NOAA's Estuarine Eutrophication Survey

Volume 3: North Atlantic Region

July 1997

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 since the early 1980s by NOAA's Office of Ocean Resources Conservation and Assessment (ORCA) 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 build a foundation of data that can be used to formulate a national response. The Survey is based, in part, on 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, and regional reports on the results. The North Atlantic regional workshop was held in October 1996; this document, Volume 3, is the regional report. It was preceded by the South Atlantic (Volume 1, September 1996) and Mid-Atlantic (Volume 2, March 1997) reports.

Site visits, regional workshops, and regional reports will be completed for the Gulf of Mexico, and West Coast in 1997. 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 proposed methods 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 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's 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 the inside front cover of this report.

About This Report

This report presents the results of ORCA's Estuarine Eutrophication Survey for 18 estuaries of the North Atlantic region of the United States. It is the third in a series of five regional summaries that also includes the South Atlantic (NOAA, 1996), Mid-Atlantic (NOAA, 1997), Gulf of Mexico (NOAA, in prep.), and West Coast (NOAA, in prep.). A national summary of project results is also planned. The Survey is a component of ORCA's National Estuarine Inventory (NEI)—an ongoing series of activities that 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 as well as maps illustrating the results for selected parameters. Next are the Estuary Summaries—one-page summaries of Survey results for each of the 18 North 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 as useful background material on the status and trends of nutrient enrichment in North Atlantic estuaries. Appendix 3 presents a complete list of NEI estuaries.

The Problem

Between 1960-2010, the U.S. population increased, and is projected to continue to increase, most significantly in coastal states (Culliton et al., 1990). This influx of people is placing unprecedented stress on the Nation's coasts and estuaries. 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 nutrient imputs.

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 (Boynton et al., 1982; Rabalais and Harper, 1992; Rabalais, 1992; Paerl, 1988; Whitledge and Pulich, 1991; NOAA, 1992; Burkholder et al., 1992a; Cooper, 1995; Lowe et al., 1991; Orth and Moore, 1984; Kemp et al., 1983; Stevenson et al., 1993; Burkholder et al., 1992b; Ryther and Dunstan, 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; EPA, 1995.). 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 so, 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, 17 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 $\geq 0.1 < 1$ 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 spring runoff and/or turnover. For chlorophyll *a*, ORCA collected information on peak concentrations that are typically reached during an algal 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 conditions.

For some parameters, such as nuisance and toxic algal blooms, there is no standard threshold concentration

	PARAMETERS	EXISTING CONDITIONS (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]
ALGAL CONDITIONS	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]
ALGAL CONDITIONS	SUSPENDED SOLIDS	• Concentrations: Problem (significant impact upon biological resources) No Problem (no significant impact) • Months of occurrence, Frequency of occurrence[2]	(no trends information collected)
ALGAL CONDITIONS	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]
ALGAL CONDITIONS	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]
NUTRIENTS	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 (>0mg/l ≤ 2mg/l) BIOL. STRESS (>2mg/l ≤ 5mg/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]
ECOSYSTEM / COMMUNITY RESPONSE	PLANKTONIC COMMUNITY	• Dominant taxonomic group (number of cells): Diatoms, Flagellates, Blue-green algae, Diverse mixture, Other	• Temporal shift • Contributing factors[5]
ECOSYSTEM / COMMUNITY RESPONSE	BENTHIC COMMUNITY	• Dominant taxonomic group (number of organisms): Crustaceans, Molluscs, Annelids, Diverse mixture, Other	• Temporal shift • Contributing factors[5]
ECOSYSTEM / COMMUNITY RESPONSE	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.*

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).

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 upon which the response is based. 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, were distributed with the survey questions for orientation. Updates and/or revisions to these maps were made as appropriate.

Collecting the Data

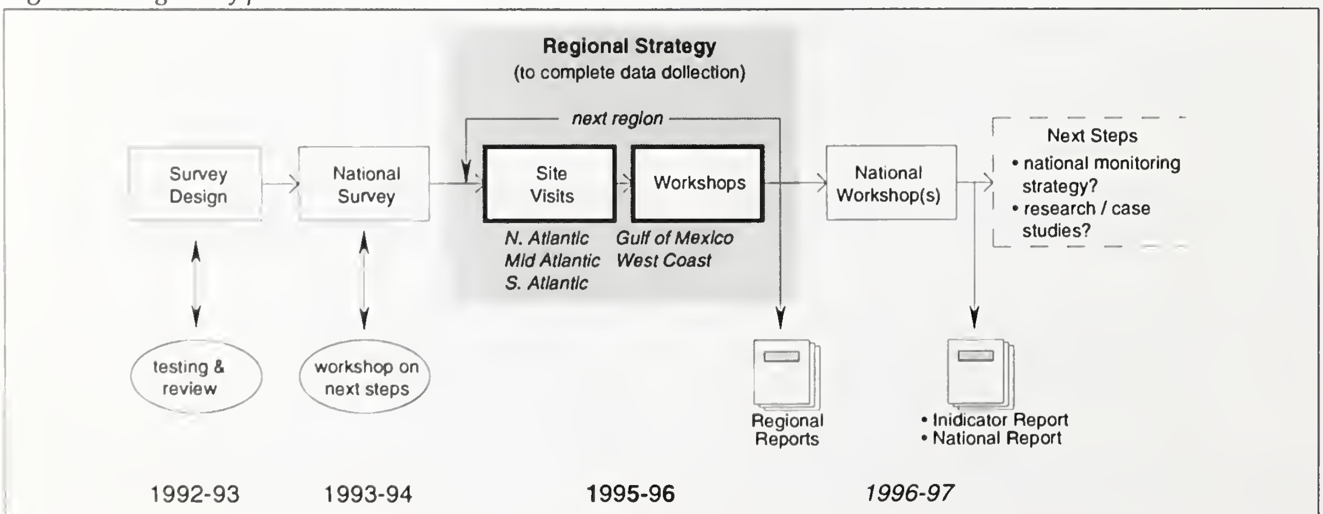
Over 400 experts and managers agreed to participate in the initial survey. Survey forms were mailed to the experts, who then mailed in their responses. The response rate was approximately 25 percent, with at least one response for 112 of the 129 estuaries being surveyed.

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 (Figure 1).

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 individuals have either filled out a survey form and/or participated in

Figure 1: *Diagram of process.*



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. At the workshop, at least two workgroups are established based upon geography.

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

Regional reports are in progress for the Gulf of Mexico 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 (see inside front cover). Formulating a national response to estuarine nutrient enrichment, and developing a national "indicator" on coastal ecosystem health, will require one or more workshops to reach consensus on the methods and products resulting from these analyses. This work is currently scheduled for late 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 the 18 North 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 North Atlantic region, part of the New England Coastal Province, includes 18 estuarine systems, encompassing more than 2,000 square miles of water surface area (Figure 2). The high energy coast is characterized by a rocky shoreline with numerous islands and small embayments. For this report, the region is divided into two physiographic subregions: Northern Gulf of Maine and Southern Gulf of Maine. The Northern Gulf of Maine extends from the Maine-Canadian border to just south of Cape Elizabeth, Maine. The Southern Gulf of Maine extends south from Cape Elizabeth to Monomoy Island, Massachusetts, near Cape Cod (Beccasio, 1980).

Northern Gulf of Maine

The 11 Northern Gulf of Maine estuarine systems characterized in this report encompass approximately 1,078 mi^2 of water surface area. Formed largely by episodes of glacial advance and retreat, the subregion is characterized by a rocky coastline with wave cut cliffs and large, rocky islands. Most Maine estuaries are drowned river valleys containing many small embayments (Hunt, 1967). The macrotides in estuaries of this region (20 feet in St. Croix River/Cobscook Bay) create an abundance of intertidal pool areas, and increase tidal mixing in the middle and upper sections of most estuaries. The large tidal range has a significant influence on estuarine salinity variability which can range from

Highlights of Regional Results

(Note: Tidal fresh = 1%, Mixing = 3%, Seawater = 96% of regional surface area (2,039 mi^2))

Chlorophyll *a*

Hypereutrophic concentrations (>60 µg/l) are not reported in any estuary. High or greater concentrations (>20 µg/l) are reported to occur from June to September in 4 of 18 estuaries, affecting up to 5% of the regional estuarine area. Concentrations did not change in 12 estuaries, and trends were unknown in 6 estuaries.

Toxic Algae Blooms

Toxic algal blooms, primarily *Alexandrium*, are reported to occur in 11 of 18 estuaries, mostly on a periodic basis. These blooms occur from June through September, though in some estuaries they begin in April. There was no change in the frequency of occurrence of toxic blooms for 11 estuaries, and trends were unknown for 7 estuaries. Increases and decreases were not reported for any estuary.

Nitrogen

High nitrogen concentrations (>1.0 mg/l) have been reported in Cape Cod Bay and Hampton Harbor Estuary, affecting up to 2% of the regional estuarine area. Concentrations are reported to have decreased in Penobscot Bay, increased in Cape Cod Bay urban embayments, shown no trend in 12 estuaries, and trends are unknown for 4 estuaries.

Phosphorus

High phosphorus concentrations (>0.1 mg/l) were not reported in any of the 18 estuaries. However, medium concentrations (0.01 - 0.1 mg/l) were reported in 14 estuaries, affecting up to 70% of the regional estuarine area. For most estuaries, medium concentrations occur October to March, but in some estuaries it is persistent year-round. Concentrations were reported as not changed in 12 estuaries, unknown in 5 estuaries, and decreased in Great Bay. No increases were reported.

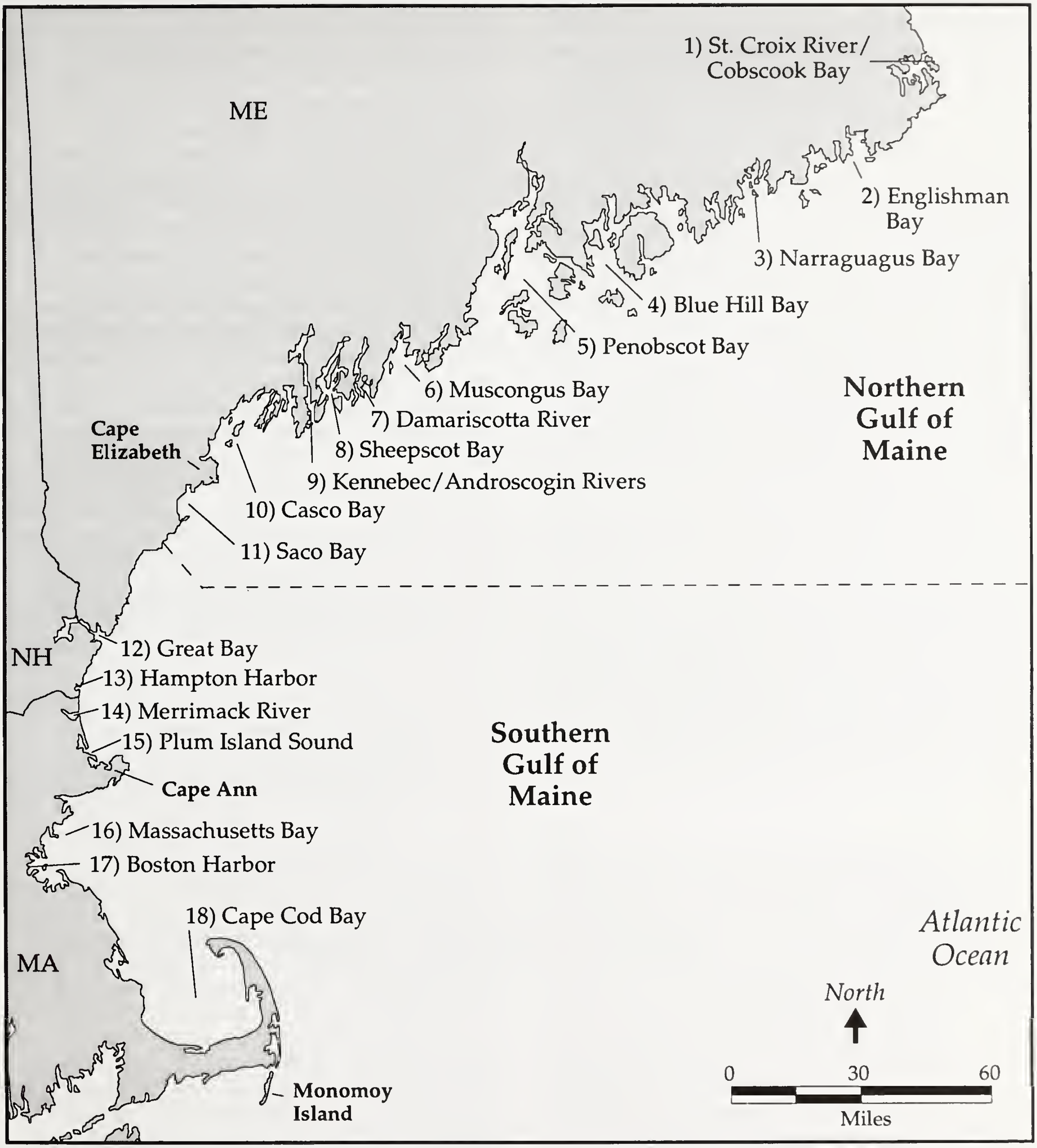
Hypoxia

Hypoxia is reported to be observed periodically from July through September in very small areas of Great Bay, Boston Harbor, and Cape Cod Bay, and episodically in Saco Bay. Stratification is influential on development of hypoxia in Great Bay and Boston Harbor. Spatial coverage of hypoxic occurrences decreased in Penobscot and Casco Bays, and remained the same for 10 estuaries. For 6 estuaries, trends in spatial coverage were unknown.

Anoxia

Anoxia is reported to be observed episodically throughout the water column in Kennebec/Androscoggin Rivers, affecting less than 1% of the regional estuarine area, 37-76% of the tidal fresh zone, 5-10% of the mixing zone, and none of the seawater zone. Stratification was not reported to be a significant influence. Spatial coverage of anoxia was reported to have decreased in Penobscot and Casco Bays, remained the same in 11 estuaries, and trends were unknown for 6 estuaries. Increases in spatial coverage were not reported for any estuary.

Figure 2: *Regional map of North Atlantic showing two subregions and 18 estuaries.*



near zero to 33 ppt in a single tidal cycle. Freshwater inflow is dominated by discharge from the St. John, Kennebec, and Penobscot river systems. Depths for the Northern Gulf of Maine systems average approximately 50 feet.

Southern Gulf of Maine

The seven Southern Gulf of Maine estuarine systems characterized in this report encompass 961 mi^2 of estuarine water surface area. The shoreline topography of this subregion also shows the distinctive features resulting from glacial advance and retreat (Figure 2). Dominant coastal features include Cape Cod, Massachusetts Bay, and Cape Ann. The coastline from Cape

Elizabeth to Cape Ann is a succession of high-energy sand, cobble or gravel beaches and rocky shores; south of Cape Ann, beaches are sand or gravel. Tidal marshes are more extensive in the Southern Gulf of Maine estuaries than in Northern Gulf of Maine estuaries. In addition, variability in tidal range among Southern Gulf of Maine estuaries (7-9 feet) is significantly less than among Northern Gulf of Maine estuaries (9-20 feet). Depths are greatest in Massachusetts and Cape Cod Bays (average 77 feet) and decrease dramatically in the smaller estuaries to the north (11 feet in Merrimack River and Great Bay). Freshwater inflow is dominated by discharge from the Merrimack River and several smaller river systems such as the Salmon Falls, Parker and Neponsett.

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, and existing conditions and trends are reviewed. Probable months of occurrence by parameter and by salinity zone are presented in Figure 3 (page 9). Regional maps summarizing existing conditions for selected parameters are presented in Figure 4 (page 11). A summary of recent trends (1970-present) for all parameters is presented in Figure 5 (page 14).

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 93 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 North 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, page 3). Maximum surface concentrations of chlorophyll *a* were not reported to reach hypereutrophic levels (>60 µg/l) in the North Atlantic region, and high concentrations (>20 µg/l) were reported in only 0.5, 1.5, and 3 percent of the tidal fresh, mixing, and seawater zones, respectively. Medium or greater concentrations of chlorophyll *a* (>5 µg/l) were reported to occur in 75 percent of the region's tidal fresh zone surface area, 11 percent of the mixing zone, and 66 percent of the seawater zone. Medium to high turbidity conditions (secchi disk depths of < 3 meters) were reported to occur in up to 79 percent of the region's tidal fresh zone surface area, 51 percent of the mixing zone, and 9 percent of the seawater zone. By contrast, high turbidity (secchi disk depths of < 1 meter) was reported to occur in 2 percent of the mixing zone, and not at all in the tidal fresh or seawater zones. Resource impacts from suspended solids were reported to occur in three of the estuaries in which high turbidity concentrations occur. Toxic algae appears to impact resources in 11 of 18 estuaries, primarily in the seawater zone. Nuisance algae resource impacts are limited to Casco Bay and small areas of Great Bay, but occur in all three zones. Macroalgal and epiphyte abundance impacts are fairly evenly distributed among the salinity zones and throughout the region, with macroalgae reported to impact resources in eight estuaries, and epiphytes in four estuaries.

