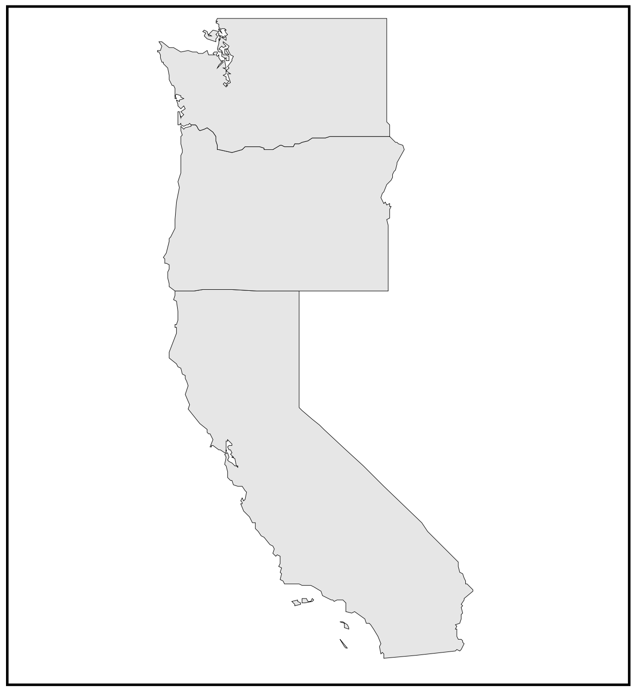
NOAA's Estuarine Eutrophication Survey

Volume 5: Pacific Coast Region



April 1998

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

The National Estuarine Inventory

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

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

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

The Estuarine Eutrophication Survey

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

The original survey forms were mailed to over 400 experts in 1993. The methods and initial results were evaluated in May 1994 by a panel of NOAA, state, and academic experts. The panel recommended that ORCA proceed with a regional approach for completing data collection, including site visits with selected experts to fill data gaps, regional workshops to finalize and reach consensus on the responses to each question, and regional reports on the results. The Pacific regional workshop was held in March 1997; this document, Volume 5, is the regional report. It was preceeded by the South Atlantic (Volume 1, September 1996), Mid-Atlantic (Volume 2, March 1997), North Atlantic (Volume 3, July 1997) and Gulf of Mexico (Volume 4, November 1997) reports.

A national-level assessment report on the status and health of U.S. estuaries is now under development. In addition, an "indicator" of ecosystem health will also be published. Both national-level products will require one or more workshops to discuss and reach consensus on the methods proposed for conducting these analyses. ORCA also expects to recommend a series of follow-up activities that may include additional and/or improved water quality monitoring, and case studies in specific estuaries for further characterization and analysis.

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

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ORCA Organization

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

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Acknowledgments

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Contents

Introduction

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

About This Report

This report presents the results of ORCA's Estuarine Eutrophication Survey for 38 estuaries of the Pacific Coast region of the United States. It is the last in a series of five regional summaries (South Atlantic (NOAA, 1996), Mid-Atlantic (NOAA, 1997), Gulf of Mexico (NOAA, 1997), North Atlantic (NOAA, 1997) and Pacific Coast). A national summary report is also under development. 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 38 Pacific 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 Pacific Coast estuaries. Appendix 3 presents a complete list of NEI estuaries.

The Problem

Between 1960-2010, the U.S. population has 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 the inputs of nutrients. Coastal and estuarine waters are now among the most heavily fertilized environments in the world (Nixon et al., 1986). Nutrient sources include point (e.g., wastewater treatment plants) and nonpoint (e.g., agriculture, lawns, gardens) discharges. These inputs are known to have direct effects on water quality. For example, in extreme conditions, excess nutrients can stimulate excessive algal blooms that can lead to increased metabolism and turbidity, decreased dissolved oxygen concentrations, 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., 1992; Cooper, 1995; Lowe et al., 1991; Orth and Moore, 1984; Kemp et al., 1983; Stevenson et al., 1993; Burkholder et al., 1992a, Ryther and 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 were 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, required 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 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 was how to best use this knowledge and information to characterize these parameters for the contiguous United States.

Preparing for a national survey

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

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

Identifying the Parameters and Parameter Characteristics

To be included in the survey, a parameter had to be (1) essential for accurate characterization of nutrient enrichment; (2) generally available for most estuaries; (3) comparable among estuaries; and (4) based upon existing data and/or knowledge (i.e., no new monitoring or analysis required). Based upon the workshops described above and additional meetings with experts, 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 $\geq$ 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 were designed to distinguish conditions among estuaries on a national basis, and may not distinguish among estuaries within a region.

Temporal Framework: Existing Conditions and Trends

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

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

	PARAMETERS	EXISTING CONDITIONS (maximum values observed over a typical annual cycle)	TRENDS (1970 - 1995)
ALGAL CONDITIONS	**CHLOROPHYLL *A***	• Surface concentrations: Hypereutrophic (>60 µg chl-a/l) High (>20, ≤60 µg chl-a/l) Medium (>5, ≤20 µg chl-a/l) Low (>0, ≤5 µg chl-a/l) • Limiting factors to algal biomass (N, P, Si, light, other) • Spatial coverage[1], Months of occurrence, Frequency of occurrence[2]	• Concentrations[3,4] • Limiting factors • Contributing factors[5]
	TURBIDITY	• Secchi disk depths: High (<1m), Medium (1≥m, ≤3m), Low (>3m), Blackwater area • Spatial coverage[1], Months of occurrence, Frequency of occurrence[2]	• Concentrations[3,4] • Contributing factors[5]
	SUSPENDED SOLIDS	• Concentrations: Problem (significant impact upon biological resources) No Problem (no significant impact) • Months of occurrence, Frequency of occurrence[2]	(no trends information collected)
	NUISANCE ALGAE **TOXIC ALGAE**	• Occurrence Problem (significant impact upon biological resources) No Problem (no significant impact) • Dominant species • Event duration (Hours, Days, Weeks, Seasonal, Other) • Months of occurrence, Frequency of occurrence[2]	• Event duration[3,4] • Frequency of occurrence[3,4] • Contributing factors[5]
	MACROALGAE **EPIPHYTES**	• Abundance Problem (significant impact upon biological resources) No Problem (no significant impact) • Months of occurrence, Frequency of occurrence[2]	• Abundance[3,4] • Contributing factors[5]
NUTRIENTS	**NITROGEN**	• Maximum dissolved surface concentration: High (≥1 mg/l), Medium (≥0.1, <1 mg/l), Low (≥0, < 0.1 mg/l) • Spatial coverage[1], Months of occurrence	• Concentrations[3,4] • Contributing factors[5]
	PHOSPHORUS	• Maximum dissolved surface concentration: High (≥0.1 mg/l), Medium (≥0.01, <0.1 mg/l), Low (≥0, < 0.01 mg/l) • Spatial coverage[1], Months of occurrence	• Concentrations[3,4] • Contributing factors[5]
DISSOLVED OXYGEN	**ANOXIA (0 mg/l)** **HYPOXIA (>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]
	PLANKTONIC COMMUNITY	• Dominant taxonomic group (number of cells): Diatoms, Flagellates, Blue-green algae, Diverse mixture, Other	• Temporal shift • Contributing factors[5]
	BENTHIC COMMUNITY	• Dominant taxonomic group (number of organisms): Crustaceans, Molluscs, Annelids, Diverse mixture, Other	• Temporal shift • Contributing factors[5]
	SUBMERGED AQUATIC VEG. **INTERTIDAL WETLANDS**	• Spatial coverage[1]	• Spatial coverage[3,4] • Contributing factors[5]

NOTES

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

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

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

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

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

Table 1: *Project parameters and characteristics.*

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

Spatial Framework

A consistently applied spatial framework was also required. ORCA's National Estuarine Inventory (NEI) was used (see inside front cover). For the survey, each parameter is characterized for three salinity zones as defined in the NEI (tidal fresh 0-0.5 ppt, mixing 0.5-25 ppt, 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

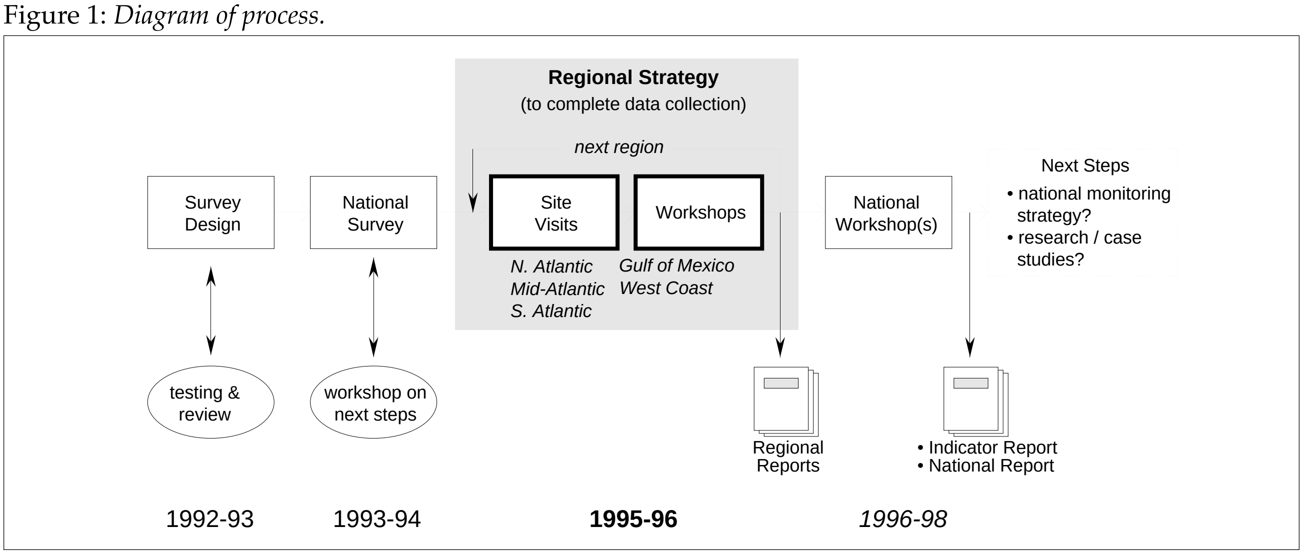
Over 400 experts and managers agreed to participate in the initial survey. Survey forms were mailed to the experts, who then mailed in their responses. The response rate was approximately 25 percent with at least one response for 112 of the 129 estuaries being surveyed.

