crustaceans.

Nutrients

	Tidal Fresh		Mixing		Seawater	
Nitrogen			H 50-100%	- - -	M 50-100%	?
Phosphorus			H 50-100%	- - -	M 50-100%	- - -

Elevated TDN concentrations occur in mixing zone in January and August to October; in seawater zone in February and August to October. Elevated TDP concentrations occur in mixing zone July to August and November; in seawater zone June to August.

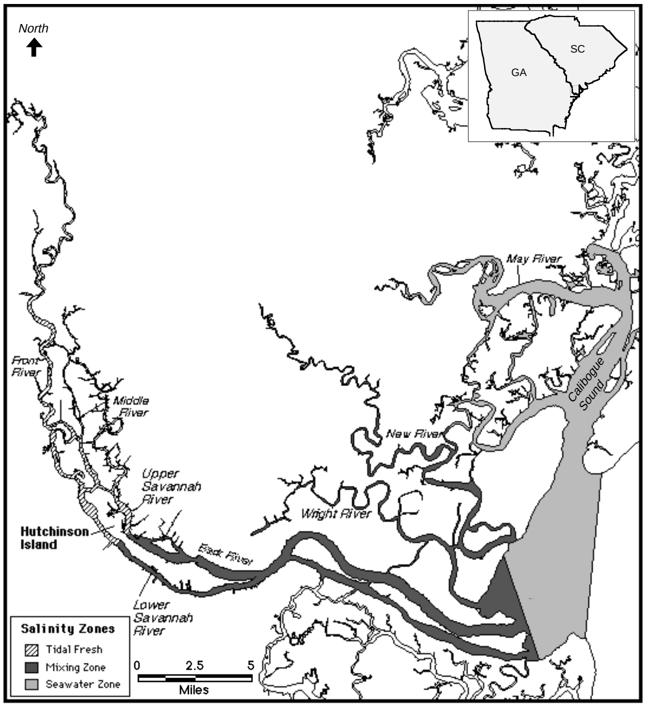
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia			Y 10-25%	?	Y 10-25%	?
Hypoxia			Y 10-25%	?	Y 10-25%	?

Anoxia/hypoxia occur periodically in mixing and seawater zones June to September. Bottom-water occurrences were reported for anoxia; hypoxic conditions occur throughout water column. Water column stratification not a factor.

 Key on page 20

Savannah River



Savannah River is characterized as having moderate levels of cholorophyll-*a* and moderate to high levels of turbidity, particularly in the mixing zone. Biological resource impacts from nuisance and toxic algae do not occur. Nutrients are reported as moderate to relatively high, particularly in the tidal fresh zone. Bottom-water anoxia and hypoxia occur periodically during the summer.

The spatial extent of most of these conditions is unknown. Trends are reported as either unknown or no trends with the exception of a possible increase in turbidity in the tidal fresh zone. SAV is unknown in the tidal fresh zone and not present in the rest of the estuary.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyll-a	L*	?	M* (?)	?	M* (?)	?
Turbidity	?	⇧ (?)	H (?)	---	M (?)	?
Nuisance Algae	N	---	N	---	N	---
Toxic Algae	N	---	N	---	N	---

Maximum chl-a concentrations occur periodically June to August with light limiting in mixing zone and silica in seawater zone. Turbidity maximums occur continuously throughout year.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	?	?	NS	---	NS	---

Primary productivity is dominated by intertidal wetlands. Planktonic community dominated by diatoms and diverse mixture; benthic community dominated by crustaceans in tidal fresh zone and annelids in mixing zone.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **1,316** Avg. Daily Inflow *(cfs)* **12,800**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	71.8	18.7	17.7	35.4
Average Depth *(ft)*	15.2	9.3	16.2	17.3
Volume *(billion cu ft)*	29.9	4.8	8	17

Part of a drowned river valley system receiving the majority of freshwater inflow from the Savannah River. Discharge is determined by controlled releases of freshwater. Salinity structure is moderately stratified and salinity variability within the estuary is more significant below Hutchinson Island. Tides range 6.5 ft at estuary mouth and are a dominant forcing mechanism to the overall salinity structure.

Nutrients

	Tidal Fresh		Mixing		Seawater	
Nitrogen	H (?)	---	M (?)	---	M (?)	---
Phosphorus	H (?)	---	M (?)	---	M (?)	---

More than 50% of TDN is organic nitrogen. Elevated concentrations occur May to August in tidal fresh and mixing zones.

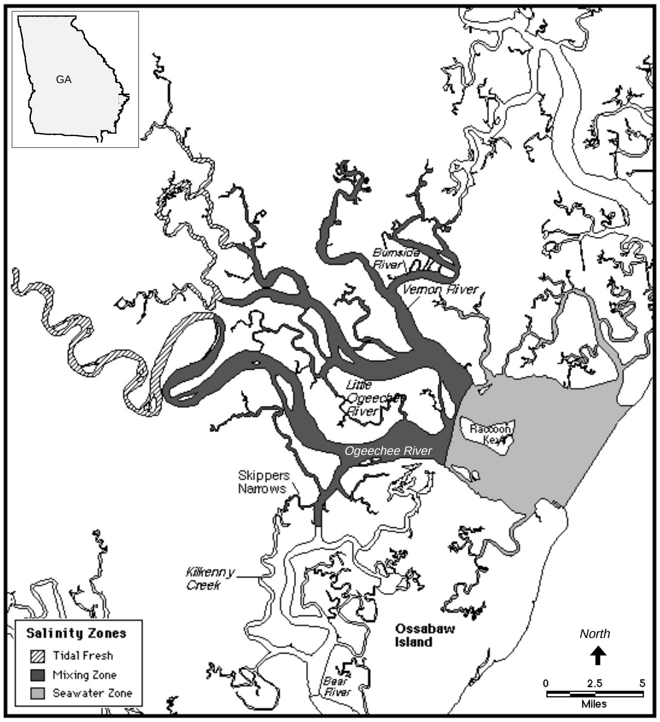
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	N	?	Y (10-25%)	?	N	?
Hypoxia	N	?	Y (25-50%)	?	N	?

Anoxia occurs periodically June to August, and hypoxia May to September, both typically at bottom of water column. Water column stratification contributes moderately to these conditions. There was an increase in minimum average monthly bottom dissolved oxygen concentrations and an increase in the spatial coverage of hypoxic conditions in mixing zone. Nonpoint sources are associated with the trends.

Key on page 20

Ossabaw Sound



Ossabaw Sound is characterized as having high to moderate levels of chlorophyll-*a* and turbidity. Biological resource impacts from nuisance and toxic algae generally do not occur. Nutrients are reported at low to moderate levels. Anoxia and hypoxia do not occur.