Chlorophyll a

High concentrations (>20, ≤60 µg/l) of chlorophyll *a* were reported in four estuaries, affecting a maximum of only 3 percent of the estuarine surface area (Figure 4). In contrast, medium or greater concentrations (>5 µg/l) were reported to occur in 14 estuaries, over a maximum of 65 percent of the regional estuarine surface area. In the Northen Gulf of Maine subregion, high concentrations are reported only in the inner bays of Casco Bay from July through August. Medium concentrations are typically reached from early spring through summer. St. Croix River/Cobscook Bay, Penobscot Bay, and Saco Bay were all reported to have low year-round concentrations of chlorophyll *a*. In the Southern Gulf of Maine estuaries, high concentrations are reached in Great Bay, Plum Island Sound, and Cape Cod Bay. The spatial extent was unknown for high concentrations in Plymouth, Provincetown, and Barnstable Harbors, and for medium concentrations in Blue Hill Bay and Neponset River. Thus, the regional spatial extent of medium and high concentrations could be somewhat larger than reported. Elevated concentrations of chlorophyll *a* were reported to occur at some time during spring through fall, with three estuaries having elevated winter occurrences.

There were no changes in chlorophyll *a* concentrations reported in 12 estuaries; in six, trends were reported as unknown.

Turbidity

Medium to high turbidity conditions (secchi disk depths of < 3 meters) were reported in 11 North Atlantic estuaries, covering 11 percent of the region's estuarine surface area, while high turbidity concentrations were reported to occur only in parts of Great Bay and Plum Island Sound (less than 1 percent of regional estuarine surface area).

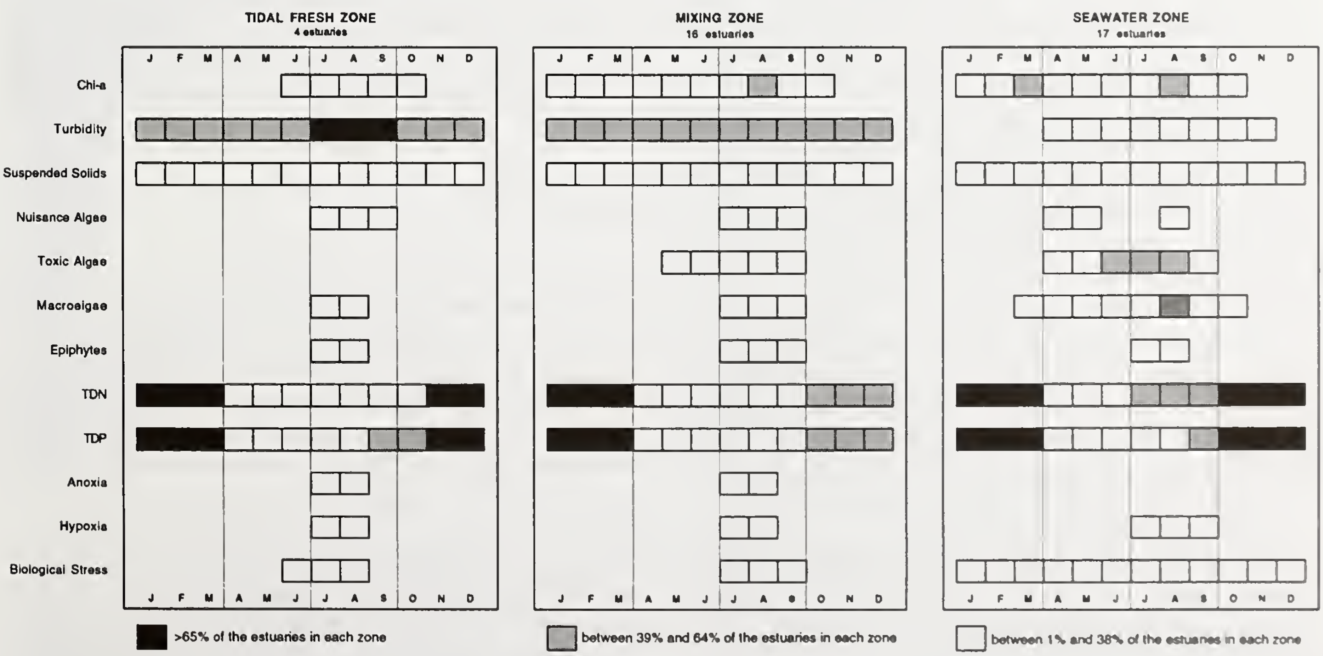
Since 1970, decreases in turbidity of a high magnitude have been reported for parts of St. Croix River/ Cobscook Bay and Casco Bay. The decreases were attributed to improvements or reductions in point-source discharges from paper mills, sewage-treatment plants, and fish-processing plants. A low-magnitude turbidity increase was reported in the seawater zone of Englishman Bay. Conditions were unchanged in at least one zone in eight estuaries, and trends were unknown for seven estuaries.

Suspended Solids

Suspended solids were reported as impacting biological resources (e.g., submerged aquatic vegetation, filter feeders, etc.) in two North Atlantic estuaries. The impacts are reported to occur persistently throughout the year in parts of Boston Harbor. In Cobscook Bay, problematic conditions were reported to occur episodically from October through January due to scallop dredging. There were no reported impacts from suspended solids in 15 estuaries; conditions are unknown for the Merrimack River. Trends information was not collected for suspended solids.

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 <u>maximum values</u> occur in at least 65 percent of the 18 North Atlantic estuaries for a particular salinity zone. For example, tidal fresh zones occur in 4 estuaries; therefore, a black tone indicates a maximum value was recorded in 2 or more estuaries. Similarly, for the mixing zone, black represents 10 or more estuaries, and for the seawater zone it represents 11 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, and SAV).



Nuisance Algae

Nuisance dinoflagellates and *Phaeocystis* spp. were reported to episodically impact resources in Casco Bay for weeks at a time, during April and May. In Great Bay, *Prorocentrum* spp. were reported to occur episodically in Spinney Creek. A diverse mixture of nuisance species episodically affects Salmon Falls/Cocheco Rivers for days at a time, from July through September. *Phaeocystis* spp. and *Prorocentrum* spp. were reported as presently occurring in Massachusetts Bay, Boston Harbor, and Cape Cod Bay, but not at problematic concentrations.

There has been no reported trend in the duration or frequency of occurrence of nuisance algae events in 11 estuaries ca. 1970 to 1995. Trends were unknown for seven estuaries.

Toxic Algae

Resource impacts from toxic algae were reported to occur in nine of the 11 Northern Gulf of Maine estuaries. *Alexandrium* spp. occur periodically for weeks to months at a time, typically from spring through summer in several estuaries; however, in the mixing zone of Narraguagas Bay, their timing and frequency have not been determined. *Gymnodinium mikimotoi* occurred for days in September of 1988 in Casco Bay inner bays. In Southern Gulf of Maine, *Alexandrium* impacts resources within Massachusetts and Cape Cod Bays, for weeks at a time.

Northern Gulf of Maine Estuaries

Northern Gulf of Maine estuaries are unique from the other North Atlantic estuaries due to their large tidal amplitude and the source of nitrogen. The estuaries in Northern Gulf of Maine have a tidal amplitude that ranges from 20 feet in St. Croix River/Cobscook Bay, the easternmost estuary in this report, to nine feet in Saco and Caso Bays to the southwest. As a result, tidal mixing and oceanic exchange are significant in these estuaries. The other defining characteristic of these estuaries is that the main source of nitrogen comes from the inflow of Gulf of Maine deep water instead of from land-based sources. Unlike many estuaries in other regions, the drainage basin has neither large centers of population (and thus little sewage-derived nutrients), nor large areas of agricultural land use that would provide nutrients through runoff (Garside et al., 1978; Fefer and Schettig, 1980).

There has been no trend reported in the duration or frequency of occurrence of toxic algae events in 14 of the North Atlantic estuaries ca. 1970 to 1995. Toxic algae trends are unknown for four estuaries.

Macroalgal Abundance

Resource impacts from macroalgae were reported in at least one salinity zone of eight estuaries in the North Atlantic region. These impacts were reported to occur periodically in six estuaries and episodically in two, typically during the summer but sometimes starting in spring. Macroalgal abundance information was unknown for Merrimack River.

Increases in macroalgal abundance were reported for seven estuaries. Trends for four of these estuaries were based in part on speculative inference. Conditions were reported to remain unchanged for five estuaries. Trends for six estuaries were unknown.

Epiphyte Abundance

Resource impacts from epiphytes were reported in the mixing zone of the St. Croix River, the East Bay portion of Casco Bay, Great Bay, and Boston Harbor. Impacts were reported to occur between July and September on a periodic basis in St. Croix River and Boston Harbor, and episodically in Great Bay. Frequency and timing for Casco Bay was not determined. Epiphyte abundance information was unknown in Saco Bay, Merrimack River, and Cape Cod Bay urban embayments.

Epiphyte abundance was speculated to have increased to a low extent from 1970 through 1995 in Great Bay. There were no reported epiphyte abundance trends in nine estuaries, and trends were unknown in the other eight.

Nutrients

Nutrient concentrations in the North Atlantic region were characterized by collecting information on the existing conditions (maximum values observed over a typical annual cycle) and trends. The intent of the survey was to collect information for total dissolved nutrients, because these forms are what is available to the phytoplankton. Unless otherwise specified, nutrient information presented in this report refers to total dissolved nitrogen (TDN) and phosphorus (TDP), including the inorganic and organic forms. For five estuaries (Penobscot, Sheepscot, Casco Bays, Damariscotta River, and most of Great Bay), nitrogen concentrations are reported as dissolved inorganic nitrogen (DIN).

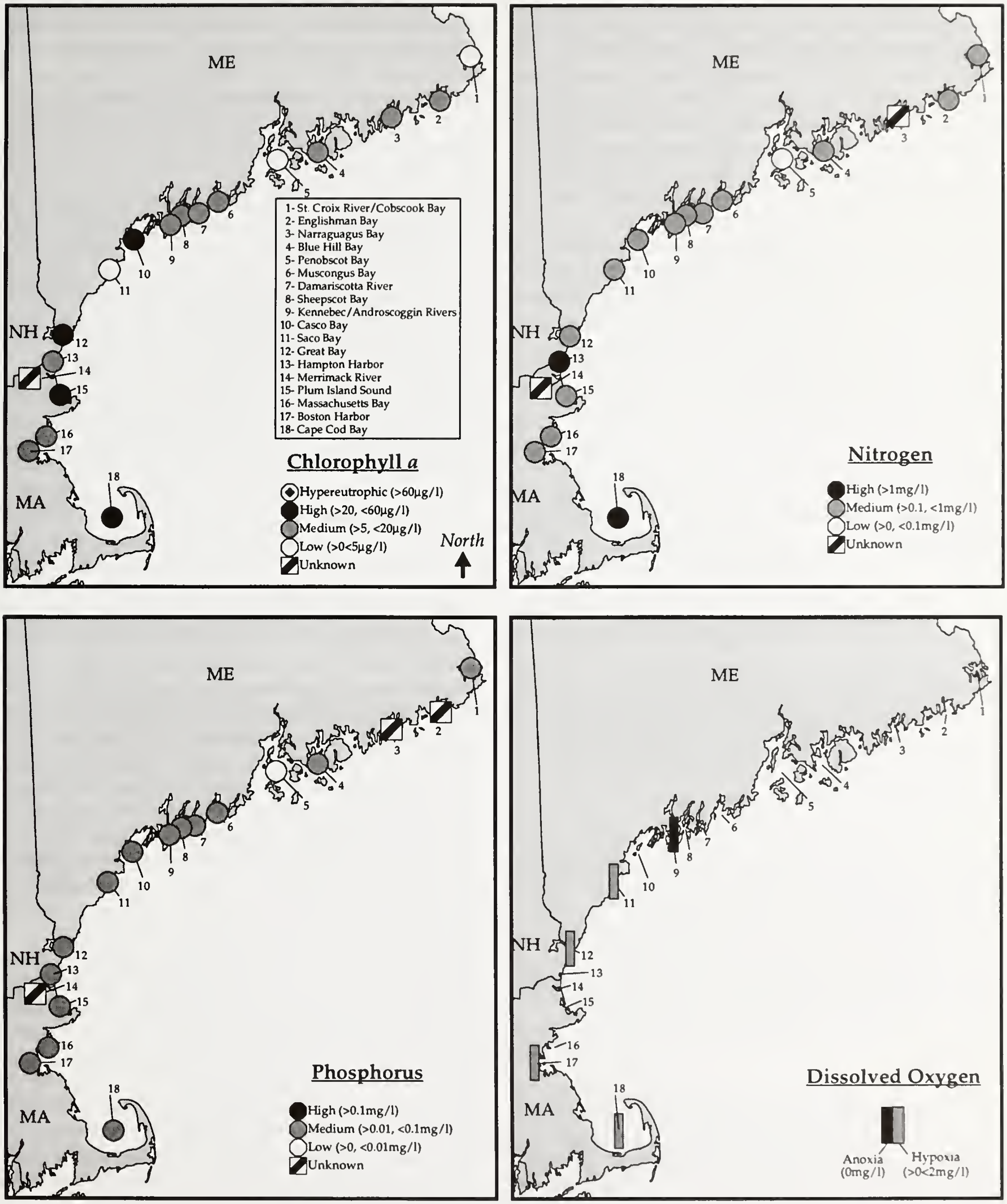


Figure 4: *Existing conditions for chlorophyll a, nitrogen, phosphorus, and dissolved oxygen. Symbols indicate that an existing condition(s) (e.g., hypereutrophic for chlorophyll a, anoxia and/or hypoxia for dissolved oxygen) was reported in at least a portion of one salinity zone of an estuary at some 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 18.*

High concentrations of phosphorus (≥ 0.1 mg/l) were not reported in any North Atlantic estuary, while high concentrations of nitrogen (≥ 1.0 mg/l) occurred in small marsh creeks of Hampton Harbor and urban embayments of Cape Cod Bay. Medium concentrations of both nitrogen (≥ 0.1 - 1.0 mg/l) and phosphorus (≥ 0.01 - 0.1 mg/l) were reported as much more pervasive, occurring over 67% of the regional area in the fall and winter.

Most estuaries have not had a reported change in the concentration of either nitrogen or phosphorus between 1970 and 1995. However, decreasing trends were reported in portions of Great Bay and Penobscot Bay, while the urban embayments of Cape Cod Bay were reported to have had an increase in nutrient concentrations since 1970 (Figure 5).

Nitrogen

High nitrogen concentrations were reported in the tidal fresh and mixing zones of Hampton Harbor and in the urban embayments of Cape Cod Bay (2 percent of the regional estuarine area). Medium concentrations of nitrogen were reported in 13 North Atlantic estuaries (Figure 4). Medium concentrations were observed in up to 80 percent of the regional tidal fresh zone, in up to 53 percent of the regional mixing zone, and in up to 72 percent of the regional seawater zone. Highest concentrations of nitrogen are observed in the fall and winter in the Northern Gulf of Maine estuaries. In Southern Gulf of Maine systems, concentrations do not vary seasonally.

Trends were reported as unknown for all or part of nine North Atlantic estuaries (Figure 5). Speculative increases of an unknown magnitude occurred over the last 25 years in the urban embayments of Cape Cod Bay. In addition, a speculative decrease of unknown magnitude was reported for the mixing zone of Penobscot Bay. No change in concentrations of nitrogen occurred in all or portions of 13 estuaries.

Phosphorus

High phosphorus concentrations were not reported for any estuary in the North Atlantic. Medium phosphorus concentrations were observed for 15 North Atlantic estuaries, in up to 67 percent of the seawater zone, up to 56 percent of the mixing zone, and up to 81 percent of the tidal fresh zone. Highest concentrations of phosphorus are observed in the fall and winter in the Northern Gulf of Maine estuaries. In Southern Gulf of Maine systems, concentrations do not vary seasonally.

Trends in phosphorus concentrations were reported as unknown for all or portions of seven estuaries (Figure 5). There were no reported changes in phosphorus concentrations in the remaining estuaries, except for a decrease in the mixing zone of Great Bay.

Dissolved Oxygen

Dissolved oxygen conditions were characterized by collecting information about existing conditions and trends for anoxia (0 mg/l), hypoxia (>0 mg/l, ≤2 mg/l), and biologically stressful concentrations (>2 mg/l, ≤5 mg/l). For each observed condition, the occurrence, timing (both time of year and duration), frequency of occurrence (periodic or episodic), location in the water column (surface, bottom, or throughout), and spatial extent was recorded. The influence of water-column stratification (high, medium, low, or not a factor) on development of low dissolved oxygen was also noted.