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

Workshop participants were 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 had either filled out a survey form and/or participated in a site visit. Preparations included sending all regional data to participants prior to the workshop. Participants were encouraged to bring to the workshop relevant data and reports. At the workshop, at least two work

Figure 1: *Diagram of process.*



groups were established based upon geography. The survey data and salinity maps for each estuary were then carefully reviewed. ORCA staff facilitated the discussions and recorded the results. At the close of the workshop, participants were asked to identify "critical" references such as reports and other publications that described nutrient enrichment in one or more of the region's estuaries.

Workshop results were summarized for each estuary and mailed to workshop participants for review. The data then was compiled for presentation in a regional report that was 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 have been conducted concurrently.

Next Steps

A national assessment report on the status and health of the nation's estuaries is under development. The regional results and final national data base will be available on the Internet. Formulating a national response to estuarine nutrient enrichment, and developing a national "indicator" on coastal ecosystem health, will require one or more workshops to discuss and reach consensus on the methods and products resulting from these analyses. This work is currently scheduled for mid-1998. 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 38 Pacific Coast 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 Pacific Coast Region includes 38 selected estuarine systems encompassing a total estuarine surface of more than 2,750 mi^2. The Pacific Coast consists of a relatively straight and uninterrupted shoreline with rocky shores, sandy beaches, and occasional river outlets. The region has a dynamic geologic history and a physiographic profile that differs greatly from the flat coastal plains of the Atlantic and Gulf of Mexico regions. Recent geologic uplift of the North American Plate has reconstructed the topography, providing limited areas of flat, lowland environments to support estuaries, bays and lagoons (Beccasio et al., 1981). Nearby mountain systems abruptly meet the coastline, creating a steep and rugged coastal topography.

For this report, the Pacific Coast is divided into three distinct subregions: The Southern California Coast, Central California Coast, and Pacific Northwest Coast. The Southern California Coast extends from the Tijuana estuary at the U.S.-Mexico border to Point Conception, California. The Central California Coast spans the coastline from Point Conception to Cape Mendocino. The Pacific Northwest Coast includes the coastline of northern California and all of the Oregon

Highlights of Regional Results

Note: Tidal fresh = 9%, Mixing = 22%, Seawater = 69% of regional estuarine surface area (2,763 mi^2)

Chlorophyll *a*

Hypereutrophic concentrations (>60 μg/l) are observed episodically in 4 estuaries, affecting a maximum of 3% of the total regional estuarine area. High or greater concentrations (>20 μg/l) are observed in 18 estuaries with highest concentrations occurring mostly during March through October, affecting up to 31% of the total regional estuarine area. Increases in Chl-*a* concentrations were observed in parts of 2 estuaries, decreases in 3 estuaries, and in 13 estuaries, concentrations remained unchanged. Trends were unknown for 21 estuaries.

Nitrogen

High nitrogen concentrations (>1.0 mg/l) have been observed in 9 of 38 estuaries, over 5 percent of the regional estuarine area, mostly from August through November. Generally, concentrations are high throughout the year in California estuaries, and during winter in Oregon and Washington estuaries. Concentrations are reported to have increased in 4 estuaries, decreased in 4 estuaries, and remained unchanged in 7 estuaries. Trends are unknown for 23 estuaries.

Hypoxia

Hypoxia is observed periodically in 10 estuaries, generally from August through November in Central and South California Coast estuaries. Hypoxia was observed in up to 4% of regional estuarine area, in bottom waters of 7 estuaries, and throughout the water column in 4 estuaries. Water column stratification was reported to be a major influence for the systems with hypoxia in bottom waters. Spatial coverage of hypoxic occurrences have decreased in 2 estuaries, increased in 2, and remained the same in 17 estuaries. Trends are unknown for 17 estuaries.

Toxic Algae Blooms

Toxic algal blooms, primarily *Alexandrium*, are reported to occur in 16 of 38 estuaries (three in Southern California, five in Central California and eight in the Pacific Northwest) for weeks at a time, mostly on a periodic basis. There was no trend in the frequency of occurrence of toxic blooms for all or parts of 15 estuaries, and trends were unknown for all or parts of 21 estuaries. An increase in frequency was reported for one estuary and a decrease in frequency was reported for another.

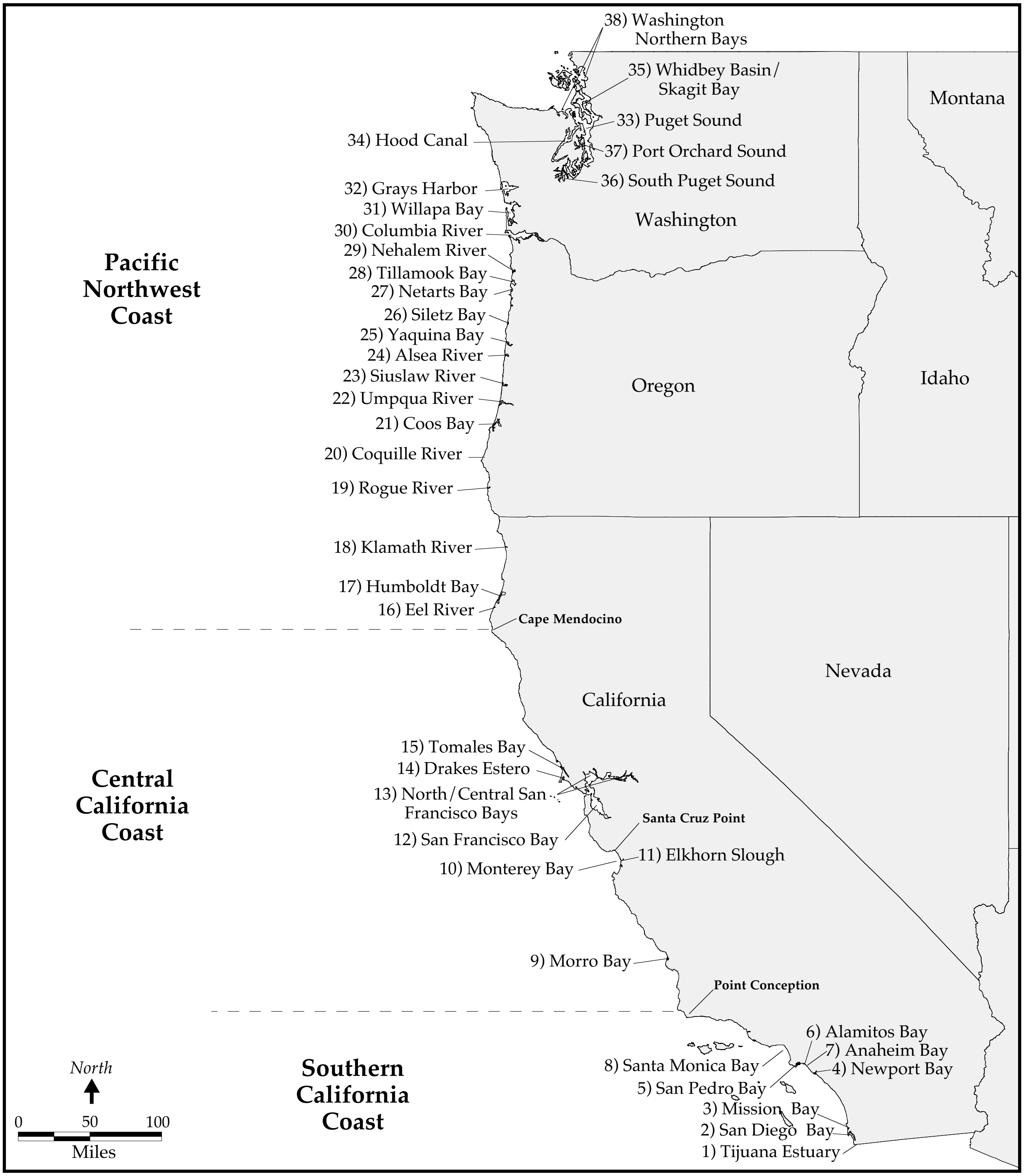
Phosphorus

High phosphorus concentrations (>0.1 mg/l) were observed in 11 estuaries, over 9 percent of the regional estuarine area. For most estuaries, high concentrations are persistent throughout the year. Concentrations have increased in 4 estuaries, decreased in 3 estuaries, remained unchanged in 7 estuaries and are unknown in 24 estuaries.

Anoxia

Anoxia is observed periodically 3 estuaries, episodically in 3 estuaries, is persistent in Tijuana Estuary, and occurs with unknown frequency in 1 estuary. Anoxic events are observed in up to 2% of the regional estuarine surface area, occurring during the months of April through November. Anoxia occurs in bottom waters of 4 estuaries and throughout the water column in Alamitos Bay and in small creeks of Monterey Bay. Stratification is a factor in development of anoxia only in estuaries where it occurs in bottom waters. The spatial coverage of anoxic events has decreased in 2 estuaries, increased in 2 estuaries, remained the same for 17 estuaries. Trends are unknown for 17 estuaries.

Figure 2: *Regional map of the Pacific Coast's 38 estuaries amd 3 subregions.*



and Washington coastline, including Puget Sound and the Washington Northern Bays.