The conditions reported occur primarily in the mixing zone. Trends are either unknown or reported as no trend. SAV is not present.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi^2)* **1,473** Avg. Daily Inflow *(cfs)* **3,000**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi^2)*	39.9	4.8	18.1	17.0
Average Depth *(ft)*	14.3	6.5	14.2	13.1
Volume *(billion cu ft)*	14.3	0.9	7.2	6.2

A small coastal plain system receiving freshwater from Ogeechee and Canoochee rivers. Seasonal variability in rainfall can alter salinity by 10 ppt in most of estuary. Tides range an average of 6.9 ft throughout Ossabaw Sound. Vertically stratified circulation pattern can persist during low salinity period within lower Ogeechee River and Ossabaw Sound.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyll-a	L*	?	H* ?	---*	M* ?	?
Turbidity	?	?	H 25-50%*	?	M 25-50%*	?
Nuisance Algae	?	?	N	---	N	---
Toxic Algae	?	?	N	---	N	---

Maximum chl-a concentrations occur episodically in mixing zone and periodically in seawater zone April to July. Medium concentrations occur periodically in mixing zone. Turbidity concentrations occur periodically from April to July.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	?	?	NS	?	NS	?

Primary productivity is dominated by intertidal wetlands. Planktonic community dominated by diverse mixture.

Nutrients

	Tidal Fresh		Mixing		Seawater	
Nitrogen	L*	---	M ?	---	?	?
Phosphorus	L*	---	M ?	---	?	?

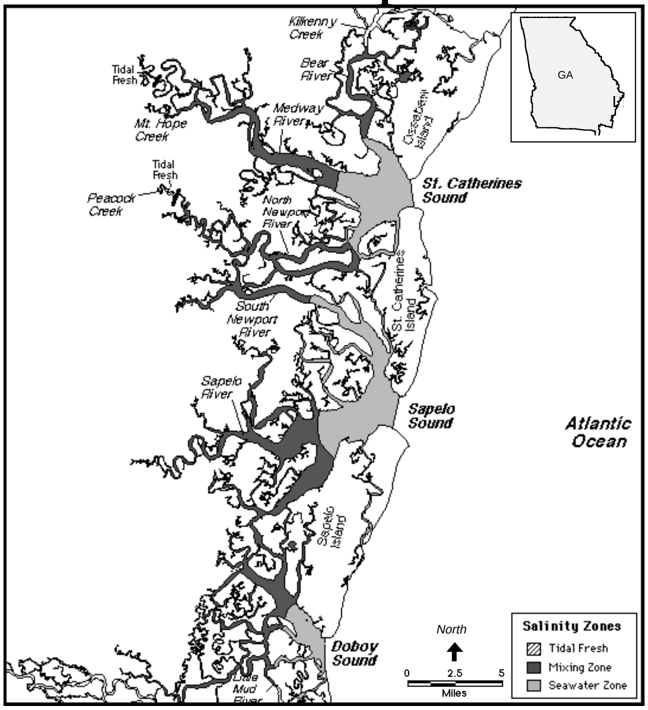
More than 50% of TDN is organic nitrogen. Maximum concentrations occur May to September.

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	N	?	N	?	N	?
Hypoxia	N	?	N	?	N	?

Key on page 20

St. Catherines/Sapelo Sounds



St. Catherines/Sapelo Sounds are characterized as having moderate levels of chlorophyll-*a* and high levels of turbidity. No occurrences of biological resource impacts from nuisance or toxic algae are reported. No anoxic or hypoxic conditions are reported. Nitrogen and phosphorus levels are low.

These conditions occur primarily in the mixing and seawater zones. Trends for nitrogen and phosphorus indicate significant increases in the mixing zone. Other trends were reported as unknown or, for nuisance/toxic algae, as no trend. SAV is not present. Several of the values reported for chlorophyll-*a*, nutrients, and dissolved oxygen are based on speculative inference.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **963** Avg. Daily Inflow *(cfs)* **800**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	92.2	0.4	54.9	36.9
Average Depth *(ft)*	14.5	7.6	14.7	22.7
Volume *(billion cu ft)*	45.9	0.09	22.5	23.4

A drowned river valley-barrier island system comprised of small tidal creeks. Receives minimal freshwater from mainland runoff, groundwater, and lateral flow from nearby rivers. Weak stratification occurs within Doboy Sound. Elsewhere, salinities are generally vertically homogeneous. Tides range 6.5 to 9 ft and are dominant forcing mechanism on salinity structure throughout most of estuary.

Algal Conditions

	Tidal Fresh	Mixing		Seawater	
Chlorophyll-a	* Tidal Fresh area not characterized for this estuary	M* 50-100%*	?	M* 50-100%*	?
Turbidity		H 50-100%	?	H 50-100%	?
Nuisance Algae		N	---	N	---
Toxic Algae		N	---	N	---

Maximum chl-a concentrations occur periodically in summer with light limiting in mixing zone and silica limiting in seawater zone. Turbidity maximums occur periodically throughout year.

Ecosystem/Community Responses

	Tidal Fresh	Mixing		Seawater	
SAV		NS	---	NS	---

Primary productivity dominated by intertidal wetlands. Planktonic and benthic communities dominated by diverse mixture.

Nutrients

	Tidal Fresh	Mixing		Seawater	
Nitrogen		L*	↑*	L*	?
Phosphorus		L*	↑*	L*	?

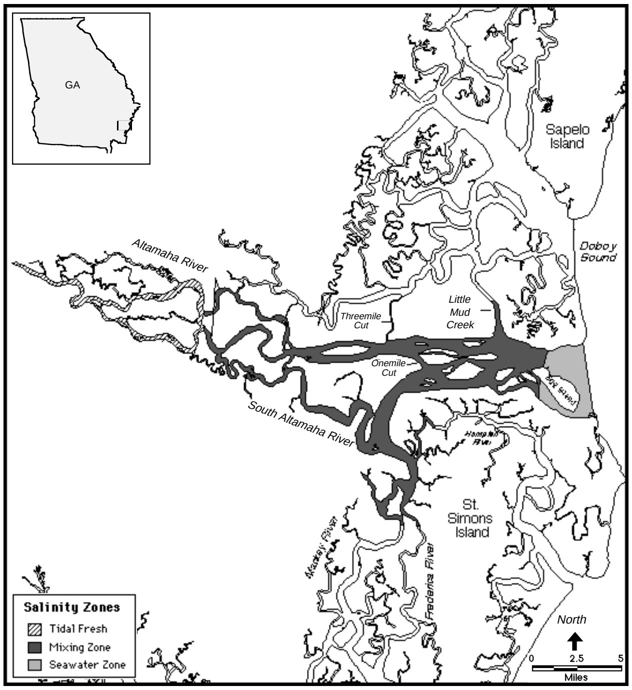
Trends are associated with nonpoint sources.

Dissolved Oxygen

	Tidal Fresh	Mixing		Seawater	
Anoxia		N	?	N*	?
Hypoxia		N	?	N*	?

Key on page 20

Altamaha River



Altamaha River is characterized as having moderate to high levels of chlorophyll-*a* and high levels of turbidity. No occurrences of biological resource impacts from nuisance or toxic algae are reported. No hypoxic or anoxic conditions are reported. Nutrients were reported as low in the seawater zone and moderate in the rest of the estuary.