Anoxic conditions were reported in one of the 18 North Atlantic estuaries, and hypoxia was reported to occur in four estuaries. Both conditions are observed during the summer months (July to August), and while anoxia is observed only episodically, hypoxia occurs on an annual basis. Anoxia is reported to occur throughout the water column, with a medium to high (>25% salinity zone) spatial coverage. Hypoxia is observed only in bottom waters at a very low spatial extent (0-10% salinity zone). For both conditions, water-column stratification is not reported as a factor in the development of low dissolved oxygen. The number of estuaries reported as having biologically stressful concentrations of dissolved oxygen (nine estuaries) was almost twice the number reported as having anoxia and hypoxia (five estuaries). Biologically stressful concentrations were reported to occur in summer in bottom waters in three estuaries, throughout the water column in four estuaries, and in surface waters in one estuary. For most estuaries, biologically stressful concentrations were reported to occur periodically over a very low spatial area; stratification was not reported as a factor in the expression of this condition.

Trends for bottom-water dissolved oxygen concentrations were reported as unchanged in eight estuaries, increased in five estauries, and speculated to have decreased in one estuary (Cape Cod Bay). Trends were unknown for the remaining four estuaries.

Anoxia

Anoxic conditions were reported to occur in the tidal fresh and mixing zones of only the Kennebec/Androscoggin Rivers, representing a maximum of 1 percent of the total North Atlantic estuarine surface area. Where reported, anoxia is observed in July and August, on an episodic basis, and occurs throughout the water column; however, water-column stratification was not reported as a factor in the development of anoxia. The spatial extent of anoxia, when reported, is high in the tidal fresh zone (>50 percent of zone) and medium in the mixing zone (25 to 50 percent). For all or part of five estuaries (Merrimack and Damariscotta Rivers, Englishman and Muscongus Bays, and Boston Harbor), it is unknown whether anoxia occurs.

Declines in both the duration and frequency of occurrence of anoxic events were reported for two estuaries, Penobscot Bay and Casco Bay. Penobscot Bay also experienced decreases in the spatial coverage of anoxia. For more than half of the estuaries, no trends were observed, though for Muscongus Bay this assessment was speculative. Trends in spatial coverage were unknown for six estuaries, and trends in duration and frequency were unknown for seven. (Figure 5).

Hypoxia

Hypoxic conditions (>0 mg/l, ≤2 mg/l) were reported in very small areas of four estuaries; Saco Bay, Great Bay, Boston Harbor, and Cape Cod Bay. This condition is observed periodically, with the exception of Saco Bay, where it is an episodic occurrence. Hypoxia is seen in the summer months, July through August, and almost exclusively in bottom waters, though for Cape Cod Bay this assessment is speculative. The spatial extent is typically reported as very low (0 to 10 percent) and is observed over a total of less than 1 percent of the total regional estuarine surface area. For all or parts of five estuaries, it is unknown whether hypoxia occurs.

Decreases in the duration, frequency of occurrence and spatial coverage of hypoxic events were reported for two estuaries, Penobscot Bay and Casco Bay. Nine estuaries were reported to have no trend in duration and frequency, and 10 estuaries were reported to have no trend in spatial coverage of hypoxia. However, for Muscongus Bay, these assessments were speculative. For seven estuaries, duration and frequency of occurrence trends were reported as unknown, and for six estuaries, trends in spatial coverage were reported as unknown. (Figure 5).

Biological Stress

Biologically stressful levels of dissolved oxygen (>2 mg/l, ≤5 mg/l) were reported to occur in all or part of 9 estuaries. This condition occurs episodically in St. Croix/Cobscook Bay, Sheepscot Bay, and Casco Bay, and periodically in Muscongus Bay, Great Bay, Hampton Harbor Estuary, Plum Island Sound, Boston Harbor and Cape Cod Bay. For Plymouth Harbor in Cape Cod Bay, biologically stressful concentrations were reported as persistent, but occurring over a very low (0 to 10 percent) spatial extent. The cumulative area over which it is reported accounts for a maximum of 1 percent of the total regional estuarine area. For less than 1 percent of the regional area, it is unknown whether this condition occurs. Biologically stressful conditions are reported to be observed from July through September, mostly on a periodic basis. It is reported to be observed both in bottom waters and throughout the water column, but stratification was not reported to be a factor.

Decreases in duration, frequency, and spatial extent were reported for Penobscot and Casco Bays. For nine estuaries, duration or spatial extent were reported as stable, and for 10 estuaries, the frequency of occurrence was reported as stable. For Muscongus Bay, assessments of no trend were speculative. For seven estuaries, trends were unknown with regard to duration and frequency, and for six estuaries, trends in spatial coverage were unknown (Figure 5).

Ecosystem/Community Response

The responses of estuarine ecosystems to nutrient inputs were characterized by collecting information on the status and trends of four parameters: primary productivity, pelagic and benthic communities, and submerged aquatic vegetation (SAV). Information regarding primary productivity indicated that the North Atlantic region is dominated almost exclusively by pelagic communities. A diverse mixture of diatoms, flagellates, and/or other plankton groups characterizes the plankton community, while the benthic community is dominated by a diverse mixture of annelids, crustaceans, mollusks, and/or other organisms. SAV was reported in all but three of the region's estuaries, primarily at a low or very low density. Little variation was reported for all four ecosystem parameters throughout the region or across salinity zones.

The North Atlantic region is generally stable with regard to changes through time (ca. 1970-95) in primary productivity and the plankton and benthic communities, with shifts reported in only two estuaries. Trends in SAV coverage were reported for only 39 percent of the region; however, where information was available, an increasing coverage was reported in parts of two estuaries and a declining coverage was noted in parts of five estuaries, mostly in the seawater zone of the Southern Gulf of Maine subregion.

Figure 5: *Recent trends (1970 - present for most estuaries) 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 888 possible values are unknown (416) or no trend (407). There are 42 decreasing trends and 21 increasing trends. Two responses display a shift in the benthic community. 41 values are based on speculative inferences. For a more complete listing of the trends parameters, see Table 1 on page 3.*

	St. Croix R./Cobscook Bay		Englishman Bay		Narraguagus Bay		Blue Hill Bay		Penobscot Bay			Muscongus Bay		Damariscotta River		Sheepscot Bay		
	M	S	M	S	M	S	M	S	T	M	S	M	S	M	S	T	M	S
CHLOROPHYLL A (µg/l)	●	●	?	?	?	?	?	●	?	?	?	?	●	?	●	?	●	●
TURBIDITY (concentrations)	↓•	●	?	↑	?	?	?	●	?	?	?	?	?	?	●	●	●	●
NUISANCE ALGAE event duration	●	●	?	?	?	?	?	?	?	●	●	?	?	?	●	●	●	●
NUISANCE ALGAE frequency of occurrence	●	●	?	?	?	?	?	?	?	●	●	?	?	●	●	●	●	●
TOXIC ALGAE event duration	●	●	?	●	?	●	?	●	?	●	●	?	?	?	●	●	●	●
TOXIC ALGAE frequency of occurrence	●	●	?	●	?	?	?	●	?	●	●	?	?	●	●	●	●	●
MACROALGAL ABUNDANCE	↑	↑•	?	↑	?	?	?	●	?	?	?	●	●	?	●	●	●	●
EPIPHYTE ABUNDANCE	?	●	?	?	?	?	?	?	?	?	?	●	●	●	●	●	●	●
NITROGEN (mg/l)	●	●	?	●	?	?	●	●	?	↓•	●	?	●	●	●	●	●	●
PHOSPHORUS (mg/l)	●	●	?	?	?	?	●	●	●	●	●	?	●	●	●	●	●	●
BOTTOM DO (mg/l)	↑	●	?	●	?	?	●	●	↑	↑	●	●	●	●	●	↑•	?	●
ANOXIA event duration	?	●	?	?	?	?	●	●	↓	↓	●	●•	?	●	●	?	?	●
ANOXIA frequency of occurrence	?	●	?	?	?	?	●	●	↓	↓	●	●•	?	●	●	?	?	?
ANOXIA spatial coverage	?	●	?	?	?	?	●	●	↓	↓	●	●•	?	●	●	?	?	●
HYPOXIA event duration	?	●	?	?	?	?	●	●	↓	↓	●	●•	?	●	●	?	?	●
HYPOXIA frequency of occurrence	?	●	?	?	?	?	●	●	↓	↓	●	●•	?	●	●	?	?	?
HYPOXIA spatial coverage	?	●	?	?	?	?	●	●	↓	↓	●	●•	?	●	●	?	?	●
BIOLOGICAL STRESS event duration	?	●	?	?	?	?	●	●	↓	↓	●	●•	?	●	●	?	?	●
BIOLOGICAL STRESS frequency of occurrence	?	●	?	?	?	?	●	●	↓	↓	●	●•	?	●	●	?	?	?
BIOLOGICAL STRESS spatial coverage	?	●	?	?	?	?	●	●	↓	↓	?	●•	?	●	●	?	?	●
PRIMARY PRODUCTIVITY	●•	●•	?	?	?	?	●	●	?	?	?	?	?	●•	●•	?	●	●
PLANKTONIC COMMUNITY	?	●	?	●	?	?	?	●	?	?	?	?	?	●	●	?	●	●
BENTHIC COMMUNITY	?	●	?	●	?	?	?	●	?	●	●	?	?	●	●	●	●	●
SAV (spatial coverage)	●	↑	?	?	?	?	●	●	?	?	?	?	?	●	●•	?	?	?

	Kennebec/Andro. Riv.			Casco Bay		Saco Bay		Great Bay		Hampton Harbor		Merrimack River		Plum Island Sound		Massachusetts Bay	Boston Harbor		Cape Cod Bay
	T	M	S	M	S	M	S	M	S	M	S	T	M	M	S	S	M	S	S
CHLOROPHYLL A (µg/l)	?	?	?	●	●	●	●	●	●	?	?	?	?	●	●	●	?	●	●
TURBIDITY (concentrations)	?	?	?	↓	●	?	?	●	●	?	?	?	?	●	●	●	●	●	●
NUISANCE ALGAE event duration	?	?	?	●	●	●	●	●	●	●	●	?	?	●	●	●	?	?	●
NUISANCE ALGAE frequency of occurrence	?	?	?	●	●	●	●	●	●	●	●	?	?	●	●	●	?	?	●
TOXIC ALGAE event duration	?	?	?	●	●	●	●	●	●	●	●	?	?	●	●	●	?	?	●
TOXIC ALGAE frequency of occurrence	?	?	?	●	●	●	●	●	●	●	●	?	?	●	●	●	?	?	●
MACROALGAL ABUNDANCE	?	?	?	●	↑•	?	?	↑•	↑•	●	●	?	?	?	?	↑	?	↑•	↑
EPIPHYTE ABUNDANCE	?	?	?	●	●	?	?	●•	●•	●	●	?	?	?	?	●	?	?	●
NITROGEN (mg/l)	?	?	?	●	●	●	●	●	●	?	?	?	?	●	●	●	?	●	↑•
PHOSPHORUS (mg/l)	?	?	?	●	●	●	●	↓	●	?	?	?	?	●	●	●	?	●	●
BOTTOM DO (mg/l)	?	?	?	↑	↑	↑	●	●	●	?	?	?	?	●	●	●	?	●	↓•
ANOXIA event duration	?	?	?	?	↓	?	?	●	●	?	?	?	?	●	●	●	?	?	●
ANOXIA frequency of occurrence	?	?	?	?	↓	?	?	●	●	?	?	?	?	●	●	●	?	●	●
ANOXIA spatial coverage	?	?	?	?	↓	?	?	●	●	?	?	?	?	●	●	●	?	●	●
HYPOXIA event duration	?	?	?	↓	↓	?	?	●	●	?	?	?	?	●	●	●	?	?	●
HYPOXIA frequency of occurrence	?	?	?	↓	↓	?	?	●	●	?	?	?	?	●	●	●	?	●	●
HYPOXIA spatial coverage	?	?	?	↓	↓	?	?	●	●	?	?	?	?	●	●	●	?	●	●
BIOLOGICAL STRESS event duration	?	?	?	↓	↓	?	?	●	●	?	?	?	?	●	●	●	?	?	●
BIOLOGICAL STRESS frequency of occurrence	?	?	?	●	↓	?	?	●	●	?	?	?	?	●	●	●	?	●	●
BIOLOGICAL STRESS spatial coverage	?	?	?	↓	↓	?	?	●	●	?	?	?	?	●	●	●	?	●	●
PRIMARY PRODUCTIVITY	●•	●•	●•	?	?	?	?	●	●	?	?	?	?	●	●	●	?	●	●
PLANKTONIC COMMUNITY	●•	●•	●•	?	●	?	?	?	●	?	?	?	?	●	●	●	?	●	●
BENTHIC COMMUNITY	●•	●•	●•	●	●	?	?	●	●	?	?	?	?	●	●	(1)	●	(2)	●
SAV (spatial coverage)	●•	●•	●•	●	↓	?	?	↑	↑	●	●	?	↓	●	●	↓	●	↓	↓

? - unknown ↓ - decreasing trend • - speculative response ● - no trend or shift ↑ - increasing trend (1) - shift from annelids to diverse (2) - shift from a mixture of annelids and crustaceans to crustaceans

Primary Productivity

Pelagic (plankton) communities were identified as the dominant primary producer in the mixing and/or seawater zones of 14 estuaries, representing 83 percent of the region's estuarine surface area. A diverse mixture of pelagic and benthic communities was the next most reported group, accounting for 2 percent of the region but including 79 percent of the region's tidal fresh zone. In remaining areas, the dominant producers reported were: benthic communities in the mixing zone of Sheepscot Bay and in all of St. Croix/Cobscook Bay; SAV in parts of the mixing zone of Great Bay and the mixing zone of the Damariscotta River; and wetlands in the mixing zones of Saco Bay and Plum Island Sound.

Historical shifts (ca. 1970-95) in primary productivity, i.e., shifts in dominance from one primary producer to another, were reported as unknown for one or more salinity zones in 15 estuaries (40 percent of the region's estuarine surface area). Where information was available, no shifts were reported.

Pelagic Community

A diverse mixture of diatoms, flagellates, and/or other plankton groups dominated the plankton community in the North Atlantic region, in at least one salinity zone in 13 estuaries. Diatoms, the only other group reported, were dominant in the tidal fresh zone of Penobscot Bay.

Temporal shifts in plankton dominance, from one taxonomic group to another, were reported as unchanged in all or parts of 12 estuaries (68 percent of the region's estuarine surface area). No information was available for the remaining area.

Benthic Community

The dominant benthic community (with regard to abundance) reported in the North 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 14 estuaries, representing 77 percent of the region's estuarine surface area. Annelids were the next most abundant group (reported in one or more salinity zones of five estuaries), followed by crustaceans (in the mixing zone of Sheepscot Bay and the seawater zone of Boston Harbor). Two other groups reported were mollusks, in the tidal fresh and mixing zones of Penobscot Bay, and insects, in the tidal fresh zone of Sheepscot Bay.

Shifts in benthic community dominance, from one taxonomic group to another, were reported in two estuaries during the period 1970-95. In the seawater zone of Boston Harbor, a shift from annelids to crustaceans was attributed to the cessation of sludge dumping. A shift from annelids to a diverse mixture of benthic groups was reported in parts of the seawater zone of Massachusetts Bay (Glouchester and Salem Harbors); the factors contributing to the shift were unknown. Shifts were reported as unchanged in all or parts of 13 estuaries, including 79 percent of the region's tidal fresh zone, 70 percent of the mixing zone, and 70 percent of the seawater zone.

Submerged Aquatic Vegetation (SAV)

The presence of SAV was reported in at least one salinity zone in 15 North Atlantic estuaries. There was no SAV reported in Hampton Harbor, and no information was available for Narraguagus and Muscongus Bays. Where reported, however, the spatial coverage of SAV (to depths of one meter below mean low water) was identified primarily as low (>10, ≤25 percent surface area) or very low (≤10 percent surface area), equating to only 3 to 12 percent of the regional estuarine surface area. Exceptions were a medium spatial coverage (>25, ≤50 percent surface area) reported for the mixing zones of Sheepscot Bay and Merrimack River, and a high spatial coverage (>50 percent surface area) reported for the mixing zone of the Damariscotta River, parts of the seawater zone in Casco Bay, and parts of the mixing zone in Great Bay.

Historical trends in SAV coverage (ca. 1970-95) were unknown in all or part of 11 estuaries (61 percent of the region's estuarine area). Where trends were reported, SAV declined in parts of five estuaries (25 percent of the region's estuarine surface area), primarily in the Southern Gulf of Maine subregion. Declining trends were reported mostly in the seawater zone at low or medium magnitudes (0-50% change). One exception was the mixing zone of the Merrimack River, where a decreasing trend of a high magnitude (>50% change) was reported. Factors reported as contributing to the declines were epiphytes and disease in Boston Harbor, point sources, and the physical alteration of the watershed in Massachusetts Bay. Contributing factors to declines in the other estuaries were unknown. No changes in spatial coverage were reported in parts of nine estuaries. However, in two of those systems, no SAV was reported at the present time. Increasing trends in SAV coverage were reported at a medium magnitude (>25≤50 percent change) in Cobscook Bay, and at a low magnitude in parts of all salinity zones of Great Bay. In both estuaries, the increases were attributed to a natural cycle/cessation of disease, in addition to replanting efforts in the lower Piscataqua River section of Great Bay.