Southern California Coast

The Southern California Coast includes eight estuarine systems encompassing approximately 251 mi^2 of estuarine water surface area, most of which is in Santa Monica Bay. The coastal mountain ranges bend eastward, and the coastline follows in a similar southeastward tract. Off the coast, the California Current parallels the shoreline, moving south towards Point Conception; a countercurrent transfers warmer waters back toward the north. Many embayments of this subregion are constructed marinas and canals that are highly engineered. Estuaries are predominantly small and have limited freshwater supply. Most coastal rivers and creeks flow only after heightened seasonal rainfall events, and during the summer, hypersaline conditions occur in many estuaries due to the decreased inflow and high evaporation rates. The coastline is characterized by long stretches of sandy beaches with rocky headlands. Tides are mixed semidiurnal, and the average tidal range is approximately 3.6 ft.

Central California Coast

The Central California Coast includes seven estuarine systems encompassing approximately 759 mi^2 of estuarine water surface area. Relatively straight and uninterrupted, the coastline is mountainous with few embayments; estuaries are relatively small and separated by large distances. Major embayments are San Francisco, Tomales and Monterey Bays, and Drakes Estero. The coastline generally grades from a rocky shore and steep seacliff setting to a low-relief, sandy beach setting with occasional bays of predominantly fine mud substrata. The continental shelf is typically only a few miles wide in this subregion. Submarine canyons cut through the shelf and the slope in some offshore areas along the coast. Immediately offshore, the substratum grades from relatively course sediment to finer silts and clays. A common feature of the rocky coastline is the sea stack, a small island composed of resistant rock formed from cliff erosion. Rivers north of Santa Cruz have flows year-round, while many systems south of Santa Cruz have flows only during peak rainfall months. Freshwater inflow is dominated by the Sacramento River, which empties into San Francisco Bay. Tides are semidiurnal and range between five and six ft.

Pacific Northwest Coast

The Pacific Northwest Coast includes 23 estuarine systems encompassing approximately 1,739 mi^2 of estuarine water surface area. The Oregon coastline is relatively straight and uninterrupted. Recent geologic uplift in the area, a consequence of tectonic movements, typifies the overall "youth and instability" of Pacific Northwest estuaries. Estuaries are typically small, with freshwater inflow occurring year-round. The coast is typically high-cliffed with numerous pocket beaches interspersed within a predominantly sandy or rocky beach setting. Extensive mudflats and eelgrass beds are common. Tides range between five and six ft. near the estuary mouths.

Two exceptional estuaries within the subregion are the Columbia River and Puget Sound systems. The Columbia River estuary has very high freshwater inflow (highest in the region) and an extensive inland marsh complex. Puget Sound is a large, fjord-like estuary with deep basins and shallow bays and inlets. The waterway is a complex composite of several connecting basins. Tides range from 6.4 ft. near the mouth of Hood Canal to 7.4 ft. near inlets within the main basin of the Sound.

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. Regional maps summarizing existing conditions for selected parameters are presented in Figure 4 (page 11). A summary of recent trends for all parameters is presented in Figure 5 (pages 14-15).

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 95 percent of the responses are highly certain. Where relevant, speculative inferences are noted in the text 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 by characterizing existing conditions and trends for chlorophyll *a*, turbidity, suspended solids, nuisance and toxic algae, macroalgal abundance, and epiphyte abundance (Table 1). Hypereutrophic concentrations of chlorophyll *a* (>60 µg/l) were reported to occur in only four estuaries and only along the Southern and Central California Coasts, but high or greater concentrations (>20 µg/l) were reported in 18 estuaries and over larger percentages of the tidal fresh and mixing zones (56 and 45 percent, respectively) than in the seawater zone (23 percent).

High turbidity was reported in 20 estuaries, generally throughout the year, in up to 98 percent of the tidal fresh zone and 84 percent of the mixing zone, but in only 18 percent of the seawater zone surface area. Biological resource impacts due to suspended solids were reported to occur in 13 estuaries throughout the region, usually where high turbidity also was reported. Resource impacts from toxic algae were reported to occur in the mixing and seawater zones, generally on a periodic basis, while nuisance algae impacts were reported in all three zones, but mostly on an episodic basis. Resource impacts from macroalgae were reported in 12 estuaries throughout the region; epiphyte problems were uncommon.

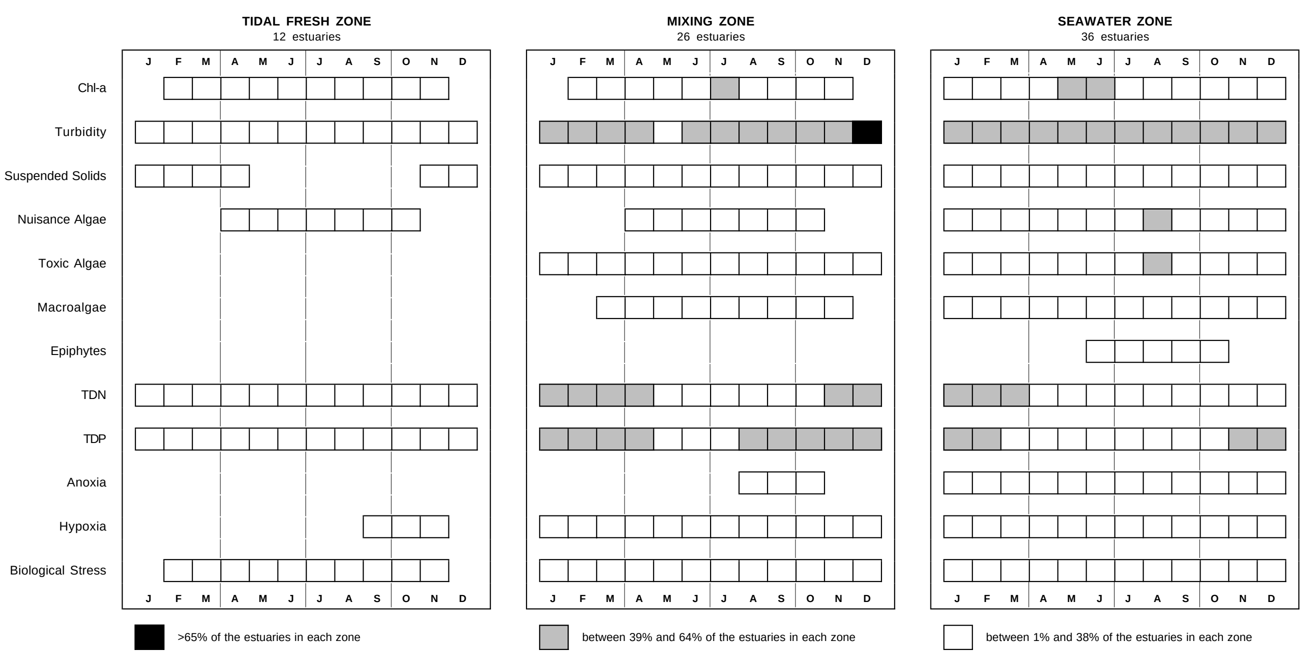
Chlorophyll a

High or greater concentrations (>20 µg/l) were reported in 18 estuaries across a maximum of 31 percent of the regional estuarine surface area. Hypereutrophic concentrations (>60 µg/l) were reported to occur episodically in four estuaries, affecting less than three percent of the regional estuarine area. Along the Southern and Central California Coasts, hypereutrophic concentrations were reported in Tijuana Estuary, Elkhorn Slough, San Francisco Bay, and the North/Central San Francisco Bay system. In general, high or greater concentrations occurred episodically. Chlorophyll *a* concentrations were unknown in seven of the 15 estuaries in these two subregions. In estuaries along the Pacific Northwest Coast, hypereutrophic concentrations were not observed, but high concentrations were reported to occur in 14 of 23 systems. This condition was reported to occur periodically from March to October. Concentration information from the Rogue River north to the Columbia River was very sparse. Most of the information for these systems was only for the seawater zone and was based to some extent on the speculative inference that offshore productivity of chlorophyll *a* moves into the seawater zone during tidal exchange.

Trends for the period 1970-1995 were unknown for 22 Pacific estuaries. Chlorophyll *a* concentrations were reported to have decreased in San Pedro Bay and parts

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 38 Pacific Coast estuaries for a particular salinity zone. For example, tidal fresh zones occur in 12 estuaries; therefore, a black tone indicates a maximum value was recorded in 8 or more estuaries. Similarly, for the mixing zone, black represents 17 or more estuaries, and for the seawater zone it represents 23 or more estuaries. Gray represents months where maximum values occur in 39 to 64 percent of the estuaries in that salinity zone, and unshaded boxes (white) represent months where maximum values occur between 1 and 38 percent of the estuaries in that zone. "Months-of-occurrence" data were not collected for Ecosystem/Community Response parameters (i.e., primary productivity, planktonic community, benthic community, SAV, and intertidal wetlands).*



of the San Joaquin River portion of the North/Central San Francisco Bay system. However, concentrations increased in other parts of the San Joaquin River and in Elkhorn Slough. Concentrations remained unchanged in 13 estuaries.

Turbidity

High turbidity (Secchi disk depths <1 m) was reported in 20 estuaries covering 41 percent of the regional estuarine surface area. Medium turbidity (Secchi disk depths <3 m) or higher was reported in 32 estuaries over 70 percent of the area. High turbidity levels were reported to occur episodically between October and March in Southern California coastal waters. In the Central California Coast, high levels were reported to occur throughout the year, except in Morro Bay and small areas of Monterey Bay, where high turbidity was reported to occur periodically from November to February. In the Pacific Northwest Coast, high turbidity conditions were reported to occur episodically in two estuaries, periodically in one, and most of the year in all or parts of seven estuaries.