These conditions occur primarily in the mixing zone which represents approximately 80 percent of the estuary. Trends are generally reported as unknown or no trend with the exception of significant decreases in nitrogen in the tidal fresh and mixing zones. SAV is not present.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi²)* **1,512** Avg. Daily Inflow *(cfs)* **14,900**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	16.7	2.5	12.0	2.2
Average Depth *(ft)*	10.2	4.3	12.1	13.1
Volume *(billion cu ft)*	5.2	0.3	4.1	0.8

A coastal plain system consisting of the Altamaha River and several tidal creeks. Seasonal freshwater discharge is dominant forcing mechanism on salinity variability. Moderate to highly stratified conditions exist in central and lower estuary. During high-inflow, vertically homogeneous conditions occur in Altamaha River above Onemile Cut. Semi-diurnal tides range an average of 6.5 ft near estuary mouth.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyll-a	L*	?	H* 50-100%*	?	M* 50-100%*	?
Turbidity	?	?	H 50-100%	- - -	H 50-100%	?
Nuisance Algae	?	?	N	- - -	N	- - -
Toxic Algae	?	?	N	- - -	N	- - -

Maximum chl-a concentrations occur episodically in mixing zone and periodically in seawater zone in summer. Medium chl-a concentrations occur periodically in mixing zone. Light is limiting in mixing zone and silica in seawater zone. Turbidity maximums occur continuously throughout year.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	?	?	NS	- - -	NS	- - -

Primary productivity dominated by intertidal wetlands. Planktonic and benthic communities dominated by diverse mixture.

Nutrients

	Tidal Fresh		Mixing		Seawater	
Nitrogen	M 50-100%*	↓	M 50-100%*	↓	L*	?
Phosphorus	M* 50-100%*	- - -	M* 50-100%*	- - -	L	?

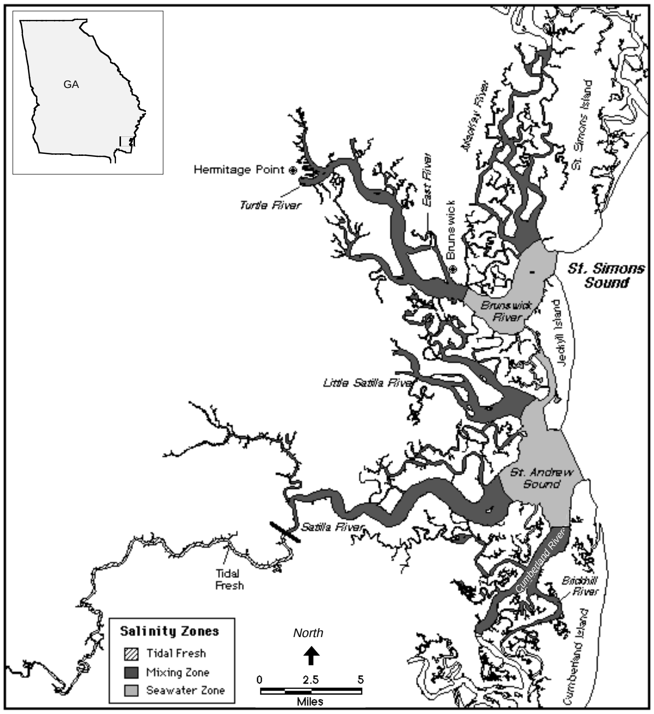
In tidal fresh zone, elevated nutrient concentrations occur March to May, and in mixing zone, May to August.

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	N	?	N	?	N*	?
Hypoxia	N	?	N	?	N*	?

Key on page 20

St. Andrew/St. Simons Sounds



St. Andrew/St. Simon Sounds are characterized as having moderate levels of chlorophyll-*a*. Turbidity is not characterized because the estuary is classified as a blackwater system. No occurrences of biological resource impacts from nuisance or toxic algae are reported. No hypoxic or anoxic conditions are reported. Nitrogen is reported as generally moderate to high, and phosphorous is reported as generally moderate.

The conditions reported occur primarily in the mixing and seawater zones which represent over 95 percent of the estuary. Trends are generally reported as unknown or no trend with the exception of significant nutrient increases in the tidal fresh and mixing zones. SAV is not present. Several of the values reported for chlorophyll-*a*, nutrients and dissolved oxygen are based on speculative inference.

Physical and Hydrologic Characteristics

Estuarine Drainage Area (*mi2*) **3,213** Avg. Daily Inflow (*cfs*) **2,500**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area (*mi2*)	82.9	3.7	54.8	24.4
Average Depth (*ft*)	14.3	10.3	12.9	13.0
Volume (*billion cu ft*)	29.9	1.1	20	8.8

A drowned river valley system surrounded by barrier island features. Receives majority of freshwater from Satilla River, although seasonal salinities are also influenced by Altamaha River to the north. Salinity is weakly stratified and dominated primarily by tidal mixing. Tides range 6.5 ft at entrances of estuary to 7.8 ft near Hermitage Point.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyll-a	L*	?	M 50-100%*	?	M* 50-100%*	?
Turbidity	B	?	B	?	B	?
Nuisance Algae	?	?	N	- - -	N	- - -
Toxic Algae	?	?	N	- - -	N	- - -

Maximum chl-a concentrations occur episodically in mixing and periodically in seawater zone in summer. Medium chl-a concentrations occur periodically in mixing zone. Light is limiting in mixing zone and silica in seawater zone.

Nutrients

	Tidal Fresh		Mixing		Seawater	
Nitrogen	H* 50-100%*	↑*	M 50-100%*	↑*	L*	?
Phosphorus	M* 50-100%*	↑*	M 50-100%*	↑*	L	?

More than 50% of TDN is organic nitrogen. Elevated nutrient concentrations in tidal fresh zone occur March to May; in mixing zone May to August. Trends associated with nonpoint sources.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	?	?	NS	- - -	NS	- - -

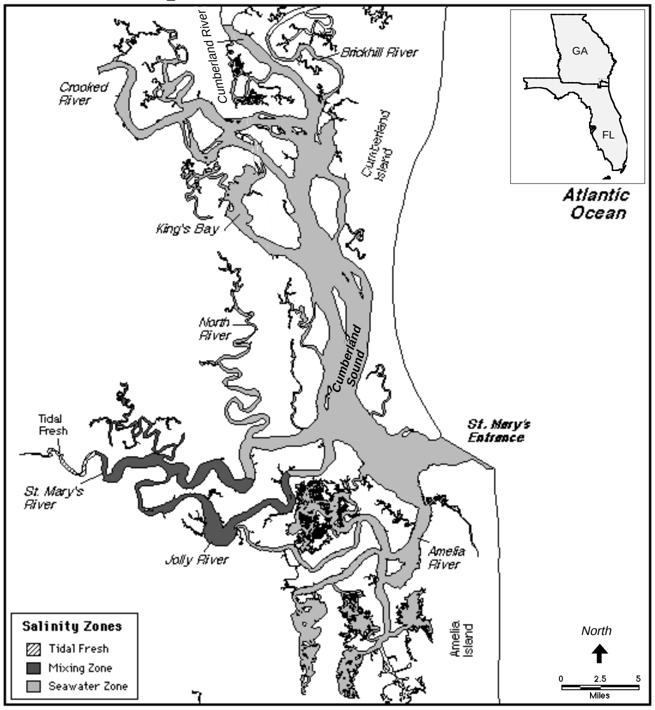
Primary producer is intertidal wetlands. Planktonic and benthic communities dominated by diverse mixture.