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Estuary Summaries

This section presents one-page summaries on the status and trends of eutrophication conditions for the 18 North 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 that were either better understood than the rest of a salinity zone, or that 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 better understand 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.

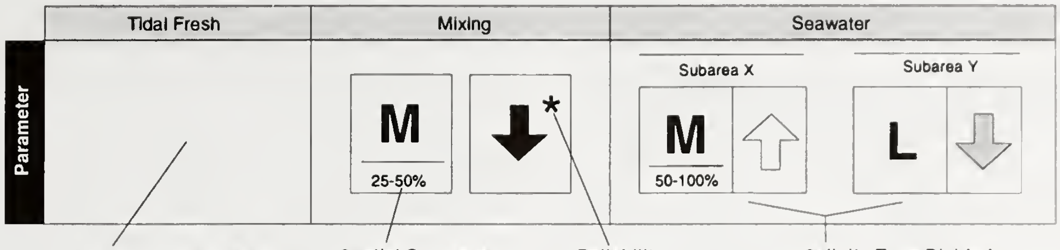
Survey Results. Selected data are presented in a unique format that is intended to highlight survey results for each estuary. The existing conditions symbols represent either the maximum conditions predominating one or more months in a typical year, or whether there are resource impacts due to bloom 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 6) and, where relevant, are highlighted in the text blocks under each parameter section on the estuary pages.

See the next page for a key 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

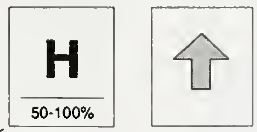


Salinity Zone Absent: if the salinity zone is not present in the estuary the entire box is left blank

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)

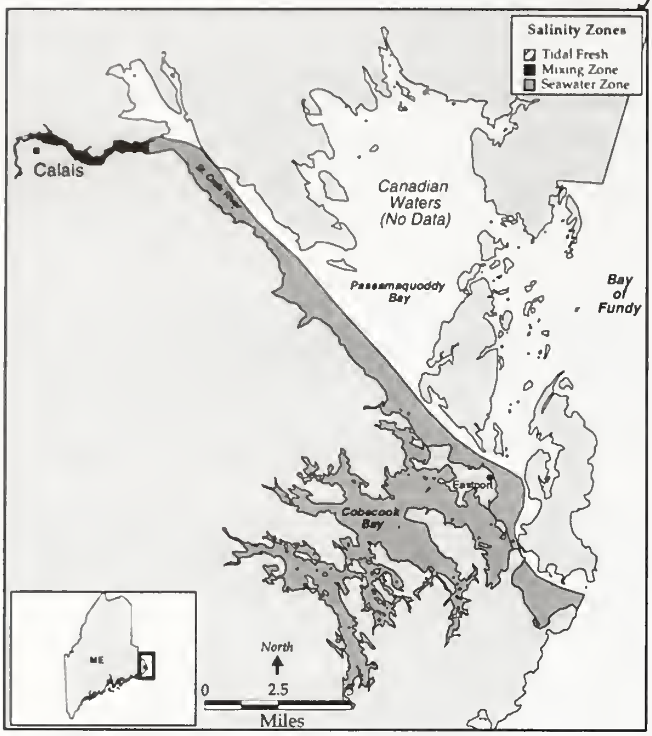
Direction of Change

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

Magnitude of Change

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

St. Croix River/Cobscook Bay



St. Croix River/Cobscook Bay, chlorophyll *a* concentrations are low and turbidity concentrations are medium. There are no biological resource impacts due to nuisance algae blooms, but toxic algal blooms occur in the seawater zone. Nitrogen and phosphorus concentrations are reported as medium throughout the estuary, and there are no reported observations of anoxia or hypoxia. In Cobscook Bay, SAV spatial coverage is very low.

Most conditions were stable with the exception of a decrease in turbidity in the mixing zone, and an increase in SAV in Cobscook Bay. Trends were unknown in the St. Croix River for chlorophyll *a*, turbidity, anoxia, hypoxia, and SAV.

Algal Conditions

	Tidal Fresh	Mixing		Seawater: St. Croix River		Seawater: Cobscook Bay	
Chlorophyll *a*		L	---	L	?	L	---
Turbidity		M 50-100%	↓	M 50-100%	?	M 50-100%	---
Nuisance Algae		N	---	N	---	N	---
Toxic Algae		N	---	Y	---	Y	---

Highest turbidity occurs episodically throughout the year in the mixing zone and in late fall in the seawater zone due to wind, dredging, and resuspension. A decrease in turbidity is attributed to a decrease in paper mill effluent. Toxic *Alexandrium* spp. and *Pseudonitzchia* spp. occur periodically in summer in subareas of the seawater zone.

Ecosystem/Community Responses

	Tidal Fresh	Mixing		Seawater: St. Croix River		Seawater: Cobscook Bay	
SAV		NS	---	NS	?	VL	↑

Primary productivity is dominated by the benthic community. Planktonic community is a diverse mixture throughout the seawater zone. SAV increase in Cobscook Bay is attributed to disappearance of wasting disease.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **n/a** Avg. Daily Inflow *(cfs)* **2,850**

	Estuary	Tidal Fresh	Mixing	Seawater: St. Croix River	Seawater: Cobscook Bay
Surface Area *(mi²)*	63.3		2.5	24.7	36.1
Average Depth *(ft)*	72.0		40.0	72.8	26
Volume *(billion cu ft)*	127		2.7	123.4	26.1

A complex estuary consisting of bays and interconnecting channels. The northern part of the bay is shallow and gently sloping while the more southern reaches are much steeper. Freshwater inflow from the St. Croix is minimal compared to the tides, therefore circulation is dominated by intense tidal exchange. Gulf of Maine salinities occur throughout the estuary due to tidal influence. The system is well mixed with a tidal range of approximately 18 ft throughout the main bay area (18.2 ft near Eastport).

Nutrients

	Tidal Fresh	Mixing		Seawater: St. Croix River		Seawater: Cobscook Bay	
Nitrogen		M 50-100%	---	M 50-100%	---	M 50-100%	---
Phosphorus		M 50-100%	---	M 50-100%	---	M 50-100%	---

Maximum concentrations occur from October through March.

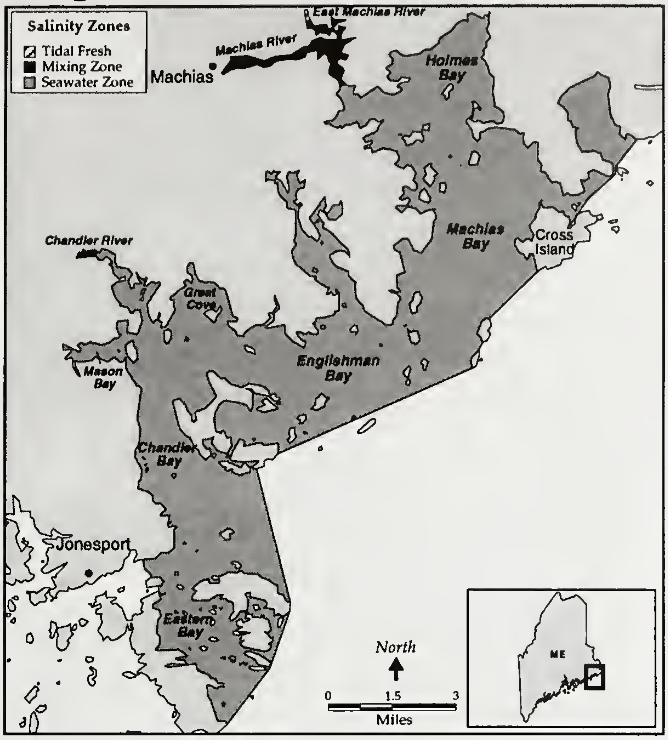
Dissolved Oxygen

	Tidal Fresh	Mixing		Seawater: St. Croix River		Seawater: Cobscook Bay	
Anoxia		N	?	N	?	N	---
Hypoxia		N	?	N	?	N	---

Biological stress is speculated to occur on bottom in Cobscook Bay episodically in association with Salmon enclosures from July through September. High magnitude increase of bottom dissolved oxygen in mixing zone occurred 1970-1995.

Key on page 19

Englishman Bay



In Englishman Bay, with the exception of SAV, all of the responses for the mixing zone are unknown. In the seawater zone, chlorophyll *a* concentrations are medium and turbidity concentrations are low. There is no impact on biological resources due to nuisance algal blooms, but impacts occur due to toxic algal blooms. Nitrogen concentrations are medium and phosphorus concentrations are unknown. There are no observations of anoxia or hypoxia. SAV is not present in the mixing zone, and is present at a very low spatial coverage in the seawater zone.

Most trends were unknown with the exception of an increase in turbidity, and no change in toxic algal bloom occurrences or nitrogen concentrations.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **1,017** Avg. Daily Inflow *(cfs)* **1,600**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	86.7		1.6	85.1
Average Depth *(ft)*	41.5		11.8	42.1
Volume *(billion cu ft)*	100.4		0.5	99.9

Consists of Englishman Bay, Machias Bay and several smaller embayments. Receives majority of freshwater from the Machias and East Machias Rivers. Most salinity variations occur within the upper reaches of the estuary. Circulation is affected largely by tidal mixing and nontidal currents. Considered to be a well mixed estuary with rapid flushing. Tidal range is 12.1 ft near the mouth of Great Cove.

Algal Conditions

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

Chl-*a* maximums and toxic *Alexandrium* spp. occur periodically.

Nutrients

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

Medium concentrations occur July through September.

Ecosystem/Community Responses

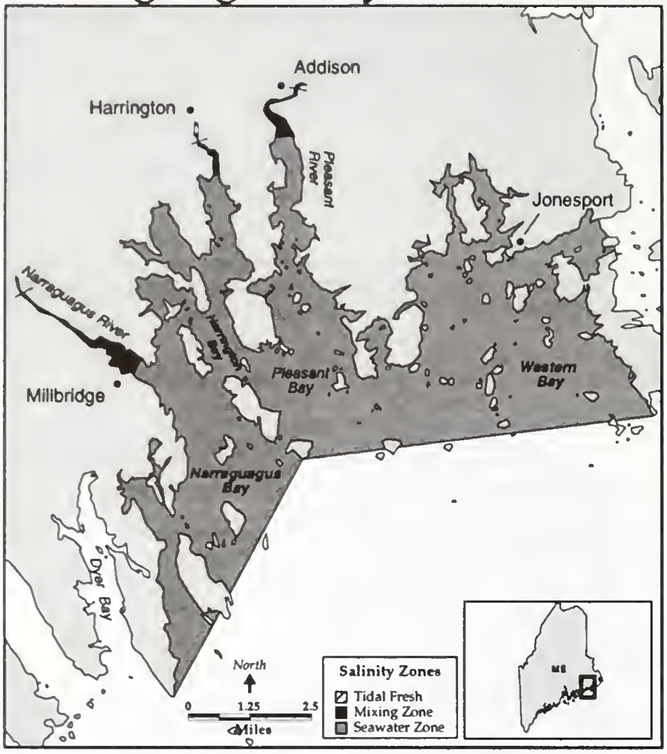
	Tidal Fresh	Mixing		Seawater	
SAV		NS	?	VL	?

Primary productivity is dominated by the pelagic community. Planktonic community is a diverse mixture in the seawater zone; benthic community is predominantly annelids in the mixing zone.

Dissolved Oxygen

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

Narraguagus Bay



In Narraguagus Bay, chlorophyll *a* concentrations are medium in both zones, and turbidity is unknown in the mixing zone and low in the seawater zone. There are no biological resource impacts due to nuisance algal blooms, but toxic algal blooms occur. Nitrogen and phosphorus concentrations are unknown, and there are no observations of anoxia or hypoxia. SAV spatial coverage is also unknown.

Trends throughout the entire estuary are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **1,131** Avg. Daily Inflow *(cfs)* **900**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi^2)*	79.3		1.5	77.8
Average Depth *(ft)*	34.0		10.6	34.5
Volume *(billion cu ft)*	75.2		0.4	74.8

Consists of Narraguagus Bay, Western Bay and several smaller embayments. Receives majority of freshwater from the Narraguagus and Pleasant Rivers. Most salinity variations occur within the upper reaches of the estuary. Circulation affected largely by tidal mixing and nontidal currents. Is well mixed with rapid flushing. Tidal range is 11.1 ft near the mouth of Pleasant River.

Algal Conditions

	Tidal Fresh	Mixing		Seawater	
Chlorophyll *a*	*Tidal Fresh area not characterized for this estuary	M* 50-100%	?	M* 25-50%	?
Turbidity		?	?	L	?
Nuisance Algae		N*	?	N	?
Toxic Algae		Y	?	Y	?

Chl-*a* maximums occur periodically July through September with light as the limiting factor. Toxic *Aexandrium* spp. occurs in the mixing zone, and periodically in summer in seawater zone.

Nutrients

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

Dissolved Oxygen

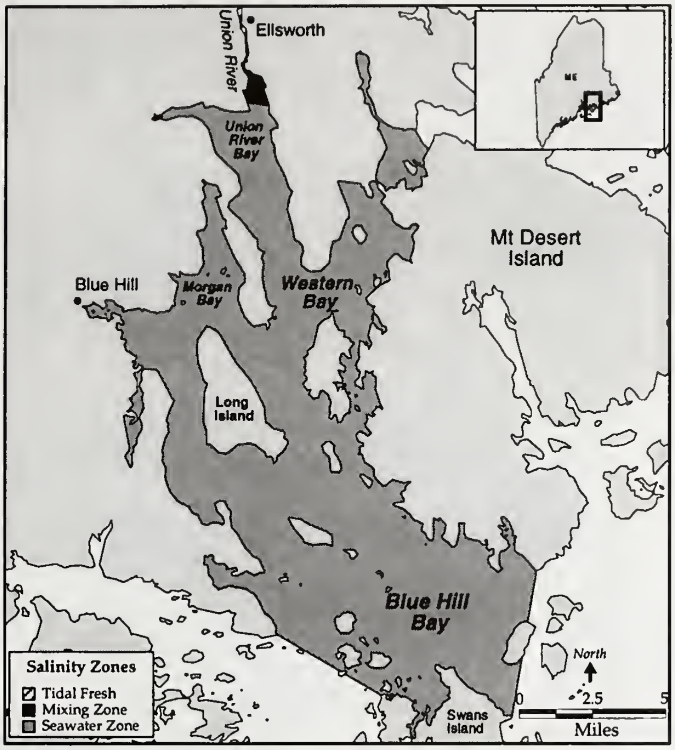
	Tidel Fresh	Mixing		Seaweter	
Anoxia		N	?	N	?
Hypoxia		N	?	N	?

Ecosystem/Community Responses

	Tidal Fresh	Mixing		Seawater	
SAV		?	?	?	?

Key on page 19

Blue Hill Bay



In Blue Hill Bay, chlorophyll *a* concentrations are unknown in the mixing zone and medium in the seawater zone, and turbidity concentrations are medium in the mixing zone and low in the seawater zone. There are no known impacts on biological resources from nuisance algal blooms, but there are impacts in the seawater zone due to toxic algal blooms. Nitrogen and phosphorus concentrations are medium throughout the estuary, and there are no observations of anoxia or hypoxia. SAV spatial coverage is speculated to be very low in both the mixing and seawater zones.

Trends were unknown for algal conditions in the mixing zone. For most of the remaining parameters, in both the mixing and seawater zones, no changes occurred.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* 880 Avg. Daily Inflow *(cfs)* 1,300

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	121.9		0.8	121.1
Average Depth *(ft)*	76.7		42.1	77.0
Volume *(billion cu ft)*	260.9		0.9	260

Consists of Union River Bay, Blue Hill Bay and smaller embayments. Receives majority of freshwater from Union River. Gulf of Maine salinities exist throughout much of the estuary. Within the narrow, upper portion of Union River Bay, vertical stratification of salinities may exist all year. Circulation is affected largely by tidal and nontidal currents. Tidal range is approximately 10 ft near the mouth of Union River.

Algal Conditions

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

Highest turbidity speculated to occur persistently throughout the year. Toxic *Alexandrium* spp. occurs episodically in summer.

Ecosystem/Community Responses

	Tidal Fresh	Mixing		Seawater	
SAV		VL*	---*	VL*	---*

Primary productivity is dominated by the pelagic community. In the seawater zone, planktonic and benthic communities are a diverse mixture.