During the period 1970-1995, turbidity was reported to have declined in seven estuaries, increased in two estuaries, and remained unchanged in 10 estuaries. Turbidity increased and decreased simultaneously in different parts of the San Joaquin River portion of the North/Central San Francisco Bay system. Trends were unknown for 20 estuaries.

Suspended Solids

Suspended solids were reported to have impacted biological resources (e.g., submerged aquatic vegetation, filter feeders) in 13 estuaries. The impacts were reported to occur episodically along the Southern California Coast between October and March. In the Central California Coast, problem conditions were reported to occur throughout the year in Elkhorn Slough and the seawater zone of San Francisco Bay, and periodically during November to April in three other estuaries. Along the Pacific Northwest Coast, impacts were reported between November and March. Trends information was not collected for suspended solids.

Nuisance Algae

Biological resource impacts due to nuisance algae were reported to occur in 22 estuaries. Along the Southern California Coast, episodic impacts from *Gonyaulax polyhedra* and/or *Gymnodinium* spp. were reported to occur in eight estuaries between April and November, for weeks at a time. Along the Central and Northern California Coasts, impacts from *Gymodinium splendens*, *Chaetoceros* spp. and/or *Prorocentrum micans* were reported to occur in parts of eight estuaries, mostly periodically for weeks, or seasonally during April to October. In the Pacific Northwest Region, nuisance algae conditions were mostly unknown from the Rogue River north to the Columbia River. *Ceratium* spp. were reported to cause resource impacts in Willapa Bay episodically, for weeks at a time from August to October. In Puget Sound, impacts were reported to occur periodically between April and October from *Chaetoceros* spp. and *Heterosigma* sp. in the main basin and from *Gymnodinium sanguineum* and *Ceratium fusus* in South Puget Sound. Episodic impacts from *Heterosigma* spp. were reported to occur for weeks at a time during April to October in Hood Canal, Whidbey Basin, and Port Orchard Sound.

Unique Characteristics of Southern California and Pacific Northwest Systems

In the Pacific coastal region, seasonal changes in rainfall and freshwater discharge are significant factors influencing sedimentation and salinity variability within river systems and estuaries. In the Pacific Northwest, intense runoff during the rainy winter season causes large amounts of sediment to be transported and deposited throughout many estuaries and lagoonal areas. The Eel River, for example, carries the highest recorded average annual sediment load per square mile of drainage area in the United States. Systems such as these experience persistently high turbidity in winter and progressively reduced tidal prisms as the estuaries accumulate sediment. The large sediment load is a product of factors ranging from deforestation and agriculture to watershed size and type of parent material.

Another distinctive feature of West Coast estuaries is the extremely variable salinity regime. Estuaries and river systems of the Pacific Northwest having large watersheds and high average annual rainfall (60-100 inches in Oregon and Washington, of which 75% occurs from November to April) exhibit extremes in seasonal salinity structure. In Southern California estuaries, high evaporation rates and minimal rainfall during the summer cause hypersaline conditions. However, during the winter rains from November to March (90% of the annual rainfall), catastrophic sedimentation can occur. In smaller watersheds of Southern California, impacts from urban development are evidenced by increased peak discharges and sediment load, and high turbidity levels. Increased erosion has been documented in lagoonal areas of Southern California where sedimentation rates have far exceeded holding capacity (Zedler et al., 1992).

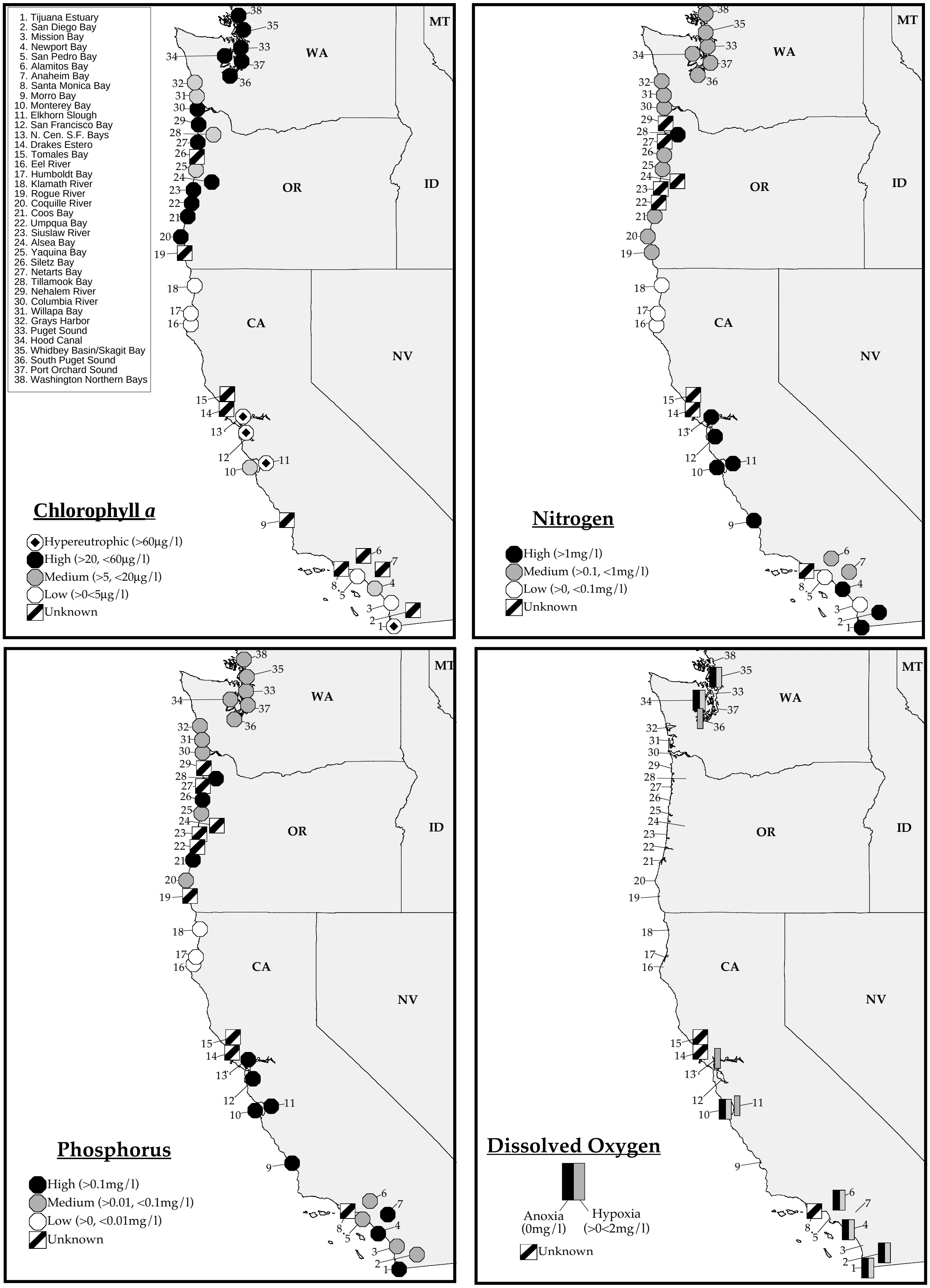


Figure 4: *Existing conditions for chlorophyll a, nitrogen, phosphorus, and dissolved oxygen. Symbols indicate that an existing condition(s) (e.g., hypereutrophic for chlorophyll a, anoxia and/or hypoxia for dissolved oxygen) was reported in at least a portion of one salinity zone of an estuary at some time during a typical annual cycle. Symbols do not necessarily represent existing conditions across an entire estuary. For a more complete review of individual estuaries, turn to the estuary summaries beginning on page 22.*

During the period 1970-1995, the frequency and/or duration of occurrences of nuisance algal blooms were reported to have increased in Puget Sound and parts of Monterey Bay. Occurrences were reported to have increased in San Pedro Bay and the San Joaquin River. Conditions remained unchanged in 13 estuaries, and were unknown in 21 estuaries.

Toxic Algae

Biological resource impacts due to toxic species were reported to occur in 18 estuaries throughout the region. In nine estuaries along the California Coast, *Alexandrium* spp. and *Pseudo-nitzchia* spp. were reported to impact resources periodically, for weeks at a time, from April to October. In seven estuaries along the Pacific Northwest Coast, *Alexandrium* spp. and *Pseudo-nitzchia* spp. were reported to impact resources periodically, for weeks at a time, from May to October, with some estuaries also affected during winter months.

Trends for the period 1970-1995 were unknown for parts of 22 Pacific estuaries. An increase of low magnitude in the duration and frequency of toxic algae events was reported in the Puget Sound main basin; a decrease of high magnitude was reported for San Pablo Bay. Conditions were reported to have remained unchanged in parts of 22 estuaries.

Macroalgal Abundance

Biological resource impacts due to macroalgae were reported to occur periodically in 12 estuaries. Along the Southern California Coast, impacts were reported between March and November (throughout the year in the Tijuana Estuary). Impacts were reported to occur between June and October along the Central California and Pacific Northwest Coasts. Macroalgal conditions were unknown in 13 estuaries, mostly in the Pacific Northwest. Reported macroalgal abundance information was based in part on speculative inference for two estuaries.

During the period 1970-1995, impacts from macroalgae were reported to have increased in five estuaries along the Southern and Central California Coasts. Impacts decreased in San Francisco and North/Central San Francisco Bays. Conditions remained unchanged in nine estuaries and were reported as unknown in 22 estuaries, mostly in the Pacific Northwest.

Epiphyte Abundance

Biological resource impacts due to epiphytes were reported to occur in only one estuary, Elkhorn Slough, from June to October. Conditions were unknown in 18 estuaries, mostly along the Pacific Northwest Coast.

Epiphyte abundance impacts for the period 1970- 1995 were reported to have remained unchanged in 14 estuaries; trends were unknown for 24 estuaries.