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	N	?	N	?	N*	?
Hypoxia	N	?	N	?	N*	?

Key on page 20

St. Marys River/Cumberland Sound



St. Marys River/Cumberland Sound is characterized as having moderate levels of chlorophyll-*a*. Turbidity is not characterized because the estuary is classified as a blackwater system. No occurrences of biological resource impacts from nuisance or toxic algae are reported. No hypoxic or anoxic conditions are reported. Nutrients are generally low except for moderate nitrogen levels in the seawater zone.

The conditions reported occur primarily in the seawater zone which represents approximately 90 percent of the estuary. Trends are generally reported as unknown or no trend except for a decrease in phosphorus in the mixing zone. SAV is not present.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **1,737** Avg. Daily Inflow *(cfs)* **8,171**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	33.8	0.1	3.7	30.0
Average Depth *(ft)*	19.7	5.7	8.4	21.1
Volume *(billion cu ft)*	18.5	0.02	0.9	17.6

A bar-built estuary receiving the majority of freshwater inflow from St. Marys River, with discharge usually highest in late winter and spring. Salinity structure is determined primarily by seasonal pulses from the St. Marys River. Vertically homogeneous conditions occur throughout most of lower river and within Cumberland Sound due to tidal mixing. Tides average 6 ft near St. Mary's Entrance.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyl-a	* Tidal Fresh area not characterized for this estuary		M* 50-100%*	?	M* 50-100%*	?
Turbidity			B	?	B	?
Nuisance Algae			N	- - -	N	- - -
Toxic Algae			N	- - -	N	- - -

Maximum chl-a concentrations occur periodically June through August. Limiting factor to algal biomass is light in mixing zone and silica in seawater zone.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV			NS	- - -	NS	- - -

Primary producer is intertidal wetlands. Planktonic and benthic communities are dominated by diverse mixture.

Nutrients

	Tidal Fresh		Mixing		Seawater	
Nitrogen			L*	- - -	M* 50-100%*	?
Phosphorus			L	⇩	L	?

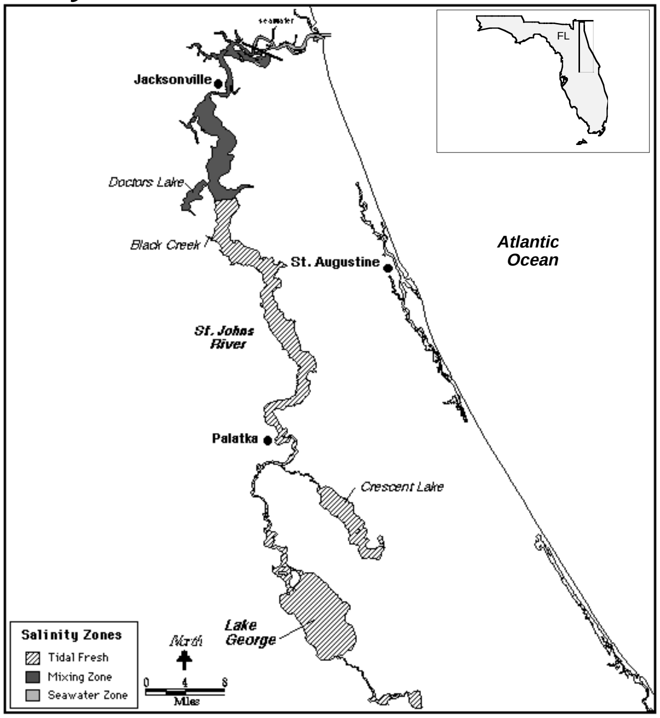
More than 50% of TDN is organic nitrogen. Elevated nutrient concentrations occur April to September.

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia			N	?	N*	?
Hypoxia			N	?	N*	?

Key on page 20

St. Johns River



St. Johns River is characterized as having high to moderate levels of chlorophyll-*a* and turbidity along with periodic occurrences of nuisance algae and episodic occurrences of toxic algae. Nitrogen and phosphorus levels are relatively moderate except for high phosphorus levels recorded for the seawater zone. No anoxia or hypoxia are observed.

The conditions observed generally occur in the tidal fresh and mixing zones which represent more than 95 percent of the estuarine surface area. No trends were reported for these conditions. Trends are observed for SAV with relatively minor declines in the tidal fresh and mixing zones.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **6,389** Avg. Daily Inflow *(cfs)* **7,800**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	**264.1**	**197.5**	**60.1**	**6.5**
Average Depth *(ft)*	**12.0**	**10.5**	**11.1**	**20.0**
Volume *(billion cu ft)*	**80.0**	**57.8**	**18.6**	**3.6**

An elongated estuarine system comprised of large lakes along most of the rivers main stem. Tidal influences are most apparent near the river mouth where tides range approximately 4 ft. Moderate vertical stratification results as freshwater overrides more dense sea water. Wind and precipitation contribute to complexity of tidal influences within estuary.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyll-a	H 25-50%	- - -	M 25-50%	- - -	M 10-25%	- - -
Turbidity	H/M	- - -	H	- - -	H	- - -
Nuisance Algae	Y	- - -	Y	- - -	N	- - -
Toxic Algae	Y	- - -	N	- - -	N	- - -

Chl-a maximums occur periodically April to early fall. Light and nitrogen are limiting factors in tidal fresh and mixing zones; residence time is limiting in seawater zone. Turbidity maximums occur April to July in tidal fresh and July to December in mixing and seawater zones. Nuisance microcystis species occur periodically June to July; toxic dinoflagellates occur episodically.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	L	↓	VL	↓	NS	- - -

Diatoms dominate planktonic community; benthic community is dominated by annelids in seawater zone and mollusks in tidal fresh and mixing zones.