Nutrients

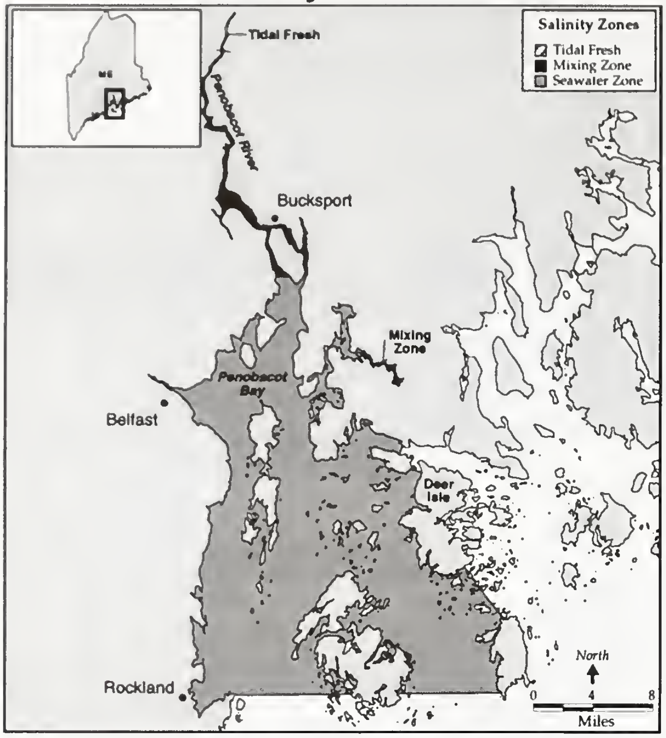
	Tidal Fresh	Mixing		Seawater	
Nitrogen		M (50-100%)	---	M (50-100%)	---
Phosphorus		M (50-100%)	---	M (50-100%)	---

Medium concentrations occur October through March.

Dissolved Oxygen

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

Penobscot Bay



In Penobscot Bay, chlorophyll *a* concentrations are low in all salinity zones, and turbidity concentrations are medium in the tidal fresh and mixing zones, and low in the seawater zone. Biological resource impacts from nuisance or toxic algal blooms are unknown in the tidal fresh zone, and do not occur in the mixing and seawater zones. Nitrogen and phosphorus concentrations are low throughout the estuary. There were no observations of anoxia or hypoxia reported. There is no SAV in the tidal fresh zone, and low spatial coverage in the rest of the estuary.

Most of the trends were either unknown or stable. However, there were decreases in nitrogen concentrations (speculative) in the mixing zone, and decreases in both anoxia and hypoxia in the tidal fresh and mixing zones. SAV trends are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **3,160** Avg. Daily Inflow *(cfs)* **16,100**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	387.0	0.5	13.1	367.1
Average Depth *(ft)*	70.1	19.5	31.0	75.1
Volume *(billion cu ft)*	755.3	0.3	11.3	743.7

Consists of Penobscot Bay with several islands interspersed throughout the estuary. Seaward boundary is difficult to define. High salinities can occur in upper reaches of the Bay. Receives majority of freshwater from Penobscot River. During periods of high flow, vertical stratification is very apparent. Lower flow periods exhibit moderate salinity stratification. Tidal range is 9.6 ft near Rockland.

Algal Conditions

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

Nitrogen is the limiting factor for chl-*a* in the seawater zone. Highest turbidity occurs persistently throughout the year.

Nutrients

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

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	NS	?	L	?	L	?

Primary productivity is dominated by the pelagic community. Planktonic community is predominantly diatoms in the tidal fresh zone, and a diverse mixture in the mixing and seawater zones. Benthic community is dominated by mollusks in the tidal fresh and mixing zones, and is diverse in the seawater zone.

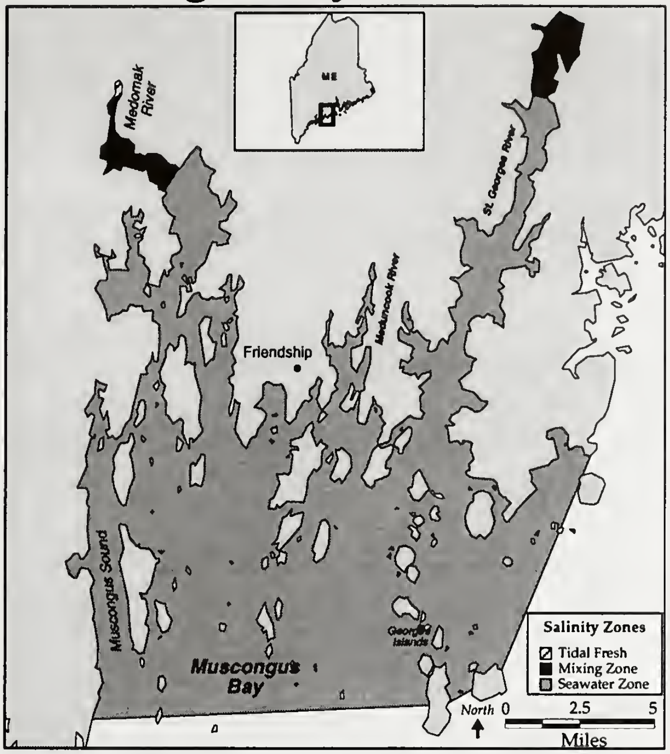
Dissolved Oxygen

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

High magnitude increase in bottom dissolved oxygen concentrations occurred 1970-1990. All trends attributed to point source changes.

Key on page 19

Muscongus Bay



In Muscongus Bay, chlorophyll *a* concentrations are medium and turbidity concentrations are unknown. There are no biological resource impacts from nuisance algal blooms, but there are impacts from toxic algal blooms in the seawater zone. Nitrogen and phosphorus concentrations are medium. There are no observations of either anoxia or hypoxia.

Trends are unknown with the exception of stable conditions reported in the seawater zone for chlorophyll *a*, nitrogen and phosphorus, and in the mixing zone for anoxia and hypoxia. SAV spatial coverage and trends are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi²)* **346** Avg. Daily Inflow *(cfs)* **600**

	Estuary	Tidal Fresh	Mixing: Medomak R.	Mixing: St. George R.	Seawater
Surface Area *(mi²)*	77.8		1.1	1.3	75.4
Average Depth *(ft)*	45.7		6.7	7.9	46.9
Volume *(billion cu ft)*	99.1		0.2	0.3	98.6

Consists of Muscongus Bay with several small islands. Receives minimal freshwater inflow from the Medomak and St. George Rivers. Most salinity variations occur within the upper reaches of the estuary. Circulation affected largely by tidal exchange and nontidal currents. Tidal range is 8.8 ft near the Georges Islands.

Algal Conditions

	Tidal Fresh	Mixing: Medomak River		Mixing: St. George River		Seawater	
Chlorophyll *a*	*Tidal Fresh area not characterized for this estuary	?	?	M 50-100%	?	M 50-100%	---
Turbidity		?	?	?	?	?	?
Nuisance Algae		N	?	N	?	N	?
Toxic Algae		N	?	N	?	Y	?

Chl-*a* maximums occur periodically June through August in the mixing zone, and in March-April and August-September in the seawater zone. Toxic *Alexandrium* spp. occurs episodically in summer.

Ecosystem/Community Responses

	Tidal Fresh	Mixing: Medomak River		Mixing: St. George River		Seawater	
SAV		?	?	?	?	?	?

Primary productivity is dominated by the pelagic community. Benthic community is speculated to be a diverse mixture.

Nutrients

	Tidal Fresh	Mixing: Medomak River		Mixing: St. George River		Seawater	
Nitrogen		?	?	M 50-100%	?	M* 50-100%	---
Phosphorus		?	?	M 50-100%	?	M* 50-100%	---

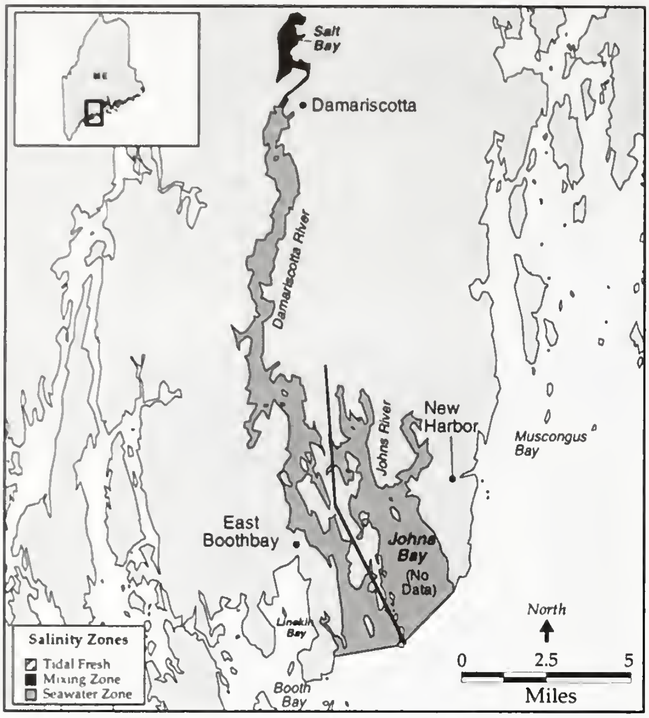
Conditions occur all year in St. George River and from October through March in seawater.

Dissolved Oxygen

	Tidal Fresh	Mixing: Medomak River		Mixing: St. George River		Seawater	
Anoxia		?	?	N	---*	N	?
Hypoxia		?	?	N	---*	N	?

A high spatial extent of biological stress is observed periodically July through August throughout the water column in the Medomak River.

Damariscotta River



In the Damariscotta River, chlorophyll *a* concentrations are medium, and turbidity concentrations are medium in the mixing zone and low in the seawater zone. Nuisance algal blooms do not impact biological resources, but in the seawater zone, toxic algal blooms do have an impact. Nitrogen and phosphorus concentrations are medium. There are no observations of anoxia or hypoxia. SAV coverage is high in the mixing zone and very low in the seawater zone.

Most of the conditions remained stable except in the mixing zone where chlorophyll *a* and turbidity trends were unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi²)* **172** Avg. Daily Inflow *(cfs)* **n/a**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	21.6		0.9	12.1
Average Depth *(ft)*	38.9		9.2	41.1
Volume *(billion cu ft)*	14.1		0.2	13.9

A relatively shallow and narrow estuary receiving minimal freshwater inflow from Salt Bay. High salinities exist throughout much of its length. Tidal currents do not have a strong effect on stratification, however, stratification does occur near the head of the estuary. Well mixed conditions prevail near the mouth of the Damariscotta. Tidal range is 8.7 ft in John's Bay.

Algal Conditions

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

Chl-*a* maximums occur periodically February through March. Toxic *Alexandrium* spp. occurs periodically in summer.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater
SAV		H ---	VL ---*

Primary productivity is speculated to be dominated by SAV. Planktonic and benthic communities are a diverse mixture.

Nutrients

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

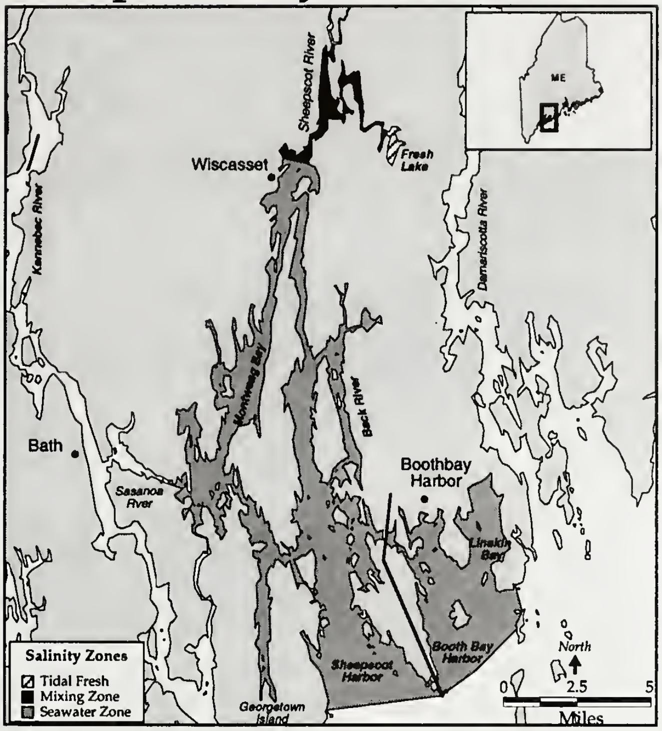
Nitrogen concentrations are based on dissolved inorganic nitrogen and occur from September through March. Maximum phosphorus concentrations occur August through March.

Dissolved Oxygen

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

Key on page 19

Sheepscot Bay



In Sheepscot Bay, chlorophyll *a* and turbidity concentrations range from low to medium. There are no biological resource impacts from nuisance algal blooms, but in the seawater zone there are impacts from toxic algal blooms. Nitrogen and phosphorus concentrations are medium. There are no observations of anoxia or hypoxia. SAV ranges from medium in the mixing zone to low in the seawater zone.

There has been no change in algal conditions and nutrient concentrations. Trends were unknown for SAV, anoxia, and hypoxia, with the exception of no trend in Boothbay Harbor dissolved oxygen observations.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **365** Avg. Daily Inflow *(cfs)* **630**

	Estuary	Tidal Fresh	Mixing	Seawater	
				Sheepscot Bay	Boothbay Harbor
Surface Area *(mi²)*	41.5	0.3	1.6	28.5	10.9
Average Depth *(ft)*	59.5	13.2	21.6	61.3	n/a
Volume *(billion cu ft)*	68.8	0.1	1.0	48.7	n/a

Deepest estuary on the East Coast, consists of narrow rivers and several interconnections between rivers and embayments. A complex circulation pattern exists. North of Wiscasset, the estuary is shallow, and a rapid tidal exchange occurs. Below Wiscasset, the rocky channel of Sheepscot River has a large influence on stratification. Significant density currents occur throughout the year. Gulf of Maine salinities are dominant in the lower part of the estuary. Tidal range is 9.3 ft near Wiscasset.

Algal Conditions

	Tidal Fresh		Mixing		Seawater			
					Sheepscot Bay		Boothbay Harbor	
Chlorophyll *a*	?	?	L	---	M 50-100%	---	M 50-100%	---
Turbidity	M ?	---	M ?	---	L	---	L	---
Nuisance Algae	N	---	N	---	N	---	N	---
Toxic Algae	N	---	N	---	Y	---	Y	---

Chl-*a* maximums occur periodically March through September with nitrogen as the limiting factor in Boothbay Harbor and light as the limiting factor in the rest of the seawater zone. Turbidity concentrations occur persistently throughout the year. Toxic *Alexandrium* spp. occurs periodically in summer.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater			
					Sheepscot Bay		Boothbay Harbor	
SAV	?	?	M	?	L	?	L	?

Primary productivity is dominated by the benthic community in the mixing zone, and the pelagic community in the seawater zone. Planktonic community is a diverse mixture; benthic community is predominantly aquatic insects in the tidal fresh zone, crustaceans in the mixing zone, and is diverse in the seawater zone.

Nutrients

	Tidal Fresh		Mixing		Seawater			
					Sheepscot Bay		Boothbay Harbor	
Nitrogen	M* 50-100%	---	M 50-100%	---	M 50-100%	---	M 50-100%	---
Phosphorus	M 50-100%	---	M 50-100%	---	M 50-100%	---	M 50-100%	---

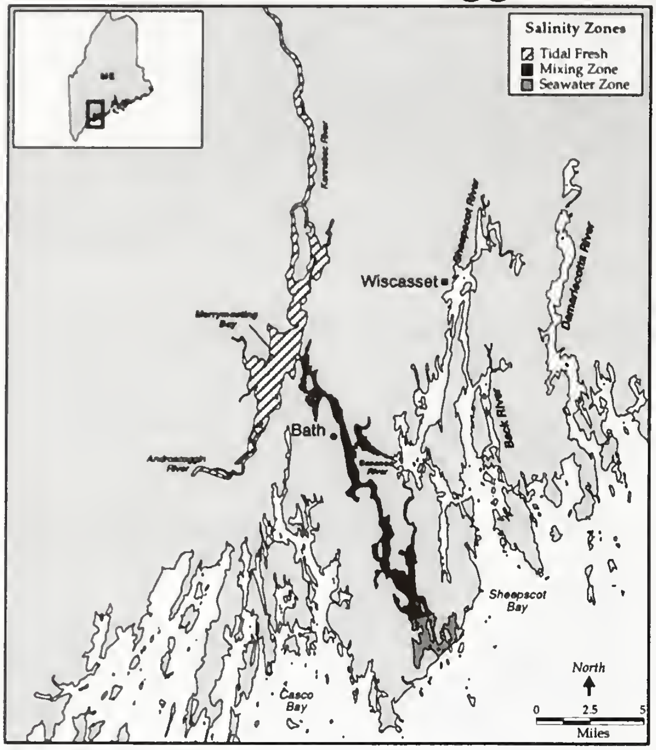
Maximum concentrations occur November through March except in Boothbay Harbor where they occur all year. Nitrogen concentrations are for dissolved inorganic nitrogen.

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater			
					Sheepscot Bay		Boothbay Harbor	
Anoxia	N	?	N	?	N	?	N	---
Hypoxia	N	?	N	?	N	?	N	---

Biological stress is observed episodically throughout the water column from June through August in Dyer River; however, it is speculated that bottom dissolved oyxgen concentrations have increased since 1970.

Kennebec/Androscoggin Rivers



In Kennebec/Androscoggin Rivers, chlorophyll *a* and turbidity concentrations range from low to medium. Nuisance or toxic algal blooms do not impact biological resources. Nitrogen and phosphorus concentrations are medium. There are observations of anoxia in the tidal fresh and mixing zones, and no observations of hypoxia reported. SAV spatial coverage ranges from low to very low.