Nutrients

Nutrient concentrations 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 directly available to 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. Nitrogen values reported for Siletz Bay and Tillamook Bay are dissolved inorganic nitrogen (DIN). For Rogue River and Coos bay, values are for total inorganic nitrogen (TIN). Phosphorus values reported for Newport Bay, Anaheim Bay, Coos Bay, Siletz Bay, and Tillamook Bays are total phosphorus (TP).

High concentrations of nitrogen (≥ 1.0 mg/l) were reported for 10 estuaries, mostly in the Southern and Central California Coast systems, while medium concentrations (≥ 0 - 0.1 mg/l) were reported for 20 estuaries, mostly in the Pacific Northwest systems. High concentrations of phosphorus (≥ 0.1 mg/l) were observed in 13 estuaries, mostly in Southern and Central California, and medium concentrations were observed in 18 estuaries, mostly in the Pacific Northwest.

Trends in nitrogen concentrations were unknown for 23 estuaries, and trends in phosphorus concentrations were unknown for 24 estuaries. For seven estuaries, nitrogen concentrations remained unchanged; phosphorus concentrations also were unchanged for seven estuaries. Nitrogen concentrations decreased in four estuaries and phosphorus concentrations decreased in three estuaries. Both nitrogen and phosphorus concentrations increased in four estuaries; all reported increases occurred in Central California estuaries.

Nitrogen

High nitrogen concentrations were reported in eight Central and Southern California Coast estuaries and in one Pacific Northwest estuary, mostly in the mixing and seawater zones (Figure 4). High concentrations were observed in up to 5 percent of the total regional estuarine area, in 21 percent of the regional tidal fresh zone, in 11 percent of the regional mixing zone, and in 1 percent of the regional seawater zone. Medium concentrations were observed in 16 estuaries in up to 82 percent of the regional estuarine area. Maximum concentrations of nitrogen occurred persistently in Southern and Central California estuaries, in late spring to early fall from Rogue River to Tillamook Bay, and in the winter from Columbia River to Puget Sound.

Trends in nitrogen concentration were unknown for 23 estuaries. However, between 1970-1995, concentrations decreased in Humboldt Bay, San Francisco Bay, and San Pedro Bay. Increases in nitrogen concentration were reported to have occurred in four Central California estuaries: Morro Bay, Monterey Bay, Elkhorn Slough, and North/Central San Francisco Bays. Nitrogen concentrations remained unchanged in seven estuaries. Trends information was based on speculative inference for two estuaries.

Phosphorus

High phosphorus concentrations (≥0.1 mg/l) were reported to occur in three Pacific Northwest estuaries and eight Southern and Central California Coast estuaries, mostly in the mixing and seawater zones. High concentrations were observed over a maximum of 9 percent of the regional estuarine area, 9 percent of the tidal fresh zone, 11 percent of the mixing zone, and 8 percent of the regional seawater zone. Medium concentrations were reported for a larger number of estuaries (26) and for a larger area, up 72 percent of the regional estuarine area, mostly in the mixing and seawater zones. In general, maximum phosphorus concentrations were observed in winter or throughout the year in Southern and Central California Coast estuaries, in summer to early winter from Coquille River to Tillamook Bay, in winter from Columbia River to Grays Harbor, and throughout the year in the Puget Sound system.

Trends in phosphorus concentrations were reported as unknown for 24 estuaries. Increases were reported for Morro Bay, Monterey Bay, Elkhorn Slough, and North/Central San Francisco Bay. Decreases were reported for Columbia River, Humboldt Bay, and San Francisco Bay. No trend in phosphorus concentrations were reported for seven estuaries. Trends were based on speculative inference for three estuaries.

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 were recorded. The influence of water-column stratification (high, medium, low, or not a factor) on the development of low dissolved oxygen also was noted. Anoxic conditions were reported to occur in seven estuaries, and hypoxia in 10 estuaries, during July to November. Biologically stressful concentrations were observed in 17 estuaries, persistently in two estuaries, episodically in two, and periodically in 13.

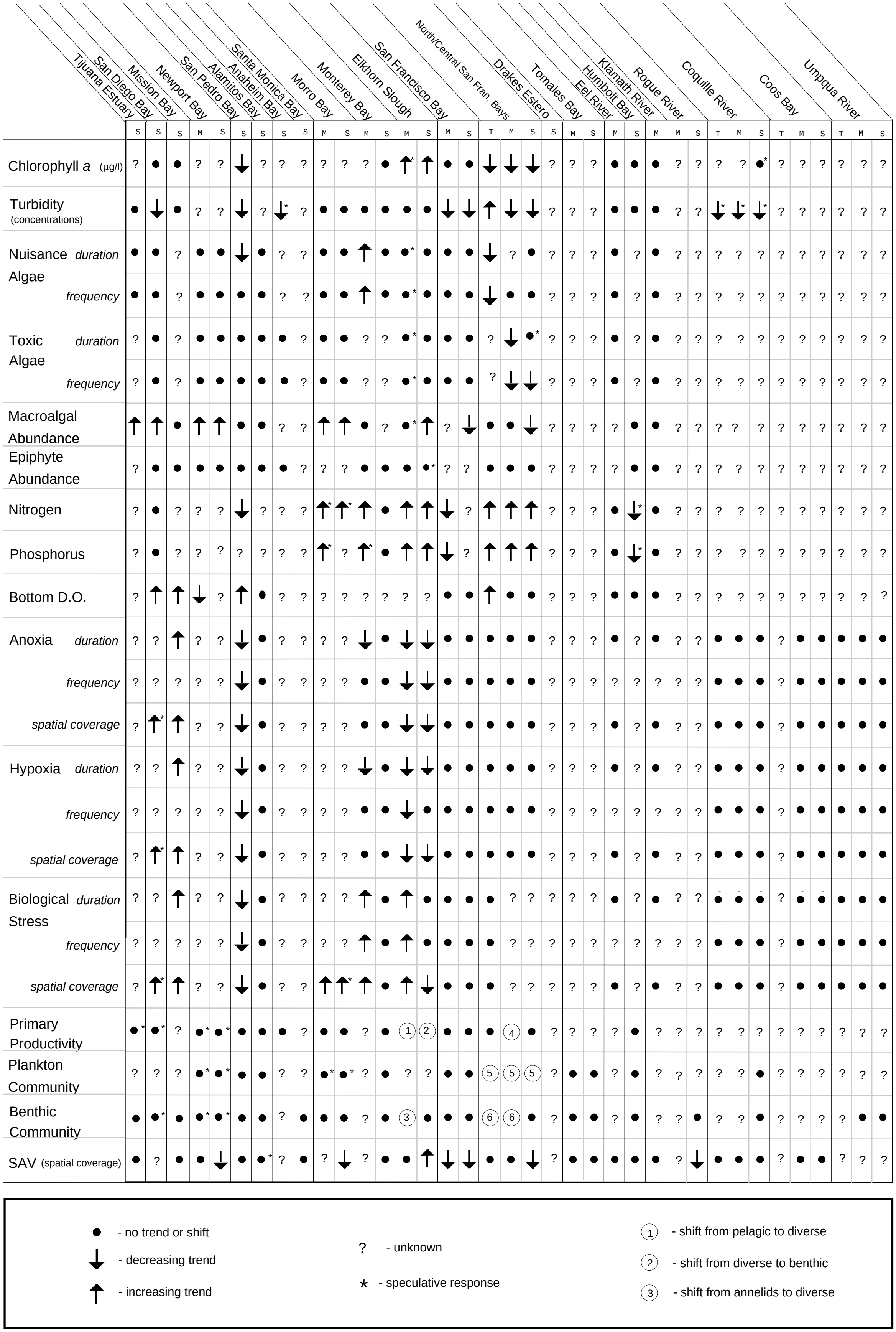
Trends in minimum bottom-water dissolved oxygen concentrations were unknown for 24 estuaries of this region. Bottom-water dissolved oxygen concentrations did not change for eight estuaries, increased in four estuaries, and decreased in two estuaries.

Anoxia

Anoxic conditions were reported to occur in seven estuaries in the mixing and seawater zones, mostly in Southern California Coast estuaries. Anoxia was reported in seven estuaries in up to 7 percent of the mixing zone, and 1 percent of the seawater zone, for a maximum of 2 percent of the total Pacific Coast regional estuarine surface area. The condition was reported to occur episodically in three systems during April through November. For another three estuaries, anoxia was reported to occur periodically, usually in October. In Tijuana Estuary, anoxia was reported over a low spatial area throughout the year. In four estuaries, anoxia occurred in bottom waters and was highly influenced by stratification of the water column. In Alamitos Bay and in small creeks of Monterey Bay, anoxia was observed throughout the water column (stratification was not an influencing factor). For all or parts of 10 estuaries, it was unknown whether anoxic conditions occurred.

Trends information for the duration, frequency of occurrence, and spatial coverage of anoxia was sparse. Duration trends were unknown for 17 estuaries, frequency of occurrence trends were unknown for 23 estuaries, and spatial coverage trends were unknown for 17 estuaries. There was no change in duration for 16 estuaries, in frequency of occurrence for 13 estuaries, and in spatial coverage for 17 estuaries. Increases in the duration of anoxic events were reported for Mission Bay and Columbia River; increases in spatial coverage were reported for San Diego Bay and Mission Bay. Decreases were reported for duration in San Pedro Bay, Monterey Bay and Elkhorn Slough; in frequency of occurrence for San Pedro Bay and Elkhorn Slough, and in spatial coverage for San Pedro Bay and Elkhorn Slough.

Figure 5: *Recent trends (1970 - present) for selected parameters by estuary by salinity zone (T, tidal fresh; M, mixing; S, seawater). All salinity zones are not present in all estuaries. Most of the 1,728 possible values are unknown (1,009). There are 65 decreasing trends, 62 increasing trends, and 579 no trends.*



The remaining 13 responses display shifts in primary productivity, the planktonic community or benthic community. Forty values are based on speculative inferences. For a more complete listing of the trends parameters, see Table 1 on page 3.