Nutrients

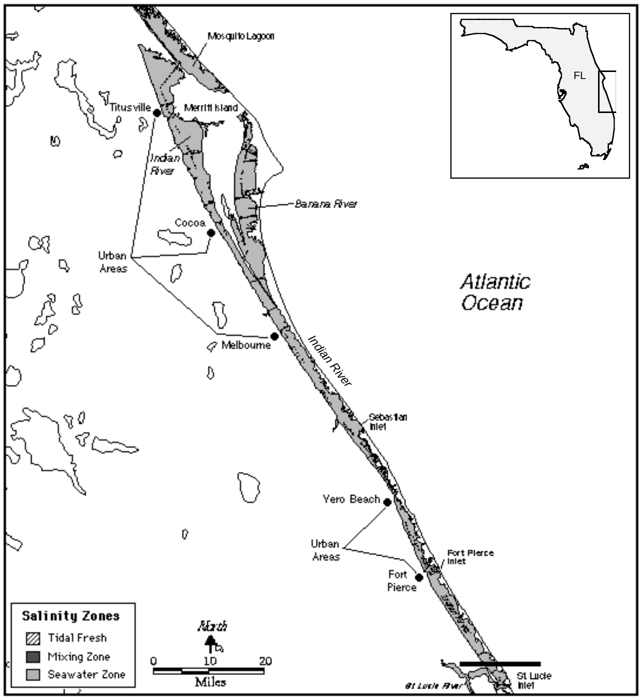
	Tidal Fresh		Mixing		Seawater	
Nitrogen	L	- - -	M 50-100%	- - -	M 50-100%	- - -
Phosphorus	M 50-100%	- - -	M 50-100%	- - -	H 50-100%	- - -

More than 50% of TDN is organic nitrogen.

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	N	- - -	N	- - -	N	- - -
Hypoxia	N	- - -	N	- - -	N	- - -

Indian River



Indian River is characterized as having high to hypereutrophic levels of chlorophyll-*a* and high levels of turbidity. Biological resource impacts from nuisance and toxic algae occur periodically during the summer. Nutrients are reported as moderate to high. Bottom-water anoxia and hypoxia occur periodically over limited areas during spring and summer.

These conditions occur only in seawater zone. Trends are generally reported as unknown or no trend except for increasing cholorophyll-*a* in the St. Lucie River. SAV is present in low to moderate amounts though trends indicate it is decreasing in both areas for which it is reported. Many of the values reported for this estuary are based on speculative inference.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **1,184** Avg. Daily Inflow *(cfs)* **N/A**

	Estuary	Tidal Fresh	Mixing	Seawater: Indian River	Seawater: St. Lucie R.	Seawater: Urban Areas
Surface Area *(mi2)*	336			296	11	36
Average Depth *(ft)*	6.6			6.6	9.0	6.6
Volume *(billion cu ft)*	64.4			55	2.8	6.6

A narrow, lagoonal system influenced by wind forcing mechanisms, storm events, freshwater runoff and evaporation. Short-term wind events coupled with longer-term seasonal storms affect overall salinity structure. Freshwater runoff from landward sources determines lateral salinity stratification and variability. Saltwater intrusion creates vertical stratification within estuary. Tidal influence is mainly through 3 inlet structures: Sebastian, Ft. Pierce and St. Lucie. Tides range 1 ft near Ft. Pierce Inlet.

Algal Conditions

	Tidal Fresh	Mixing	Seawater: Indian River	Seawater: St. Lucie River	Seawater: Urban Areas
Chlorophyll-a			H* ? / ---	H* ? / ↑*	E* ? / ---
Turbidity			H ? / ---	H* ? / ?	H ? / ---
Nuisance Algae			Y / ---	Y* / ?	Y / ---
Toxic Algae			Y / ---	Y* / ?	Y / ---

Maximum chl-a concentrations occur episodically spring to fall with light limiting in all zones. Maximum turbidity occurs episodically spring to summer in tidal fresh zone, all year in mixing zone, and periodically spring to summer in seawater zone. Nuisance and toxic algae events occur periodically June to August, lasting less than a week, and episodically in tidal fresh and seawater zones.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater: Indian River	Seawater: St. Lucie River	Seawater: Urban Areas
SAV			M / ↓	? / ?	L / ↓*

SAV is dominant primary producer and flagellates are dominant planktonic group. Benthic shift from annelids to mixture of annelids and crustaceans occurred in Indian River lagoon. Nonpoint sources associated with benthic shift and declining SAV.

Nutrients

	Tidal Fresh	Mixing	Seawater: Indian River	Seawater: St. Lucie River	Seawater: Urban Areas
Nitrogen			M ? / ---	H* ? / ---*	H ? / ---
Phosphorus			M ? / ---	H* ? / ---*	H ? / ---

Elevated nutrient concentrations occur April to September.

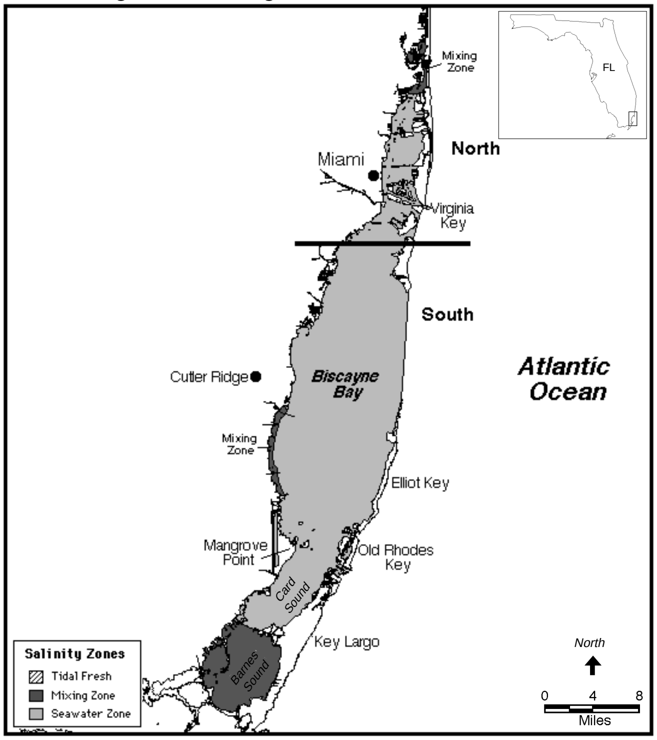
Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater: Indian River	Seawater: St. Lucie River	Seawater: Urban Areas
Anoxia			Y 10-25% / ?	Y* 10-25%* / ?	Y 25-50%* / ?
Hypoxia			Y 10-25% / ?	Y* 25-50%* / ?	Y 25-50%* / ?

Periodic occurrences of anoxia/hypoxia occur April to September, typically at bottom of water column. Water column stratification was a major factor.

 Key on page 20

Biscayne Bay



Biscayne Bay is characterized as having generally low levels of chlorophyll-*a* and low to moderate levels of turbidity. No biological resource impacts from nuisance or toxic algae are reported. Nitrogen levels range from low to medium and phosphorus levels are low. Bottom-water anoxia and hypoxia occur only in localized areas that have been artificially deepened. Surface waters in canals and adjacent areas may be anoxic or hypoxic during flood discharge events.