All trends are unknown except for SAV where there was no trend.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **5,628** Avg. Daily Inflow *(cfs)* **15,226**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	30.3	16.7	10.0	3.6
Average Depth *(ft)*	20.8	14.5	26.4	25.6
Volume *(billion cu ft)*	17.5	6.8	7.4	2.5

A narrow, shallow estuary consisting of the Kennebec and Androscoggin rivers. Freshwater inflow from both river systems dominates this estuary and is the largest source of freshwater to Maine estuaries. Circulation is affected by strong tidal and nontidal currents. Vertical mixing of salinity occurs in this estuary. Tidal range is 6.4 ft near Bath.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyll *a*	M (50-100%)	?	L	?	M (50-100%)	?
Turbidity	M (50-100%)	?	M (10-25%)	?	L	?
Nuisance Algae	N	?	N	?	N	?
Toxic Algae	N	?	N	?	N	?

Chl-*a* maximums occur periodically June through August with a speculated limiting factor of nitrogen in the tidal fresh zone, light in the mixing zone, and flushing in the seawater zone. Highest turbidity occurs throughout the year.

Ecosystem/Community Responses

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

Primary productivity is dominated by the the pelagic community in the mixing and seawater zones and the pelagic and benthic communities in the tidal fresh zone. Planktonic community is a diverse mixture. In the tidal fresh zone, benthic community is predominantly crustaceans and aquatic insects.

Nutrients

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

Maximum nitrogen concentrations occur October through May in tidal fresh and seawater zones and all year in mixing zone. Maximum phosphorus concentrations occur August through May in tidal fresh and seawater zones and June through April in mixing zone.

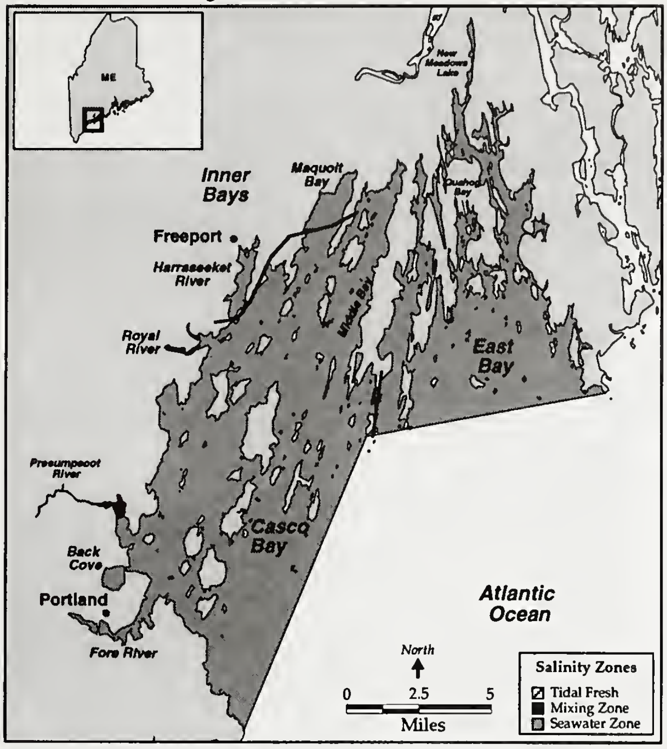
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	Y (50-100%)	?	Y (25-50%)	?	N	?
Hypoxia	N	?	N	?	N	?

Anoxia occurs very episodically throughout the water column during Atlantic Menhaden runs in July - August.

Key on page 19

Casco Bay



In Casco Bay, chlorophyll *a* concentrations range from medium to high and turbidity concentrations are medium or low. Throughout the estuary there have been biological resource impacts due to both nuisance and toxic algal blooms. Nitrogen and phosphorus concentrations are medium. There are no observations of anoxia or hypoxia. SAV is high in the inner seawater bays, and very low to nonexistent elsewhere.

Most of the conditions were stable or unknown. However there were decreases in turbidity concentrations, anoxia, and hypoxia. SAV spatial coverage has decreased in the Casco Bay portion of the seawater zone.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi²)* **1,147** Avg. Daily Inflow *(cfs)* **2,100**

	Estuary	TF	Mixing	Seawater		
				Casco Bay	Inner Bays	East Bay
Surface Area *(mi²)*	169.4	3.0	0.7	107.7	6.0	52.0
Average Depth *(ft)*	41.8	6.5	8.3	43.6	35.2	41.3
Volume *(billion cu ft)*	197.4	0.5	0.2	130.9	5.9	59.9

Estuary consists of Casco Bay and East Bay with several islands interspersed. The Presumpscot and Royal rivers are restricted by barriers. Strong tidal mixing occurs especially around shoal areas. Circulation is affected by strong tidal and nontidal currents. Considered to be a partially mixed estuary. Tidal range is 8.7 ft near mouth of Casco Bay.

Algal Conditions

	TF	Mixing		Seawater					
				Casco Bay		Inner Bays		East Bay	
Chlorophyll *a*		M 50-100%	---	M 50-100%	---	H 50-100%	?	?	?
Turbidity		M 50-100%	↓	L	---	M 50-100%	⇩	L	---
Nuisance Algae		?	---	Y	---	Y	---	Y	---
Toxic Algae		Y	---	Y	---	Y	---	Y	---

Chl-*a* maximums occur early spring and summer in mixing and seawater zones, with nitrogen limiting in seawater zone. Highest turbidity occurs periodically in summer. Decrease attributed to closing of paper mill, decrease in fish processing discharge, and a STP. Red tide occurs in summer in mixing zone. In seawater zone, nuisance *Phaeocystis* spp. and dinoflagellates occur episodically, toxic *Alexandrium* spp. occur periodically in spring and summer in East and Casco Bays, and *Gymnodinium* spp. occur episodically during spring in Inner Bays.

Ecosystem/Community Responses

	TF	Mixing		Seawater					
				Casco Bay		Inner Bays		East Bay	
SAV		NS	---	VL	⇩	H	?	VL	---

Primary productivity dominated by pelagic community. Planktonic community is a diverse mixture and benthic community is predominantly annelids, except in East Bay where it is speculated to be a diverse mixture.

Nutrients

	TF	Mixing		Seawater					
				Casco Bay		Inner Bays		East Bay	
Nitrogen		M* 50-100%	---	M* 50-100%	---	?	?	M* 50-100%	---
Phosphorus		M 50-100%	---	M* 50-100%	---	?	?	M 50-100%	---

Maximum concentrations occur October-November through March. Nitrogen concentrations are based on dissolved inorganic nitrogen.

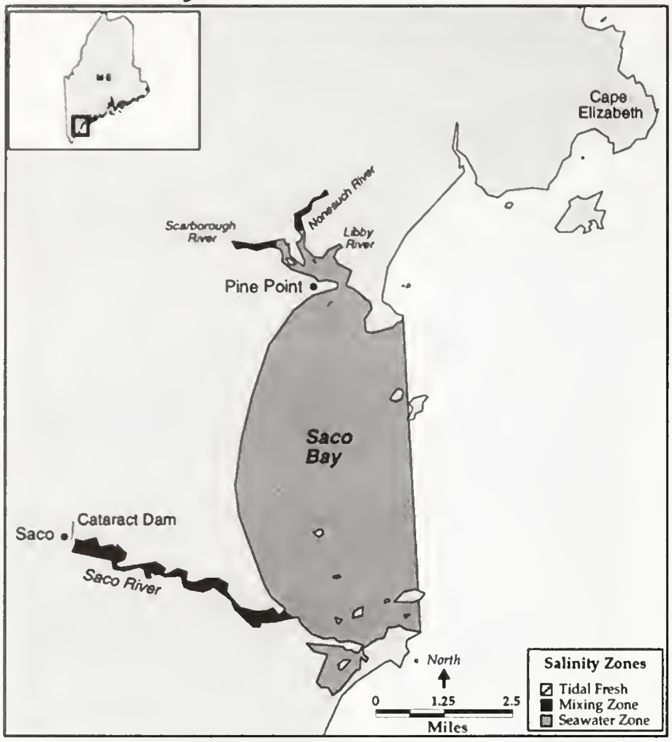
Dissolved Oxygen

	TF	Mixing		Seawater					
				Casco Bay		Inner Bays		East Bay	
Anoxia		N	?	N	↓	N	?	N	?
Hypoxia		N	↓	N	↓	N	?	N	?

Declines in frequency, duration and spatial extent occurred in mixing zone and Casco Bay and are attributed to point source changes. Anoxia/hypoxia events reported in mid 1980s due to phytoplankton bloom and warm temperatures. A very low spatial extent of biological stress is observed episodically July through August in East Bay. The frequency, duration, and spatial extent of the biological stress in East Bay has decreased due to naturally declining Atlantic Menhaden runs.

Key on page 19

Saco Bay



In Saco Bay, chlorophyll *a* concentrations are low, and turbidity concentrations range from low to medium. Nuisance algal blooms have not impacted biological resources, however toxic algal blooms have. Nitrogen and phosphorus concentrations are medium in the mixing zone and low in the seawater zone. There are no observations of anoxia, but hypoxia was observed in the seawater zone. SAV spatial coverage is either very low or nonexistent

Trends were stable for most parameters. However, trends were unknown for turbidity, dissolved oxygen, and SAV.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi²)* **1,787** Avg. Daily Inflow *(cfs)* **3,600**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	19.0		1.0	18.0
Average Depth *(ft)*	35.3		10.2	36.7
Volume *(billion cu ft)*	18.7		0.3	18.4

A highly stratified, saltwedge-type of estuary. Freshwater inflow is dominated by the Saco River. Salinity stratification is more pronounced during periods of high freshwater inflow. The estuary begins below the Cataract Dam on the Saco River. Tidal range is 8.6 ft near the mouth of the estuary.

Algal Conditions

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

Nutrients

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

Maximum concentrations occur from December through March.

Dissolved Oxygen

	Tidal Fresh	Mixing		Seawater	
Anoxia		N	?	N	?
Hypoxia		N	?	Y 0-10%	?

Hypoxia occurs in seawater bottom water episodically in August. Since 1970 there has been a high magnitude increase in bottom dissolved oxygen concentrations in Saco River, attributed to changes in point sources.

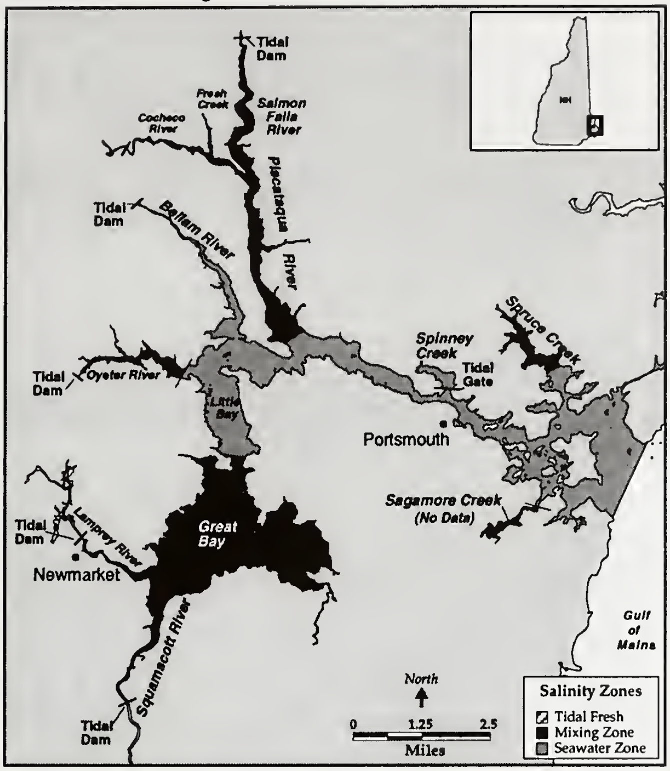
Ecosystem/Community Responses

	Tidal Fresh	Mixing		Seawater	
SAV		VL	?	NS	?

Primary productivity is dominated by wetlands in the mixing zone and by the pelagic community in the seawater zone.

Key on page 19

Great Bay



In Great Bay, chlorophyll *a* concentrations range from low to high and turbidity from low to medium. Nuisance and toxic algal blooms have an impact on biological resources in subareas of the mixing and seawater zones. Nitrogen and phosphorus concentrations are medium. There are no observations of anoxia, however hypoxia is reported in small subarea of the mixing zone. SAV coverage ranges from very low to high.

Most trends were stable, except an increase in SAV spatial coverage in subareas of both salinity zones and a decrease in phosphorus concentrations in a subarea of the mixing zone.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi²)* 997 Avg. Daily Inflow *(cfs)* 2,000

	Estuary	Mixing				Seawater	
		Piscataqua/ Salmon Falls/ Cocheco R.	Great Bay/ Lamprey R./ Squamscott R.	Oyster River	Spruce Creek	In General	Spinney Creek
Surface Area *(mi²)*	20.8	2.5	7.3	0.3	0.4	10.1	0.2
Average Depth *(ft)*	11.4	n/a	n/a	n/a	n/a	n/a	n/a
Volume *(billion cu ft)*	6.6	n/a	n/a	n/a	n/a	n/a	n/a

Consists of Great Bay, Little Bay, Piscataqua River and several smaller coastal streams and rivers. Upper broad section of estuary is shallow while lower seawater section can reach depths over 80 ft. Well mixed estuary due to tidal velocity and height, as well as estuary geometry. Moderate stratification occurs during high flow periods. Tidal range is approximately 9 ft near Portsmouth.

Algal Conditions

	Mixing				Seawater	
	Piscataqua/ Salmon Falls/ Cocheco R.	Great Bay/ Lamprey R./ Squamscott R.	Oyster River	Spruce Creek	In General	Spinney Creek
Chlorophyll *a*	H 0-10% ?	M 0-10% ---	M 10-25% ---	M 10-25% ?	L ---	M 10-25% ?
Turbidity	M 25-50% ?	M 25-50% ---	M 50-100% ---	? ?	L ---	? ?
Nuisance Algae	Y ---	N ---	N ---	N ?	N ---	Y ---
Toxic Algae	N ---	N ---	N ---	N ---	N ---	Y ?

In mixing zone, chl-*a* concentrations occur periodically summer to early fall with light and nitrogen co-limiting. Turbidity occurs periodically with tides and episodically with winds at any time of year. Nuisance blooms in mixing zone occur episodically July-September in a very small area.

Ecosystem/Community Responses

	Mixing				Seawater	
	Piscataqua/ Salmon Falls/ Cocheco R.	Great Bay/ Lamprey R./ Squamscott R.	Oyster River	Spruce Creek	In General	Spinney Creek
SAV	VL ↑	H ---	VL ---	L ?	M ↑	M ?

Primary productivity driven by pelagic and benthic mixture. Pelagic and benthic communities are diverse. SAV increase in mixing and seawater zones is attributed to natural cycle and some replanting in seawater zone.

Nutrients

	Mixing				Seawater	
	Piscataqua/ Salmon Falls/ Cocheco R.	Great Bay/ Lamprey R./ Squamscott R.	Oyster River	Spruce Creek	In General	Spinney Creek
Nitrogen	M 50-100% ---	M 50-100% ---	M 50-100% ---	M 50-100% ---	M 25-50% ---	? ?
Phosphorus	M 50-100% ---	M 50-100% ↓	M 50-100% ---	M 50-100% ?	M 50-100% ---	? ?

The medium nitrogen concentrations occur November through March, and are reported for dissolved inorganic nitrogen only. The reported phosphorus concentrations occur September through March.

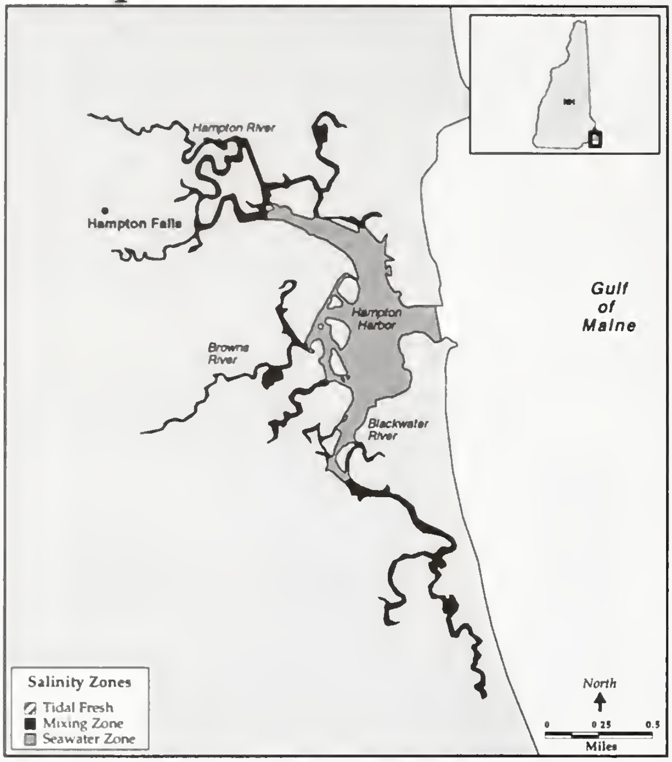
Dissolved Oxygen

	Mixing				Seawater	
	Piscataqua/ Salmon Falls/ Cocheco R.	Great Bay/ Lamprey R./ Squamscott R.	Oyster River	Spruce Creek	In General	Spinney Creek
Anoxia	N ---	N ---	N ---	N ?	N ---	N ?
Hypoxia	Y 0-10% ?	N ---	N ---	N ?	N ---	N ?