Parameter	Siuslaw River T	Siuslaw River M	Siuslaw River S	Alsea River M	Alsea River S	Yaquina Bay M	Yaquina Bay S	Siletz Bay T	Siletz Bay M	Siletz Bay S	Netarts Bay S	Tillamook Bay T	Tillamook Bay M	Tillamook Bay S	Nehalem River M	Nehalem River S	Columbia River T	Columbia River M	Willapa Bay T	Willapa Bay M	Willapa Bay S	Grays Harbor T	Grays Harbor M	Grays Harbor S	Puget Sound M	Puget Sound S	Hood Canal M	Hood Canal S	Whidbey Basin / Skagit Bay M	Whidbey Basin / Skagit Bay S	South Puget Sound S	South Puget Sound M	Port Orchard Sound S	Wash. Northern Bays S
Chlorophyll *a* (µg/l)	?	?	?	?	?	●	●	?	?	?	?	?	?	?	?	?	●	●	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
Turbidity (concentrations)	?	?	?	?	?	●	●	?	?	?	?	?	?	?	?	?	●	●	↑	↑	↑	?	?	?	?	?	?	?	?	?	?	?	?	?
Nuisance Algae *duration*	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	●	●	?	?	?	?	?	?	?	↑	?	?	?	?	?	?	?	?
Nuisance Algae *frequency*	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	●	●	?	?	?	?	?	?	?	↑	?	?	?	?	?	?	?	?
Toxic Algae *duration*	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	●	?	?	?	?	?	?	?	?	↑	?	?	?	?	?	?	?	?
Toxic Algae *frequency*	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	●	?	?	?	?	?	?	?	?	↑	?	?	?	?	?	?	?	?
Macroalgal Abundance	?	?	?	?	?	●	●	?	?	?	?	?	?	?	?	?	●	●	●	●	●	?	?	?	?	?	?	?	?	?	?	?	?	?
Epiphyte Abundance	?	?	?	?	?	●	●	?	?	?	?	?	?	?	?	?	●	●	●	●	●	?	?	?	?	?	?	?	?	?	?	?	?	?
Nitrogen	?	?	?	?	?	●	●	?	?	?	?	?	?	?	?	?	●	●	?	?	?	?	?	?	?	?	?	?	?	?	↓	?	?	?
Phosphorus	?	?	?	?	?	●	●	?	?	?	?	?	?	?	?	?	↓	↓	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
Bottom D.O.	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	↓	↓	?	●	●	?	?	?	●	●	?	?	●	●	?	?	?	?
Anoxia *duration*	?	?	?	●	●	●	●	?	●	●	●	?	●	●	●	●	↑	↑	?	?	?	?	?	?	●	●	?	?	●	●	?	?	?	?
Anoxia *frequency*	?	?	?	●	●	●	●	?	●	●	●	?	●	●	●	●	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
Anoxia *spatial coverage*	?	?	?	●	●	●	●	?	●	●	●	?	●	●	●	●	●	●	?	?	?	?	?	?	●	●	?	?	?	?	?	?	?	?
Hypoxia *duration*	?	?	?	●	●	●	●	?	●	●	●	?	●	●	●	●	↑	↑	?	?	?	?	?	?	●	●	?	?	●	●	?	?	?	?
Hypoxia *frequency*	?	?	?	●	●	●	●	?	●	●	●	?	●	●	●	●	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
Hypoxia *spatial coverage*	?	?	?	●	●	●	●	?	●	●	●	?	●	●	●	●	●	●	?	?	?	?	?	?	●	●	?	?	?	?	?	?	?	?
Biological Stress *duration*	?	?	?	●	●	?	?	?	●	●	●	?	●	●	●	●	↑	↑	?	?	?	?	?	?	●	●	?	?	●	●	?	?	?	?
Biological Stress *frequency*	?	?	?	●	●	?	?	?	●	●	●	?	●	●	●	●	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
Biological Stress *spatial coverage*	?	?	?	●	●	?	?	?	●	●	●	?	●	●	●	●	?	?	?	?	?	?	?	?	●	●	?	?	?	?	?	?	?	?
Primary Productivity	?	?	?	?	?	?	●	?	?	?	●	?	?	●*	?	●	?	?	?	●	?	?	?	?	●	●	?	?	?	?	?	?	?	?
Plankton Community	?	?	●	?	●	●	●	?	?	?	●	?	?	●	?	●	●	(7)	●	●	●	?	?	?	●	●	?	?	?	?	?	?	?	?
Benthic Community	?	●	●	●	●	●	●	?	?	?	●	?	●	●	●	●	?	?	●	●	●	?	?	?	●	●	(9)	(8)	●	●	?	?	?	?
SAV (spatial coverage)	?	●	●	●	●	●	●	?	?	?	●	?	●	●	●	●	●	↑*	●	↓*	↓*	?	?	?	?	↓	?	?	?	?	?	?	↓*	↑

(4) - shift from pelagic to benthic

(5) - shift from diatoms to diverse

(7) - shift diatoms and flagellates to diatoms

(6) - shift from arthropods to annelids

(8) - shift from diverse to annelids

(9) - shift from mollusks to annelids

Hypoxia

Hypoxic conditions (>0 mg/l, ≤2 mg/l) were observed in 10 estuaries, mostly in Central and Southern California Coast estuaries; in the bottom waters of six estuaries; and throughout the water column in four. In estuaries where hypoxia was reported in bottom waters, stratification highly influenced the development of the condition. Hypoxia was reported to occur periodically in parts or all of six estuaries, episodically in two estuaries, and persistently in Tijuana Estuary and Hood Canal. In Newport Bay, Alamitos Bay, Elkhorn Slough, and Suisun Bay, hypoxia was reported to occur throughout the water column; with the exception of Suisun Bay, stratification was not reported to be an influencing factor. Hypoxia was reported to occur usually from August through November, but in some estuaries as early as April. The spatial extent varied among estuaries from very low to high, and was observed in up to four percent of the regional estuarine area, 0.5 percent of the tidal fresh zone, six percent of the mixing zone, and four percent of the seawater zone. For all or parts of 10 estuaries, it was unknown whether hypoxia occurred.

Trends information for the duration, frequency of occurrence, and spatial coverage of hypoxia was sparse. For 17 estuaries, trends in duration were unknown; for 23 estuaries, trends in frequency of occurrence were unknown; and for 17 estuaries, trends in spatial coverage were unknown. From 1970-1995, there was no change in the duration of hypoxia for 16 estuaries; no change in the frequency of occurrence for 13 estuaries; and no change in the spatial coverage for 17 estuaries. Decreases in duration were reported for San Pedro Bay, Monterey Bay, and Elkhorn Slough; decreases in both spatial coverage and frequency of occurrence were reported for San Pedro Bay and Elkhorn Slough. Increases in event duration were reported for Mission Bay and Columbia River; increases in spatial coverage were reported for San Diego Bay and Mission Bay.

Biological Stress

Biologically stressful levels of dissolved oxygen (>2 mg/l, ≤5 mg/l) were reported to occur in all or part of 17 estuaries, mostly in the summer and fall. This condition was reported to occur periodically in 13 estuaries and episodically in Alamitos and Anaheim Bays. Biologically stressful dissolved oxygen concentrations occurred all year over a low spatial extent in Tijuana Estuary, and over a high spatial extent in Hood Canal. For all or parts of 10 estuaries, this condition was reported in bottom waters and stratification was a highly influencing factor, particularly in the Washington State estuaries. In Newport Bay, Elkhorn Slough, and the mixing zone of Yaquina Bay, biologically stressful concentrations were reported to occur throughout the water column. The cumulative area over which it was reported is up to 12 percent of the total regional estuarine area, 1 percent of the tidal fresh zone, 20 percent of the mixing zone, and 11 percent of the seawater zone. For all or parts of eight estuaries, it was unknown whether this condition occurred.

The most frequent response for trends of duration, frequency of occurrence and spatial extent of biologically stressful concentrations of dissolved oxygen was unknown. For 18 estuaries, trends in duration were unknown; for 24 estuaries, trends in frequency of occurrence were unknown; and for 18 estuaries, trends in spatial coverage were unknown. There was no change in duration of biologically stressful concentrations reported for 15 estuaries, no change in frequency for 11 estuaries, and no change in spatial extent for 14 estuaries. Decreases in duration, frequency of occurrence, and spatial coverage were reported for San Pedro Bay and for the seawater zone of Elkhorn Slough. Increases in event duration were reported for four estuaries, increases in spatial coverage were reported for five estuaries, and increases in frequency of occurrence were reported for two estuaries. For Elkhorn Slough, spatial coverage increased in the mixing zone and decreased in the seawater zone.

Ecosystem/Community Response

The responses of estuarine ecosystems to nutrient inputs were characterized by collecting information on the status and trends of five parameters: primary productivity, pelagic and benthic communities, submerged aquatic vegetation (SAV), and intertidal wetlands. Pelagic communities, particularly diatoms, were identified as the dominant primary producers in the Pacific region. A diverse mixture of annelids, mollusks, and/or crustaceans dominated the benthic community. SAV and intertidal wetlands were reported in nearly all Pacific estuaries, generally at a low or very low spatial coverage.