These conditions occur in the mixing and seawater zones. Trends are generally reported as no trends except for decreasing turbidity in the seawater zone and increasing nutrients in some parts of both the mixing and seawater zones. SAV is widely distributed and generally stable except with slight increases reported for the north end of the seawater zone. Values for nuisance and toxic algae are based on speculative inference.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **2,876** Avg. Daily Inflow *(cfs)* **N/A**

	Estuary	Tidal Fresh	Mixing		Seawater	
			North Area	South Area	North Area	South Area
Surface Area *(mi2)*	**269.5**		**1.2**	**34.0**	**26.7**	**209.2**
Average Depth *(ft)*	**7.7**		**8.4**	**7.7**	**8.4**	**7.7**
Volume *(billion cu ft)*	**58.9**		**0.3**	**7.3**	**6.3**	**45**

A shallow, lagoonal estuary highly influenced by flood control and upstream intrusion of saltwater. Salinity patterns are affected by periodic discharges from water control structures on canals and tributaries. Circulation is tidally driven. Wind and tidal influences generally maintain a vertically mixed water column throughout the estuary.

Algal Conditions

	Tidal Fresh	Mixing North	Mixing South	Seawater North	Seawater South
Chlorophyll-a		L ---	L ---	L ---	L ---
Turbidity		L ---	L ---	M (0-10%) ⇩	L ⇩
Nuisance Algae		N* ---*	N* ---*	N* ---*	N* ---*
Toxic Algae		N* ---*	N* ---*	N* ---*	N* ---*

Chl-a maximums occur periodically September to October with phosphorus and light limiting algal biomass. Turbidity maximums occur continuously in northern mixing zone and periodically in northern seawater zone. Impacts from suspended solids occur October to December in northern mixing zone.

Nutrients

	Tidal Fresh	Mixing North	Mixing South	Seawater North	Seawater South
Nitrogen		H (0-10%) ---	M (10-25%) ⇩	M (10-25%) ⇧	L ---
Phosphorus		L ---	L ---	L ⇩	L ---

Elevated nutrient concentrations occur September to January in both zones. Trends are associated with nonpoint sources.

Ecosystem/Community Responses

	Tidal Fresh	Mixing North	Mixing South	Seawater North	Seawater South
SAV		L ?	H ---	M ⇧	M ---

Benthic community is dominated by seagrass, and some hardbottom areas are dominated by soft corals and sponges. Diatoms dominate planktonic community.

Dissolved Oxygen

	Tidal Fresh	Mixing North	Mixing South	Seawater North	Seawater South
Anoxia		Y (10-25%) ---	Y (10-25%) ---	N ---	N ---
Hypoxia		Y (10-25%) ---	Y (10-25%) ---	N ---	N ---

Anoxia and hypoxia occur in the north mixing zone from June to September primarily in dredged areas and at the water surface in or near canals. In the south mixing zone, anoxia and hypoxia are rare and occur only during extraordinary releases of freshwater from canals. In the channels and canals, water column stratification contributed moderately to anoxic and hypoxic conditions freshwater discharges. The seawater zones are unstratified and have high oxygen levels.

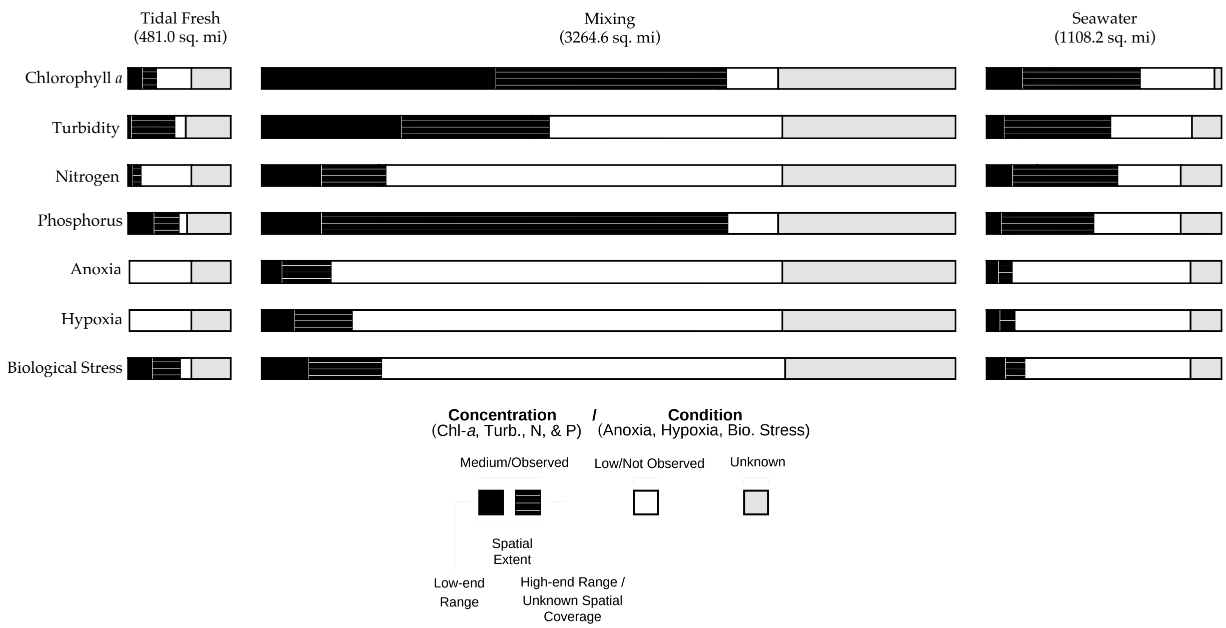
Key on page 20

Regional Summary

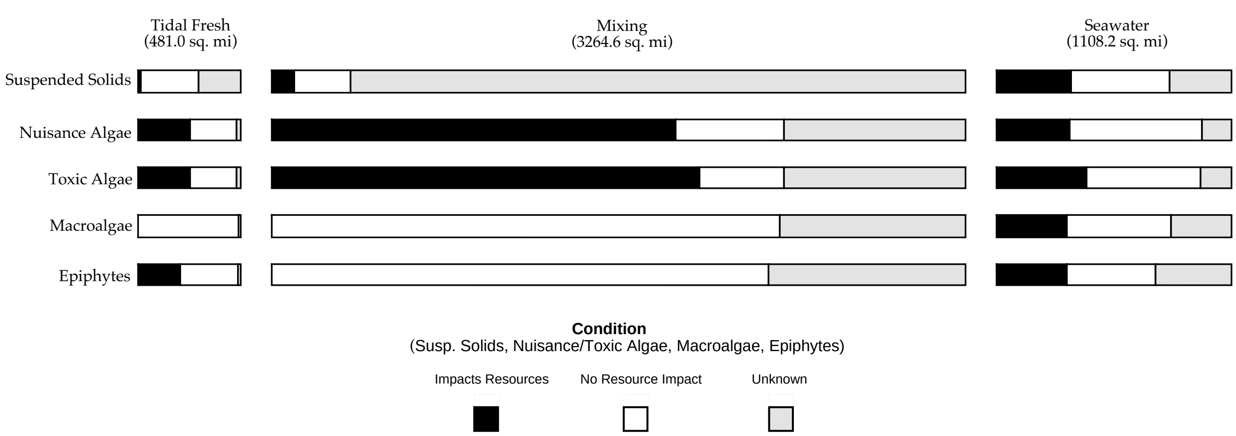
Regional classification status of existing conditions for twelve parameters as a cumulative percent of total estuarine surface area for three salinity zones.