Observed hypoxia occurs on bottom episodically July through August. Biological stress occurs over a very low extent of mixing zone episodically July through September, usually throughout the water column.

Key on page 19

Hampton Harbor



In Hampton Harbor, chlorophyll *a* concentrations are medium and turbidity concentrations are unknown. There are no biological resource impacts from nuisance or toxic algal blooms. Nitrogen concentrations range from medium to high, and phosphorus concentrations are medium. There are no observations of anoxia or hypoxia. SAV is not present.

Stable trends were reported for nuisance and toxic algal blooms and SAV spatial coverage. All other trends were unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **n/a** Avg. Daily Inflow *(cfs)* **n/a**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	1.5		0.6	0.9
Average Depth *(ft)*	n/a		n/a	n/a
Volume *(billion cu ft)*	n/a		n/a	n/a

A small, very shallow system consisting of several small coastal streams and rivers. Most of the surrounding area is made up of extensive salt marshes and tidal flats. Shallowness, rapid flushing, and limited freshwater inflow contribute to it being a well mixed estuary. Tidal range is approximately 9 ft near Hampton Harbor.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyll *a*			M 25-50%	?	M 10-25%	?
Turbidity			?	?	?	?
Nuisance Algae			N	---	N	---
Toxic Algae			N	---	N	---

Chl-*a* maximums occur periodically in summer in the mixing and seawater zones, with nitrogen as the limiting factor in the seawater zone.

Nutrients

	Tidal Fresh		Mixing		Seawater	
Nitrogen			H 0-10%	?	M 10-25%	?
Phosphorus			M 50-100%	?	M 50-100%	?

Reported nutrient concentrations occur throughout the year.

Ecosystem/Community Responses

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

Primary productivity is dominated by both pelagic and benthic communities in the mixing and seawater zones. Benthic community is diverse.

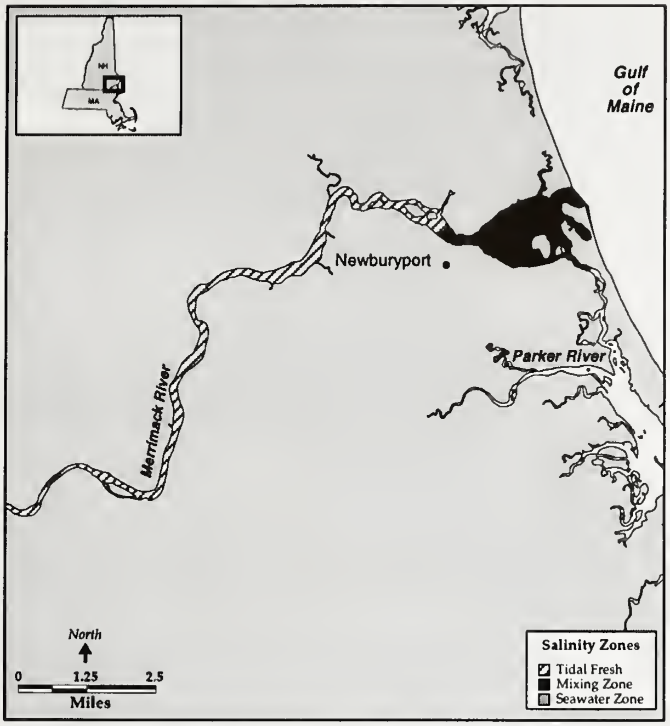
Dissolved Oxygen

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

Biological stress is observed over a small spatial extent of the mixing zone episodically from July through October.

Key on page 19

Merrimack River



In the Merrimack River, every parameter is unknown except for SAV spatial coverage, which is medium in the mixing zone and has decreased by a high magnitude since 1970.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **2,313** Avg. Daily Inflow *(cfs)* **8,400**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	6.7	3.3	3.4	
Average Depth *(ft)*	11.8	13.2	10.1	
Volume *(billion cu ft)*	2.2	1.2	1.0	

Shallow, riverine, salt-wedge estuary. Salinities tend to be moderately to highly stratified throughout the year. Freshwater inflow is dominated by the Merrimack River. Tidal range is 8.2 ft near the mouth of the estuary.

Algal Conditions

	Tidal Fresh		Mixing		Seawater
Chlorophyll a	?	?	?	?	
Turbidity	?	?	?	?	
Nuisance Algae	?	?	?	?	
Toxic Algae	?	?	?	?	

Nutrients

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

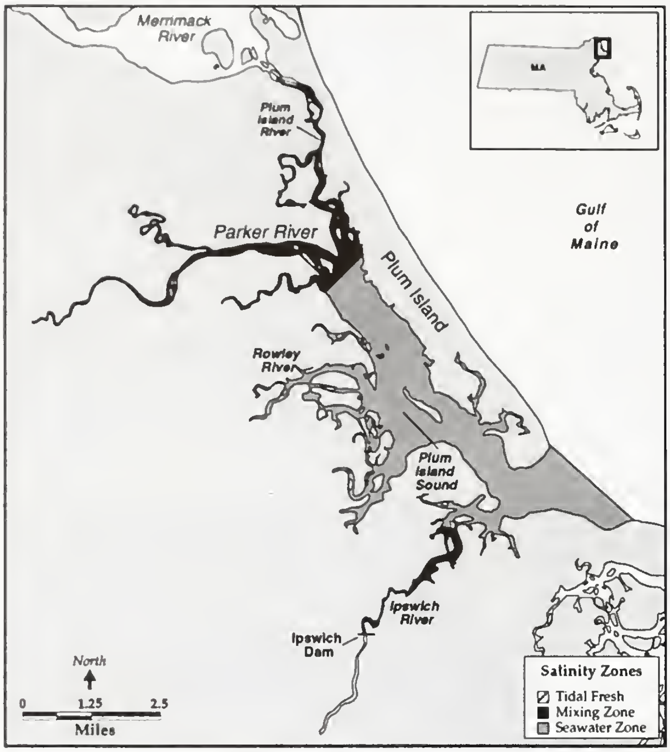
Dissolved Oxygen

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

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater
SAV	?	?	M	↓	

Plum Island Sound



In Plum Island Sound, chlorophyll *a* concentrations range from medium to high, and turbidity concentrations range from low to high. There are no biological resource impacts from nuisance or toxic algal blooms. Nitrogen and phosphorus concentrations are medium. Anoxia and hypoxia do not occur. SAV spatial coverage ranges from very low in the mixing zone to nonexistent in the seawater zone.

The trends for all parameters were stable.

Physical and Hydrologic Characteristics

Estuarine Drainage Area (mi^2) **n/a** Avg. Daily Inflow (*cfs*) **32.5**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area (mi^2)	7.1		1.6	5.5
Average Depth (*ft*)	n/a		n/a	n/a
Volume (*billion cu ft*)	n/a		n/a	n/a

A shallow estuary consisting of several small coastal streams and rivers. Most of the surrounding areas consist of extensive salt marshes and tidal flats. Salinities in the sound can vary significantly due to freshets and seasonal freshwater pulses. Receives the majority of freshwater inflow from the Parker River. Tidal range is 8.6 ft near the mouth of the sound.

Algal Conditions

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

Chl-*a* maximums occur periodically in summer in the mixing zone and in winter in the seawater zone, with limiting factors of light and nitrogen for both zones. Highest turbidity occurs throughout the year.

Ecosystem/Community Responses

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

Primary productivity is dominated by wetlands in the mixing zone and by the pelagic and benthic communities in the seawater zone. Both planktonic and benthic communities are a diverse mixture.

Nutrients

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

Elevated concentrations occur all year except phosphorus concentrations in seawater zone occur from September to February.

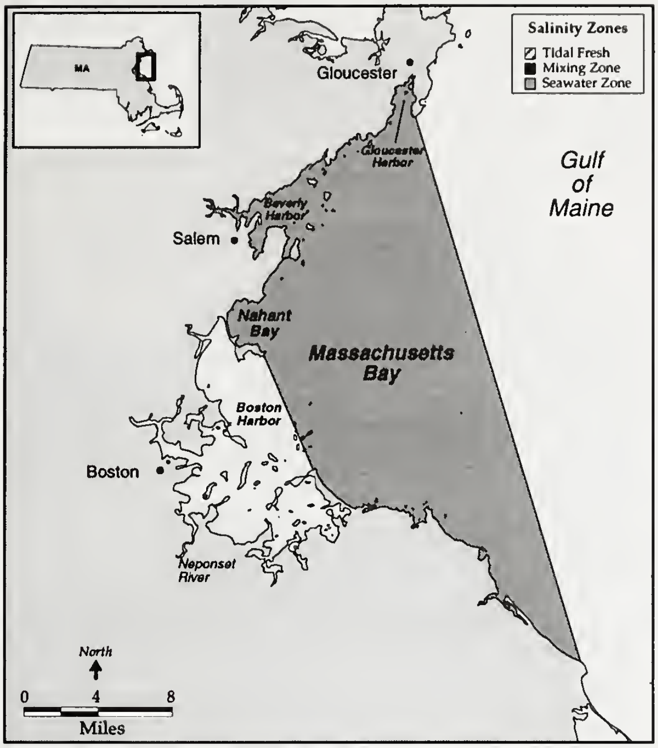
Dissolved Oxygen

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

Biological stress is observed throughout the water column over a very low spatial extent of the mixing zone, periodically July and August.

Key on page 19

Massachusetts Bay



In Massachusetts Bay, chlorophyll *a* concentrations are medium and turbidity concentrations are low. Nuisance algal blooms do not have an impact on biological resources, but toxic algal blooms do occur. Nitrogen and phosphorus concentrations are medium. There are no occurrences of anoxia or hypoxia. SAV spatial coverage is very low.

All of the conditions have been stable, except SAV coverage which has slightly declined.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **1,197** Avg. Daily Inflow *(cfs)* **2,900**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	297			297
Average Depth *(ft)*	89.5			89.5
Volume *(billion cu ft)*	741			741

A large coastal bay with smaller coastal embayments. Gulf of Maine salinities exist within the main bay. Circulation is strongly influenced by tidas and nontidal surface currents. Tidal range is approximately 9 ft near Beverly Harbor.

Algal Conditions

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

Chl-*a* maximums occur periodically in fall in the mixing zone and in winter in the seawater zone, with a limiting factor of nitrogen for both zones. Nuisance *Phaeocystis* spp. is present, but speculated not to be a problem to biological resources. Toxic *Alexandrium* spp. blooms occur periodically in summer.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater	
SAV			VL	⇩

Primary productivity is dominated by the pelagic community. Planktonic and benthic communities are a diverse mixture, except in urban areas where the benthic community is dominated by annelids. The decrease in SAV is attributed to increased point sources and physical alterations to the watershed.

Nutrients

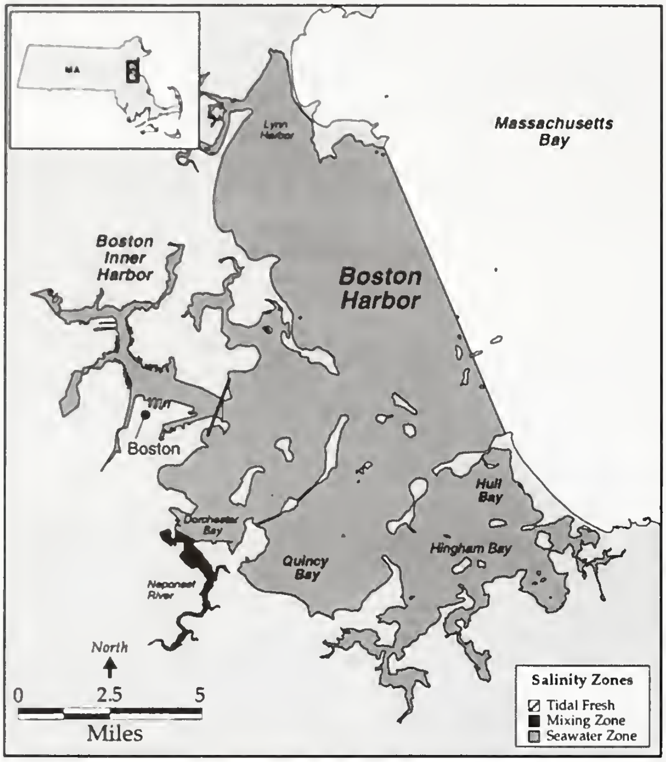
	Tidal Fresh	Mixing	Seawater	
Nitrogen			M (50-100%)	---
Phosphorus			M (50-100%)	---

Medium concentrations occur all year.

Dissolved Oxygen

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

Boston Harbor



In Boston Harbor, chlorophyll *a* and turbidity concentrations are medium. There are no biological resource impacts due to either nuisance or toxic algal blooms. Nitrogen and phosphorus concentrations are also medium. There are no observations of anoxia, but hypoxia was observed in the Inner Harbor area. SAV is present in very low concentrations.

Trends were either stable or unknown except a decrease in SAV in the Boston Harbor seawater zone.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **840** Avg. Daily Inflow *(cfs)* **1,800**

	Estuary	Tidal Fresh	Mixing	Seawater: Boston Harbor	Seawater: Inner Harbor
Surface Area *(mi²)*	76.0		1.0	72.0	3.0
Average Depth *(ft)*	25.8		37.8	25.6	n/a
Volume *(billion cu ft)*	52.5		1.1	51.4	n/a

Consists of Boston Harbor, and several smaller coastal embayments. Gulf of Maine salinities exist within the main harbor. Freshwater inflow is dominated by the Neponset River. Salinity is vertically homogeneous throughout the bay. Circulation is strongly affected by tidal influences and nontidal surface currents. Tidal range is approximately 9 ft near the mouth of Boston Harbor.

Algal Conditions

	Tidal Fresh	Mixing		Seawater: Boston Inner Harbor		Seawater: Boston Harbor	
Chlorophyll *a*		M 50-100%	?	M 50-100%	---	M 50-100%	---
Turbidity		M 50-100%	---	M 50-100%	---	M 50-100%	---
Nuisance Algae		N	?	N	?	N	?
Toxic Algae		N	?	N	?	N	?

Chl-*a* maximums occur periodically in summer with a limiting factor of light for Boston Harbor and residence time for Boston Inner Harbor. Highest turbidity occurs periodically between late spring and late summer. Nuisance *Phaeocystis* spp. is present, but not a problem to biological resources.

Ecosystem/Community Responses

	Tidal Fresh	Mixing		Seawater: Boston Inner Harbor		Seawater: Boston Harbor	
SAV		VL	---	NS	---	VL	⇩

Primary productivity dominated by diverse mixture in mixing zone, and pelagic community in seawater zone. Planktonic community is a diverse mixture; benthic community is predominantly crustaceans in Boston Harbor, and annelids in Boston Inner Harbor. Historically, Boston Harbor was dominated by annelids and crustaceans, but annelids dominance stopped with the cessation of sludge dumping. Decrease in SAV is attributed to epiphytes and disease.

Nutrients

	Tidal Fresh	Mixing		Seawater: Boston Inner Harbor		Seawater: Boston Harbor	
Nitrogen		?	?	M 50-100%	---	M 50-100%	---
Phosphorus		?	?	M 50-100%	---	M 50-100%	---

Medium concentrations occur throughout the year.

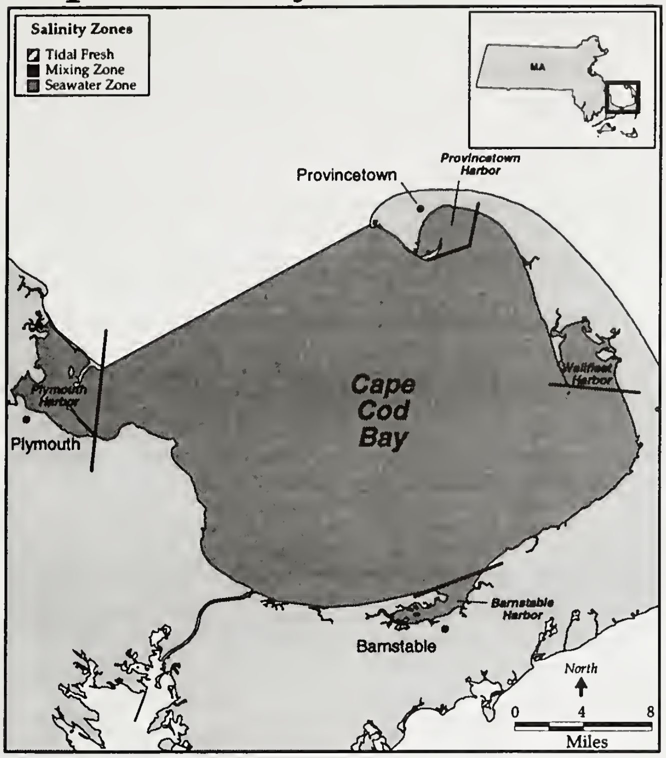
Dissolved Oxygen

	Tidal Fresh	Mixing		Seawater: Boston Inner Harbor		Seawater: Boston Harbor	
Anoxia		?	?	N	?	N	---
Hypoxia		?	?	Y 0-10%	?	N	---

Hypoxia and biological stress conditions occur periodically July through September on the bottom. Biological stress occurs over a high spatial extent. Water column stratification contributes moderately to development of hypoxia and biological stress.