Information regarding historical shifts in the estuarine ecosystem indicated that between 1970 and 1995, changes took place in all but 10 estuaries, particularly with regard to intertidal wetlands, for which coverage declined in 19 systems. Changes in the spatial coverage of SAV were the second most reported trend, with decreases occurring in eight estuaries and increases in four estuaries. Shifts in primary productivity and the pelagic and benthic communities were reported almost exclusively in four estuaries: Elkhorn Slough, the North/Central San Francisco Bays system, Willapa Bay, and Hood Canal. Changes across all five ecosystem parameters were reported in the North/Central San Francisco Bays and Willapa Bay. With the exception of intertidal wetlands, changes in ecosystem parameters were reported primarily in the Central California Coast and Pacific Northwest Coast in the mixing and seawater zones. Trends information was unavailable for the tidal fresh zone of many estuaries. The factors said to contribute most to shifts/trends were changes in nonpoint sources, changes in hydrology, and the introduction of exotic species.

Primary Productivity

Pelagic communities were identified as the dominant primary producer in parts of 20 Pacific estuaries (57% of the region's estuarine surface area), particularly in the seawater zone and in the Pacific Northwest and Central California Coast subregions. Benthic communities were reported as dominant in the mixing and/or seawater zones of seven estuaries, while a diverse mixture of pelagic, benthic and/or emergent communities was reported in 11 estuaries, primarily in the Pacific Northwest. No information was available for parts of 19 estuaries (12% of the region's estuarine surface area), including 11 of 12 estuaries with tidal fresh zones.

Temporal shifts in primary productivity, i.e., shifts in dominance from one primary producer to another, were reported as unknown in parts or all of 28 Pacific estuaries (57% of the region's estuarine surface area), including 89% of the region's tidal fresh zone. Where information was available, a shift in dominance was reported in four estuaries. Primary production was reported to have shifted from benthic organisms or a diverse mixture of benthic and other organisms to pelagic organisms in the mixing zone of Elkhorn Slough, due to changes in nonpoint sources; in the mixing zone of Willapa Bay, due to a reduction in freshwater input and an increase in upwelling; and in a portion of the seawater zone of San Pedro Bay, due to changes in vessel-source pollutants from marinas. A shift from benthic organisms to a diverse mixture of benthic, pelagic and/or other organisms in the seawater zone of Elkhorn Slough was attributed to changes in nonpoint sources. The invasion of the exotic clam, *Potamocorbula amurensis*, contributed to a reported shift in dominance from pelagic to benthic organisms in portions of the mixing and seawater zones of Suisun and San Pablo Bays. Shifts were reported as unchanged in parts of 16 estuaries (36% of the region's estuarine surface area), including 72% of the Central California Coast subregion.

Plankton Community

Diatoms were reported as the dominant plankton group, in terms of abundance, in parts of 21 Pacific estuaries, mostly in the mixing and seawater zones. A diverse mixture of diatoms, dinoflagellates, and/or other plankton groups was the next most reported community, occurring in nine estuaries but accounting for 54% of the region's estuarine surface area. For estuaries within Puget Sound, except for Hood Canal, the dominant plankton community was reported to fluctuate from diatoms in winter and spring months to flagellates in summer and fall. No information was available for parts of 20 estuaries (11% of the region's estuarine surface area).

Shifts in plankton dominance, from one taxonomic group to another, were reported in three estuaries during the period 1970-95. A temporary shift from diatoms to a toxic dinoflagellate species (*Alexandrium*) was reported in the seawater zone of Hood Canal and the mixing and seawater zones of Willapa Bay, due to changes in freshwater input and upwelling. A shift from a diverse mixture of plankton groups to a community dominated by diatoms occurred in parts of the mixing and seawater zones in the North/Central San Francisco Bay system; however, the factors that contributed to the shift are unknown. Shifts were reported as unchanged in parts of 17 estuaries (45% of the region's estuarine surface area), including 72% of the Central California Coast subregion. No information was available for parts of 28 estuaries, particularly in the Pacific Northwest subregion.

Benthic Community

A diverse mixture of annelids, mollusks, and/or crustaceans was identified as the dominant benthic community, in terms of abundance, in parts of 22 estuaries (59% of the region's estuarine surface area), mostly in the seawater zone. Annelids, the next most reported group, were dominant in parts of 12 estuaries, primarily in the tidal fresh zone. Most of the remaining area in the region was dominated by crustaceans (six estuaries) and mollusks (four estuaries). The dominant benthic community was unknown in parts of 16 estuaries (15% of the region's estuarine surface area).

Historical shifts (ca. 1970-95) in benthic community dominance, from one taxonomic group to another, were reported as unchanged in parts of 25 estuaries, representing 50% of the region's estuarine surface area. Shifts were reported in four estuaries, including the Elkhorn Slough mixing zone, where a shift from a diverse benthic community to annelids was attributed to changes in nonpoint sources; and the Willapa Bay mixing and seawater zones, where crustaceans were reported as increasingly dominant in a diverse community due to overfishing of predators. In the Hood Canal system, dominance reportedly shifted from annelids to mollusks in the mixing zone and from annelids to a diverse community in the seawater zone; the contributing factors to the shift were unknown. In the North/Central San Francisco Bays system, dominance reportedly shifted from arthropods to mollusks in the Suisun Bay mixing zone as a result of an invasion of the exotic clam, *Potamocorbula amurensis*. Within the same estuary, dominance reportedly shifted from arthropods to annelids in the Western San Joaquin and Northern Sacramento Rivers, and from annelids to arthropods in the Lower San Joaquin River, due to unknown factors. No information was available for parts of 22 estuaries.

Submerged Aquatic Vegetation (SAV)

The presence of SAV was reported in at least one salinity zone in 31 Pacific estuaries. Only seven estuaries had no SAV reported within any zone: five in the Southern California Coast and one each in the Central California and Pacific Northwest Coasts. In 29 of the estuaries in which SAV was reported, the spatial coverage (to depths of one meter below mean low water) was identified as low (>10≤25% surface area) or very low (≤10% surface area). Exceptions were a medium spatial coverage (>25≤50% surface area) reported for six estuaries in the Pacific Northwest Coast, and a high spatial coverage (>50% surface area) reported for the tidal fresh zone of San Francisco Bay and the mixing zone of Willapa Bay. The combined spatial coverage of SAV throughout the Pacific Coast region was between 6 and 17 percent of the total estuarine surface area (to depths of one meter). No information was available for parts of 14 estuaries.

During the period 1970-95, the spatial coverage of SAV was reported to have declined in eight estuaries (30% of the region's estuarine area), mostly in the seawater zone at a medium or high magnitude (50-100% change). The declines were attributed to such factors as dredging and changes in nonpoint sources and sediment loads. Other contributing factors were the introduction of an exotic wetland species (*Spartina*) in the mixing and seawater zones of Willapa Bay, and macroalgae blooms in the seawater zone of Elliott and Commencement Bays (Puget Sound) and Port Orchard Sound. SAV coverage increased at a low magnitude (≤25% change) in four estuaries, representing eight percent of the region's estuarine area. The factors said to contribute to the increases included changes in nonpoint sources, the reduction of freshwater input and sediments, and the expansion of tidal mudflats. No changes in spatial coverage were reported for parts of 24 estuaries and no information was available for parts of 22 estuaries.

Intertidal Wetlands

Emergent (intertidal wetland) communities were reported in at least one salinity zone in 32 estuaries. Below high water, wetlands were reported at a low or very low spatial coverage (≤25% surface area) in 83% of the region, a medium spatial coverage (>25≤50% surface area) in 5% of the region, and a high spatial coverage (>50% surface area) in less than 1% of the region. The combined spatial coverage of all wetlands reported was between five and 15% of the region's estuarine surface area. No information was available for parts of 15 estuaries (11% of the region's estuarine surface area), primarily in the tidal fresh zone.

Wetlands coverage declined (ca. 1970-95) in 19 estuaries, mostly in the Pacific Northwest and Southern California Coasts and at a low magnitude (≤25% change). Losses in wetland coverage were attributed almost exclusively to development activities. Wetlands coverage increased in seven estuaries, mostly in the mixing zone and at a low magnitude. Factors contributing to the increases included physical alteration of the watershed, restoration activities, and the introduction of an exotic wetland species (*Spartina*). No changes in spatial coverage were reported for parts of eight estuaries (22% of the region) and trends information was unknown for parts of 21 estuaries (39% of the region).

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Estuary Summaries

This section presents one-page summaries on the status and trends of eutrophication conditions for the 38 Pacific Coast 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.

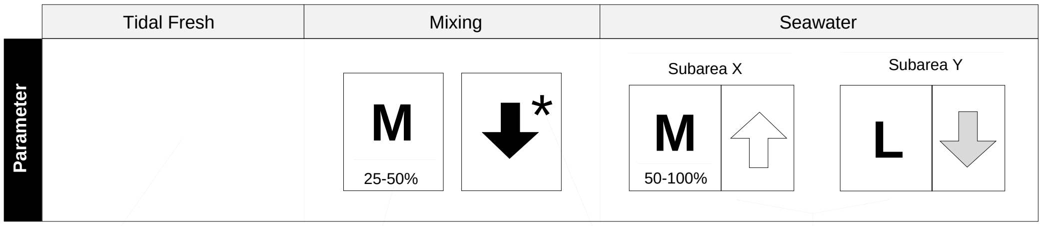
Survey Results. Selected data are presented in a unique format that is intended to highlight survey results for each estuary. The existing conditions symbols represent either the maximum conditions predominating one or more months in a typical year, or whether there are resource impacts due to bloom 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, 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

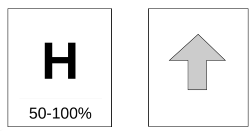


Salinity Zone Absent: if the salinity zone is not present in the estuary the entire box is left blank

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
- biological stress: >2, ≤5 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)