The spatial extent of existing conditions was recorded for each salinity zone in each estuary when concentrations of chl-a, turbidity, nitrogen, or phosphorus were indicated as medium or greater, and when anoxia, hypoxia, or biologically stressful dissolved oxygen conditions were observed. Four broad ranges of spatial extent were used; high (100-51% of the surface area in a particular zone of an estuary), medium (50-26%), low (25-11%), and very low (10-1%). For some estuaries, existing conditions were reported but spatial extent was unknown.

The figure represents a method for quantifying these results. Black shows conservative estimates of cummulative spatial extent (e.g. high spatial extent equals 51% of an estuary's surface area). Black with white lines shows liberal estimates (e.g. high equals 100%, and unknown spatial extent also equals 100%). White shows the cummulative total surface area reported to have low concentrations or no observed conditions. Gray shows the cummulative total surface area reported as unknown concentrations or conditions.



The presence of suspended solids, nuisance algae, toxic algae, macroalgae, and epiphytes in each salinty zone were reported as either impacting resources, not impacting resources, or unknown. The spatial extent of these conditions was not recorded.



Appendix 1: Participants

The persons below supplied the information included in this report. Survey participants provided the initial data to ORCA via survey forms sent through the mail. Site visit participants provided additional data through on-site interviews with project staff. These persons also reviewed initial survey data where available. Workshop participants reviewed and revised, in a workshop setting, preliminary aggregate results and, where possible, provided additional data that was still missing. All participants also had the opportunity to provide comments and suggestions on the estuary salinity maps.

South Atlantic Regional Workshop

North Section (Albemarle/Pamlico Sounds to Broad R.)

Elizabeth Blood	J.W. Jones Ecological Research Center
David Chestnut	South Carolina Department of Health & Environmental Conservation
Mark Evans	Coastal Services Center/NOAA
Fred Holland	South Carolina Department of Wildlife & Marine Resources
Jeff Hyland	Office of Ocean Resouces Conservation and Assessment/NOS/NOAA
Michael Mallin	Univeristy of North Carolina Department of Biological Sciences
Hank McKellar	University of South Carolina, Department of Environmental Health Science
Joe Rudek	North Carolina Environmental Defense Fund
Donald Stanley	East Carolina University, Institute for Coastal & Marine Research
PatriciaTestor	Southeast Fisheries Science Center/NMFS/NOAA
BobVan Dolah	South Carolina Department of Wildlife & Marine Resources

South Section (Savannah R. to Biscayne Bay)

Merryl Alber	University of Georgia Department of Marine Science
Jim Alberts	University of Georgia Marine Institute
Ramesh Buch	Dade County Environmental Resources Management Division
Wayne Magley	Florida Department of Environmental Protection
Jay Pinckney	University of North Carolina Institute of Marine Science
Peter Verity	Skidaway Institute of Oceanography
ConradWhite	Brevard County Natural Resources Management Division
JohnWindsor	Florida Institute of Technology, Department of Oceanography

Survey/Site Visits

* participated in site visit
• participated in survey and site visit

Albemarle/Pamlico Sounds

JoAnn Burkholder*	NC State Univ.
John E. Cooper	E. Carolina Univ.
Donald W. Stanley	" " " "
Jess H. Hawkins III	NC Div. of Marine Fisheries
Jimmie Overton	NC Div. of Env. Mgt.
Hans Paerl	Univ. of NC

Pamlico/Pungo Rivers

Vincent J. Bellis	E. Carolina Univ.
Donald W. Stanley	" " " "
Jimmie Overton	NC Div. of Env. Mgt.

Neuse River

Richard Barber	Duke Univ.
JoAnn Burkholder*	NC State Univ.
William W. Kirby-Smith	" " " "
Larry Cahoon*	Univ. of NC/Wilmington
Michael Mallin•	" " " "
Robert R. Christian	E. Carolina Univ.
Donald W. Stanley	" " " "
Jimmie Overton	NC Div. of Env. Mgt.
Hans Paerl	Univ. of NC

Bogue Sound

Larry Cahoon*	Univ. of NC/Wilmington
Michael Mallin•	" " " "
Lisa Levin	Scripps Inst. of Oceanog.
Jimmie Overton	NC Div. of Env. Mgt.
Frederick T. Short	Univ. of NH

New River

Larry Cahoon*	Univ. of NC/Wilmington
Michael Mallin•	" " " "
Jimmie Overton	NC Div. of Env. Mgt.

Cape Fear River

Larry Cahoon	Univ. of NC/Wilmington
Michael Mallin	" " " "
Donald W. Stanley	E. Carolina Univ.
Steve Tedder	NC Div. of Env. Mgt.

Winyah Bay

Dennis Allen	Univ. of SC
Daniel L. Childers	Natl. Marine Fisheries Svc.
Russell W. Sherer	SC Dept. of Health & Env. Con.

North/South Santee Rivers

David M. Knott	SC Dept. Wildlife & Mar. Res.
Russell W. Sherer	SC Dept. of Health & Env. Con.

Charleston Harbor

Phillip Dunstan	College of Charleston
A. Fred Holland*	SC Dept. of Nat. Res.
Hank McKellar	Univ. of SC
Russell W. Sherer	SC Dept. of Health & Env. Con.
Bob Van Dolah	SC Dept. Wildlife & Mar. Res.

Stono/North Edisto Rivers

David Chestnut	SC Dept. of Health & Env. Con.
Bob Van Dolah	SC Dept. Wildlife & Mar. Res.

St. Helena Sound

Russell W. Sherer	SC Dept. of Health & Env. Con.

Broad River

Russell W. Sherer	SC Dept. of Health & Env. Con.

Savannah River

James Alberts•	Univ. of GA
Robert Hodson*	" " " "
Jackson Blanton*	Skidaway Inst. of Oceanog.
James Nelson*	" " " "
Peter Verity•	" " " "
Richard Wiegert*	" " " "
David M. Knott	SC Dept. Wildlife & Mar. Res.
Louis E. Sage	Acad. of Nat. Sciences
Russell W. Sherer	SC Dept. of Health & Env. Con.
Stuart Stevens*	GA Dept. of Nat. Res.

Ossabaw Sound

James Alberts•	Univ. of GA
Deborah Bronk*	" " " "
Robert Hodson*	" " " "
Mary Ann Moran*	" " " "
Richard Wiegert*	" " " "
Clark Alexander*	Skidaway Inst. of Oceanog.
James Nelson*	" " " "
Peter Verity•	" " " "
Randy Walker*	" " " "
Jim Henry*	GA State Univ.
Stuart Stevens*	GA Dept. of Nat. Res.