Key on page 19

Cape Cod Bay



In Cape Cod Bay, chlorophyll *a* concentrations range from medium to high, and turbidity concentrations are low. Nuisance algal blooms have not impacted biological resources, but toxic algal blooms have. Nitrogen concentrations range from medium to high, and phosphorus concentrations are medium. There are no observations of anoxia, but hypoxia was observed in the Urban Embayments. SAV concentrations range from low to very low.

Trends were either stable or unknown except for an increase in nitrogen (speculative) and a decrease in SAV in the Urban Embayments.

Physical and Hydrologic Characteristics

Estuarine Drainage Area (*mi2*) **774** Avg. Daily Inflow (*cfs*) **1,800**

	Estuary	Tidal Fresh	Mixing	Seawater In General	Seawater Urban Emby.
Surface Area (*mi²*)	554.0			506.6	47.4
Average Depth (*ft*)	77.1			77.7	69.9
Volume (*billion cu ft*)	1191			1097	92.4

Consists of a large coastal bay (largest in the region) that is partially enclosed by Cape Cod, a ridge on the Coastal Plain consisting of glacial deposits. Four smaller bays and harbors make up the rest of the system. Circulation is strongly affected by tidal influences and nontidal surface currents. Salinity is vertically homogeneous throughout the bay. Tidal range is approximately 9 ft near Wellfleet Harbor.

Algal Conditions

	Tidal Fresh	Mixing	Seawater In General		Seawater Urban Embayments	
Chlorophyll *a*			M (50-100%)	---	H (0-10%)	?
Turbidity			L	---	?	?
Nuisance Algae			N	---	N*	---
Toxic Algae			Y	---	N	---

Chl-*a* maximums occur periodically in winter. Nuisance *Phaeocystis spp.* occurs in spring and toxic *Alexandrium spp.* occurs episodically in June.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater In General		Seawater Urban Embayments	
SAV			VL	?	L	⇩

Primary productivity is dominated by the pelagic community. Benthic community is predominantly annelids near Plymouth, and is diverse elsewhere. The decrease in SAV is speculated to be attributed to increases in non-point sources.

Nutrients

	Tidal Fresh	Mixing	Seawater In General		Seawater Urban Embayments	
Nitrogen			M (50-100%)	---	H (10-25%)	⇧ ?*
Phosphorus			M (50-100%)	---	M (?)	---

Concentrations occur all year in Cape Cod Bay but months of occurrence are unknown for the embayments. Increase in nitrogen attributed to point sources.

Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater In General		Seawater Urban Embayments	
Anoxia			N	---	N	---
Hypoxia			N	---	Y (0-10%)	?

Hypoxic and biological stress conditions occur on bottom periodically July through September. Bottom dissolved oxygen concentrations in the embayments are speculated to have decreased since 1970.

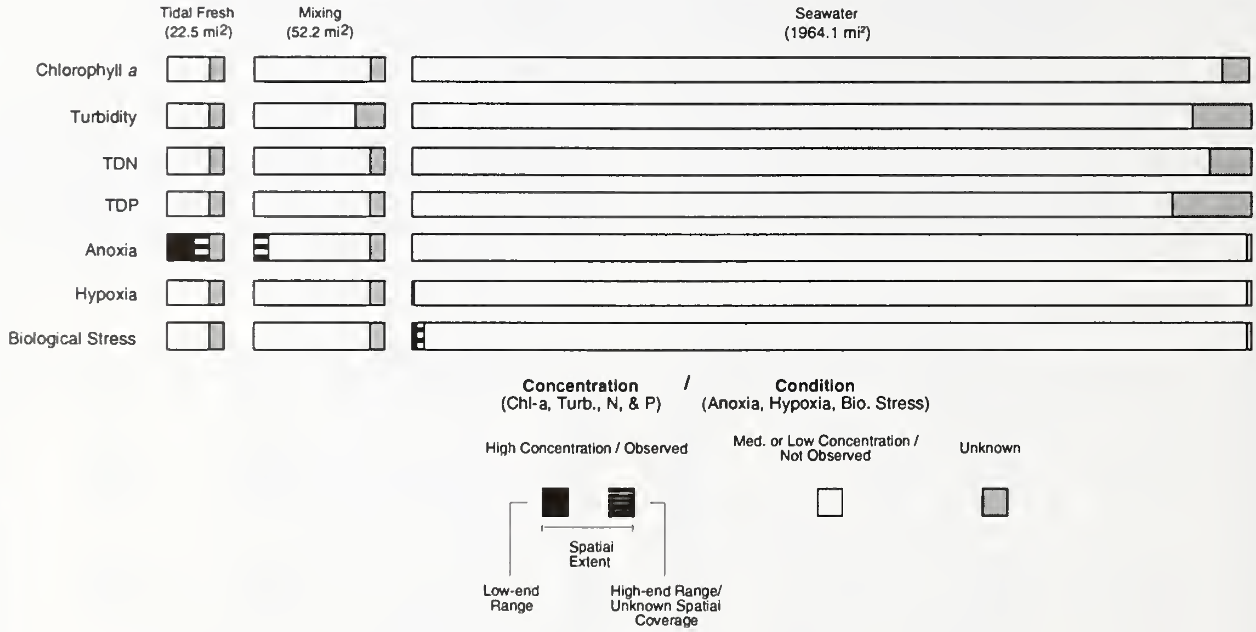
Key on page 19

Regional Summary

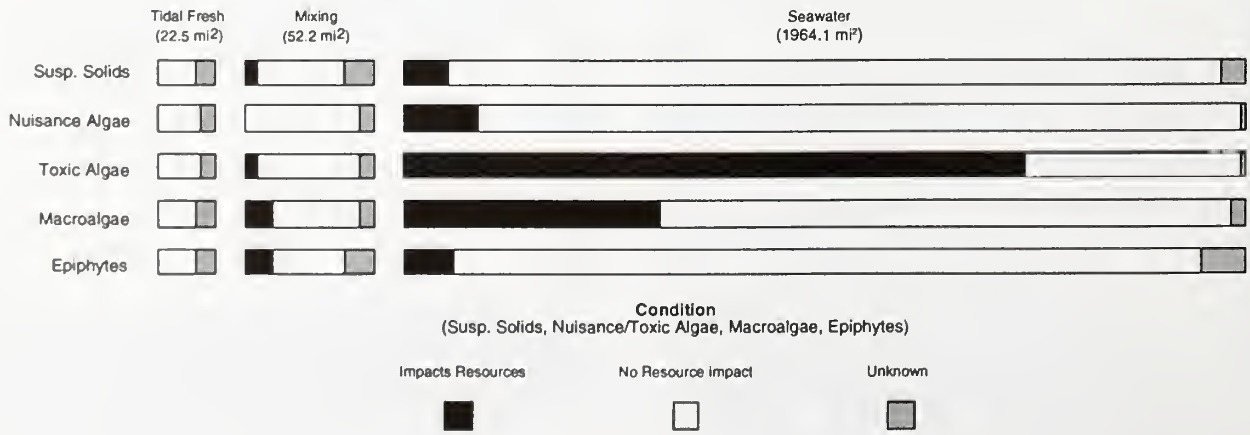
Regional classification status of existing conditions for 12 parameters as a cumulative percent of total estuarine surface area for three salinity zones.

The spatial extent of existing conditions was recorded for each salinity zone in each estuary when indicators were recorded at their maximum thresholds (i.e., when chl-*a* was recorded as hypereutrophic, when turbidity, nitrogen, or phosphorus were recorded as high, and when anoxia, hypoxia, or biologically stressed oxygen conditions were observed). Four broad ranges of spatial extent were used: high (51%-100% of the surface area in a particular zone of an estuary), medium (26%-50%), low (10%-25%), and very low (1%-10%). For some estuaries, existing conditions were reported but spatial coverage was unknown.

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



The presence of suspended solids, nuisance algae, toxic algae, macroalgae, and epiphytes in each salinity zone was 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.

North Atlantic Regional Workshop (October 2-3, 1996 Boothbay Harbor, ME)

Joceline Boucher	Maine Maritime Academy
Phillip Calarusso	U.S. Environmental Protection Agency
Jerome Cura	Menzie-Cura & Associates
Lee Doggett	Casco Bay Estuary Project
Bernie Gardner	Environmental Sciences Program - UMass
Chris Garside	Bigelow Laboratory for Ocean Sciences
Hap Garritt	Marine Biological Laboratory
Diane Gould	Massachusetts Bay Program
John Hurst	Maine Department of Marine Resources
Maureen Keller	Bigelow Laboratory for Ocean Sciences
Jack Kelly	Independent Contractor
Peter Larsen	Bigelow Laboratory for Ocean Sciences
Theodore Loder	University of New Hampshire
Lawrence Mayer	Darling Marine Center - University of Maine
Michael Mickelson	Massachusetts Water Resources Authority
Paul Mitnik	Maine Department of Environmental Protection
Judith Pederson	MIT Sea Grant
David A. Phinney	Bigelow Laboratory for Ocean Sciences
Fred Short	Jackson Laboratory - University of New Hampshire
David Taylor	Massachusetts Water Resources Authority

Survey/Site Visits

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

St. Croix River/Cobscook Bay

Laurice Churchill	Maine Dept. of Marine Res.
Lee Doggett*	Casco Bay Estuary Project
Chris Garside•	Bigelow Laboratory
Chris Heinig	Intertide Corporation
Peter Larsen•	Bigelow Laboratory
Paul Mitnik*	Maine DEP
Dave Phinney*	Bigelow Laboratory
John Sowles	Maine DEP
Robert Vadas	University of Maine

Englishman Bay

Laurice Churchill	Maine Dept. of Marine Res.
Lee Doggett*	Casco Bay Estuary Project
Paul Mitnik*	Maine DEP
Carter Newell	Great Eastern Mussel Farm
John Sowles*	Maine DEP

Narraguagus Bay

Seth Barker*	Maine Dept. of Marine Res.
Laurice Churchill	Maine Dept. of Marine Res.
Lee Doggett*	Casco Bay Estuary Project

Narraguagus Bay (cont.)

Paul Mitnik*	Maine DEP
Carter Newell	Great Eastern Mussel Farm
John Sowles*	Maine DEP

Blue Hill Bay

Seth Barker*	Maine Dept. of Marine Res.
Laurice Churchill	Maine Dept. of Marine Res.
Lee Doggett*	Casco Bay Estuary Project
Paul Mitnik*	Maine DEP
John Sowles*	Maine DEP

Penobscot Bay

Seth Barker*	Maine Dept. of Marine Res.
Joceline Boucher•	Maine Maritime Academy
Laurice Churchill	Maine Dept. of Marine Res.
Lee Doggett*	Casco Bay Estuary Project
William Ellis*	Maine Maritime Academy
Chris Garside•	Bigelow Laboratory
Peter Larsen•	Bigelow Laboratory
Paul Mitnik*	Maine DEP
Carter Newell	Great Eastern Mussel Farm
John Sowles*	Maine DEP

Muscongus Bay

Seth Barker*	Maine Dept. of Marine Res.
Lee Doggett*	Casco Bay Estuary Project
Paul Mitnik*	Maine DEP
John Sowles*	Maine DEP

Damariscotta River

Seth Barker*	Maine Dept. of Marine Res.
Lee Doggett*	Casco Bay Estuary Project
Chris Garside*	Bigelow Laboratory
Peter Larsen•	Bigelow Laboratory
Theodore Loder*	University of New Hampshire
Bernard McAlice	Bigelow Laboratory
Lawrence Mayer*	Darling Marine Center - UNH
Paul Mitnik•	Maine DEP
Byard Mosher*	University of New Hampshire
Carter Newell	Great Eastern Mussel Farm
John Sowles*	Maine DEP
David Townsend	Bigelow Laboratory
Robert Vadas	University of Maine

Sheepscot Bay

Arnold Banner*	U.S. Fish and Wildlife
Seth Barker*	Maine Dept. of Marine Res.
Lee Doggett*	Casco Bay Estuary Project
Chris Garside•	Bigelow Laboratory
Peter Larsen•	Bigelow Laboratory
Theodore Loder*	University of New Hampshire
Bernard McAlice	Bigelow Laboratory
Lawrence Mayer*	Darling Marine Center - UNH
Paul Mitnik•	Maine DEP
Byard Mosher*	University of New Hampshire
John Sowles*	Maine DEP
Robert Vadas	University of Maine

Kennebec/Androscoggin Rivers

Seth Barker*	Maine Dept. of Marine Res.
Lee Doggett*	Casco Bay Estuary Project
Chris Garside*	Bigelow Laboratory
Peter Larsen•	Bigelow Laboratory
Theodore Loder*	University of New Hampshire
Lawrence Mayer*	Darling Marine Center - UNH
Paul Mitnik•	Maine DEP
Byard Mosher*	University of New Hampshire
John Sowles*	Maine DEP

Casco Bay

Arnold Banner*	U.S. Fish and Wildlife
Seth Barker*	Maine Dept. of Marine Res.
Lee Doggett*	Casco Bay Estuary Project
Chris Garside•	Bigelow Laboratory
Chris Heinig	Intertide Corporation
Peter Larsen•	Bigelow Laboratory
Lawrence Mayer*	Darling Marine Center - UNH
Paul Mitnik*	Maine DEP
Carter Newell	Great Eastern Mussel Farm
Dave Phinney*	Bigelow Laboratory
Frederick Short	University of New Hampshire
John Sowles*	Maine DEP

Saco Bay

Seth Barker*	Maine Dept. of Marine Res.
Lee Doggett*	Casco Bay Estuary Project
Chris Garside•	Bigelow Laboratory
Chris Heinig	Intertide Corporation
Peter Larsen•	Bigelow Laboratory
Paul Mitnik•	Maine DEP
Carter Newell	Great Eastern Mussel Farm
Frederick Short	University of New Hampshire
John Sowles*	Maine DEP

Great Bay

Chris Garside•	Bigelow Laboratory
Frederick Short	University of New Hampshire

Hampton Harbor

David Burdick	University of New Hampshire
Richard Langan	University of New Hampshire
Arthur Mathieson	University of New Hampshire
Stephen Jones	University of New Hampshire

Merrimack River

n/a

Plum Island Sound

Charles Hopkinson, Jr.	Woods Hole Ocean. Institute

Massachusetts Bay

Larry Cahoon	University of NC, Wilmington
Cathy Coniaris*	University of New Hampshire
Michael Connor	MA Water Resources Authority
Jack Kelly	Independent Contractor
Theodore Loder•	University of New Hampshire
Caroline Martorano*	University of New Hampshire
James Maughn	CH2M Hill
Michael Mickelson	MA Water Resources Authority
Candace Oviatt	University of Rhode Island

Boston Harbor

Michael Connor	MA Water Resources Authority
Kenneth Keay	MA Water Resources Authority
Jack Kelly	Independent Contractor

Cape Cod Bay

Cathy Coniaris*	University of New Hampshire
Michael Connor	MA Water Resources Authority
Theodore Loder•	University of New Hampshire
Caroline Martorano*	University of New Hampshire

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 North 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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Narraguagus Bay

Fefer, S.I. and P.A. Schettig. 1980. An ecological characterization of coastal Maine (north and east of Cape Elizabeth) Volume 2. FWS/OBS-80/29. Newton Corner, MA: USFWS.

Shumway, S.E., S. Sherman-Caswell, and J.W. Hurst. 1988. Paralytic shellfish poisoning in Maine: monitoring a monster. Journal of Shellfish Research 7(4): 643-652.

Blue Hill Bay

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Shumway, S.E., S. Sherman-Caswell, and J.W. Hurst. 1988. Paralytic shellfish poisoning in Maine: monitoring a monster. Journal of Shellfish Research7(4): 643-652.

Muscongus Bay

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Shumway, S.E., S. Sherman-Caswell, and J.W. Hurst. 1988. Paralytic shellfish poisoning in Maine: monitoring a monster. Journal of Shellfish Research 7(4): 643-652.

Damariscotta River

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Saco Bay

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Appendix 3: NEI Estuaries

One hundred twenty-nine estuaries are included in the National Estuarine Inventory (NEI). 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 sub-system of Chesapeake Bay). __There are additional estuaries characterized for the Eutrophication Survey project that are not NEI estuaries__. However, those estuaries may be added to the NEI in the future. For more information on the National Estuarine Inventory, see the inside 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 Snds
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
Alamitos Bay
Anaheim Bay
Santa Monica Bay
Morro Bay
Monterey Bay
Elkhorn Slough
San Francisco Bay
Cent. San Francisco Bay/
San Pablo/Suisun Bays
Drakes Estero
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

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