St. Catherines/Sapelo Sounds

James Alberts•	Univ. of GA
Deborah Bronk*	" " " "
Robert Hodson*	" " " "
Mary Ann Moran*	" " " "
Richard Wiegert*	" " " "
Clark Alexander*	Skidaway Inst. of Oceanog.
Jackson Blanton*	" " " "
James Nelson*	" " " "
Peter Verity*	" " " "
Randy Walker*	" " " "
Herb Windom*	" " " "
Jim Henry *	GA State Univ.
Stuart Stevens*	GA Dept. of Nat. Res.

Altamaha River

James Alberts•	Univ. of GA
Deborah Bronk*	" " " "
Robert Hodson*	" " " "
Mary Ann Moran*	" " " "
Lawrence Pomeroy*	Univ. of GA
Richard Wiegert*	" " " "
Clark Alexander*	Skidaway Inst. of Oceanog.
Jackson Blanton*	" " " "
James Nelson*	" " " "
Peter Verity*	" " " "
Randy Walker*	" " " "
Herb Windom*	" " " "
Jim Henry*	GA State Univ.
Stuart Stevens?	GA Dept. of Nat. Res.

St. Andrew/St. Simons Sounds

Clark Alexander*	Skidaway Inst. of Oceanog.
Jackson Blanton*	" " " "
James Nelson*	" " " "
Peter Verity*	" " " "
Randy Walker*	" " " "
Herb Windom*	" " " "
Deborah Bronk*	Univ. of GA
Robert Hodson*	" " " "
Mary Ann Moran*	" " " "
Richard Wiegert*	" " " "
Jim Henry*	GA State Univ.
Stuart Stevens?	GA Dept. of Nat. Res.

St. Marys River/Cumberland Sounds

Clark Alexander*	Skidaway Inst. of Oceanog.
Jackson Blanton*	" " " "
James Nelson*	" " " "
Peter Verity*	" " " "
Randy Walker*	" " " "
Herb Windom*	" " " "
Deborah Bronk*	Univ. of GA
Robert Hodson*	" " " "
Mary Ann Moran*	" " " "
Richard Wiegert*	" " " "
Jim Henry*	GA State Univ.
Stuart Stevens?	GA Dept. of Nat. Res.

St. Johns River

Bob Brody	St. Johns R. Water Mgt. Dist.
Betsy J. Deuerling	City of Jacksonville
A. Quinton White	Jacksonville Univ.

Indian River

Diane D. Barile	Marine Res. Council of E. FL
Bob Frease	" " " "
David L. Correll	Smithsonian Env. Research Ctr.
Terry L. Davis	FL Dept. of Env. Reg.
Greg A. Graves	" " " "
Guy P. Hadley	" " " "
John C. Higman	St. Johns R. Water Mgt. Dist.
Robert W. Virnstein	" " " "

Biscayne Bay

Richard W. Alleman	S. FL Water Mgt. Dist.
Susan M. Markley	Dade Cty. Env. Res. Mgt. Div.
Cecelia A. Weaver	" " " "

Appendix 2: Estuary References

The following references were recommended by one or more Eutrophication Survey participants as critical background material for understanding the nutrient enrichment characteristics of individual South Atlantic estuaries. In some cases, the survey results are based directly upon these publications. This list is not comprehensive. Some estuaries are not included because no suggestions were received.

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Appendix 3: NEI Estuaries

One hundred twenty-nine estuaries are included in the National Estuarine Inventory. New systems are occasionally added. Some estuaries are actually subsystems of larger estuaries, although each is being evaluated indepedently for the Eutrophication Survey project (e.g., Potomac River is a subsystem of Chesapeake Bay). For more information on the National Estuarine Inventory, see inside the front cover of this report.

North Atlantic (16)

Passamaquoddy Bay
Englishman Bay
Narraguagus Bay
Blue Hill Bay
Penobscot Bay
Muscongus Bay
Damariscotta River
Sheepscot Bay
Kennebec/Androscoggin Rivers
Casco Bay
Saco Bay
Great Bay
Merrimack River
Massachusetts Bay
Boston Bay
Cape Cod Bay

Mid-Atlantic (22)

Buzzards Bay
Narragansett Bay
Gardiners Bay
Long Island Sound
Connecticut River
Great South Bay
Hudson River/Raritan Bay
Barnegat Bay
New Jersey Inland Bays
Delaware Bay
Delaware Inland Bays
Maryland Inland Bays
Chincoteague Bay
Chesapeake Bay
Patuxent River
Potomac River
Rappahannock River
York River
James River
Chester River
Choptank River
Tangier/Pocomoke Sounds

South Atlantic (21)

Albemarle/Pamlico Sounds
Pamlico/Pungo Rivers
Neuse River
Bogue Sound
New River
Cape Fear River
Winyah Bay
North/South Santee Rivers
Charleston Harbor
Stono/North Edisto Rivers
St. Helena Sounds
Broad River
Savannah River
Ossabaw Sound
St. Catherines/Sapelo Sounds
Altamaha River
St. Andrew/St. Simons Sounds
St. Marys R./Cumberland Snd
St. Johns River
Indian River
Biscayne Bay

Gulf of Mexico (36)

Florida Bay
South Ten Thousand Islands
North Ten Thousand Islands
Rookery Bay
Charlotte Harbor
Caloosahatchee River
Sarasota Bay
Tampa Bay
Suwannee River
Apalachee Bay
Apalachicola Bay
St. Andrew Bay
Choctawhatchee Bay
Pensacola Bay
Perdido Bay
Mobile Bay
Mississippi Sound
Lake Borgne
Lake Pontchartrain
Breton/Chandeleur Sounds
Mississippi River
Barataria Bay
Terrebonne/Timbalier Bays
Atchafalaya/Vermilion Bays
Mermentau Estuary
Calcasieu Lake
Sabine Lake
Galveston Bay
Brazos River
Matagorda Bay
San Antonio Bay
Aransas Bay
Corpus Christi Bay
Upper Laguna Madre
Baffin Bay
Lower Laguna Madre

West Coast (34)

Tijuana Estuary
San Diego Bay
Mission Bay
Newport Bay
San Pedro Bay
Alemitos Bay
Anaheim Bay
Santa Monica Bay
Morro Bay
Monterey Bay
Elkhorn Slough
San Francisco Bay
Cent. San Francisco Bay/
San Pablo/Suisun Bays
Drakes Ester
Tomales Bay
Eel River
Humboldt Bay
Klamath River
Rogue River
Coos Bay
Umpqua River
Siuslaw River
Alsea River
Yaquina Bay
Siletz Bay
Netarts Bay
Tillamook Bay
Nehalem River
Columbia River
Willapa Bay
Grays Harbor
Puget Sound
Hood Canal
Skagit Bay