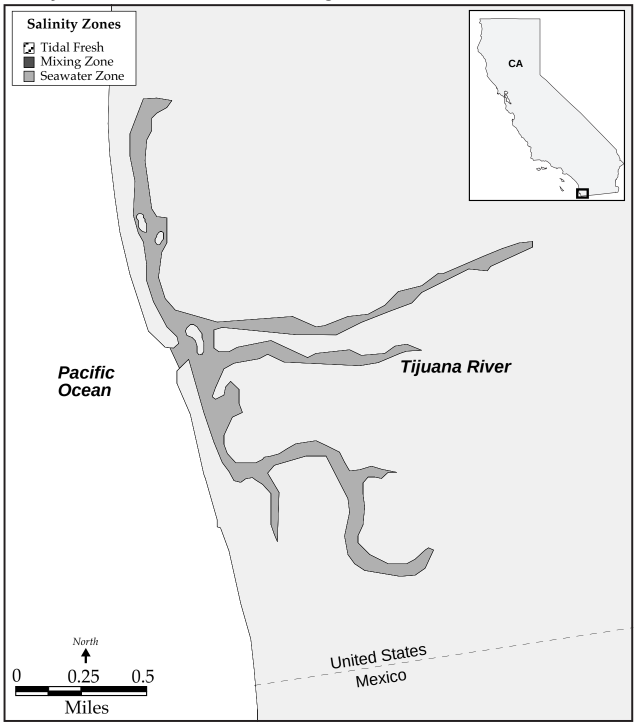
Direction of Change

- ⬆ increase
- ⬇ decrease
- – – – no trend
- **?** unknown

Magnitude of Change

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

Tijuana Estuary



In Tijuana Estuary, concentrations of chlorophyll *a* are hypereutrophic. Nuisance blooms occur, and dissolved nitrogen and phosphorus concentrations are high. Anoxia, hypoxia, and biological stress are observed in bottom waters. There is no SAV in this system.

Trends for all parameters are unknown, except turbidity levels and nuisance bloom events, which have not changed.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **1,700** Avg. Daily Inflow *(cfs)* **42**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	**0.2**			**0.2**
Average Depth *(ft)*	**0.7**			**0.7**
Volume *(billion cu ft)*	**0.004**			**0.004**

This southernmost California system is a small, coastal plain-type estuary. Oceanic influence is dominant forcing mechanism on salinity structure. Streamflow from the Tijuana River occurs in February through April and there is minimal to no freshwater inflow in summer. The water column is vertically mixed, and salinities are high to hypersaline throughout the year. Three-quarters of watershed is located within Mexico. Tidal range is approximately 3 ft near the estuary mouth.

Algal Conditions

	Tidal Fresh	Mixing	Seawater
Chlorophyll *a*			E (25-50%) ?
Turbidity			H (50-100%) – – –
Nuisance Algae			Y – – –
Toxic Algae			? ?

Chl-*a* blooms occur episodically all year with seasonal limiting factors of nitrogen and phosphorus. Highest turbidity occurs episodically January to February. Nuisance *Gonyaulax polyhedra* occurs episodically April to November.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater
SAV			NS – – –

Primary productivity dominated by wetlands and macroalgae. Pelagic community dominated by diatoms and blue-green algae; benthic community dominated by annelids. Intertidal wetland coverage is high with a low magnitude decrease attributed to sedimentation.

Nutrients

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

High nutrient concentrations occur throughout the year.

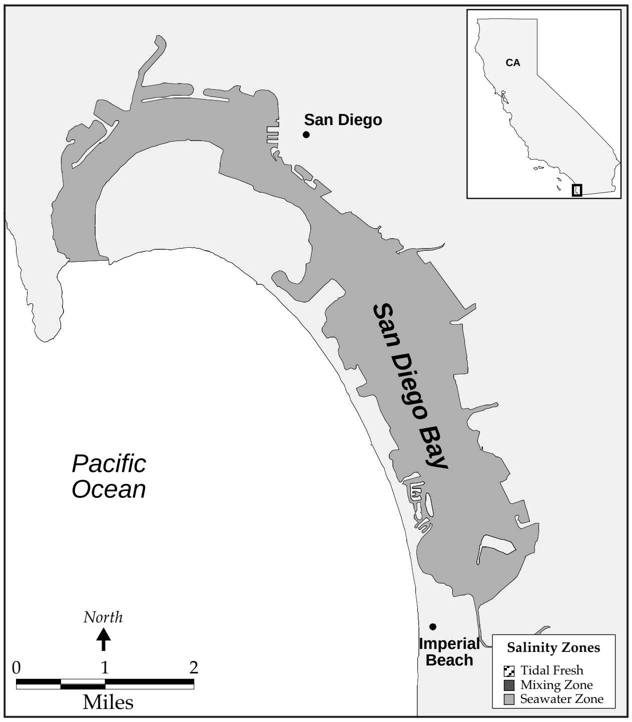
Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater
Anoxia			Y (10-25%) ?
Hypoxia			Y (10-25%) ?
Bio. Stress			Y (10-25%) ?

Dissolved oxygen conditions speculated to occur all year in bottom waters. Water column stratification is a highly significant factor.

Key on page 23

San Diego Bay



In San Diego Bay, chlorophyll *a* concentrations and SAV spatial coverage are unknown. Turbidity is medium and nuisance blooms occur in this system, but toxic blooms do not. Nitrogen concentrations are high and phosphorus concentrations are medium. Anoxia, hypoxia, and biological stress are observed.

Chlorophyll *a* concentrations, nuisance and toxic bloom occurrences, and nitrogen and phosphorus concentrations have not changed. Turbidity concentrations have decreased. Trends for SAV spatial coverage and dissolved oxygen conditions are unknown.

Algal Conditions

	Tidal Fresh	Mixing	Seawater	
Chlorophyll a			?	– – –
Turbidity			M ?	↓
Nuisance Algae			Y	– – –
Toxic Algae			N	– – –

Limiting factor for Chl-*a* speculated to be nitrogen. Nuisance *Gonyaulax polyhedra* occurs episodically April to November for weeks at a time.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater	
SAV			?	?

Primary productivity dominated by pelagic community. Benthic community dominated by annelids. Intertidal wetland coverage in southern portion is very low with overall decrease due to development, but recent small increase due to mitigation.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **453** Avg. Daily Inflow *(cfs)* **100**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	**17.2**			**17.2**
Average Depth *(ft)*	**22.4**			**22.4**
Volume *(billion cu ft)*	**10.7**			**10.7**

A highly engineered, nearly-enclosed bay consisting of the main bay, several small rivers and creeks, and dredge spoil islands. Freshwater is limited to periodic surface runoff and intermittent flow from several rivers and creeks during short periods of rainfall during winter. Tides are diurnal with a range of 4.2 ft within the bay.

Nutrients

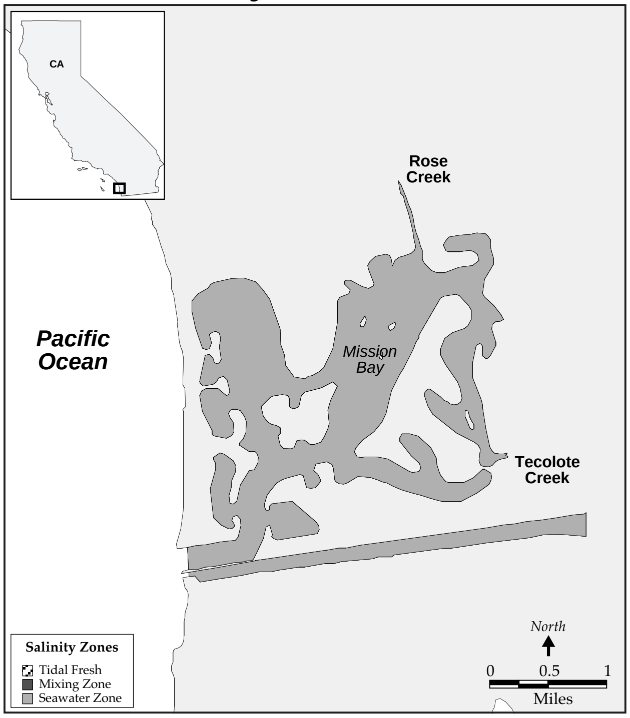
	Tidal Fresh	Mixing	Seawater	
Nitrogen			H	– – –
Phosphorus			M ?	– – –

Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater	
Anoxia			Y 0-10%	?
Hypoxia			Y 0-10%	?
Bio. Stress			Y 0-10%	?

Low dissolved oxygen conditions observed periodically in Sweetwater Marsh and dredged channels. The spatial coverage of these conditions has increased.

Mission Bay



In Mission Bay, chlorophyll *a* concentrations are low and turbidity is medium. Nuisance and toxic algal blooms occur. Nitrogen concentration is low and phosphorus is medium. Anoxia, hypoxia, and biological stress are not observed in this system. SAV spatial coverage is low.

Chlorophyll *a* and turbidity concentrations and SAV coverage have remained the same. Trends for all other parameters are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **52** Avg. Daily Inflow *(cfs)* **2**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	**3.6**			**3.6**
Average Depth *(ft)*	**8.0**			**8.0**
Volume *(billion cu ft)*	**0.8**			**0.8**

A highly modified lagoon consisting of Mission Bay, Tecolote and Rose Creek. Freshwater is limited to input from major rain events. Additions of freshwater into Mission occur at Rose Inlet and Tecolote Creek. Salinities are fairly uniform. Mean tidal range is nearly 4 ft.

Algal Conditions

	Tidal Fresh	Mixing	Seawater
Chlorophyll *a*			L / – – –
Turbidity			M ? / – – –
Nuisance Algae			Y / ?
Toxic Algae			Y / ?

Highest turbidity occurs periodically January to March. Nuisance *Noctiluca scintillans* and *Gonylaulax polyedra* occur during spring along nearshore. At least one bloom of toxic *Pseudo-nitzschia* spp. has been observed.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater
SAV			L / – – –

Benthic community dominated by annelids.

Nutrients

	Tidal Fresh	Mixing	Seawater
Nitrogen			L / ?
Phosphorus			M ? / ?

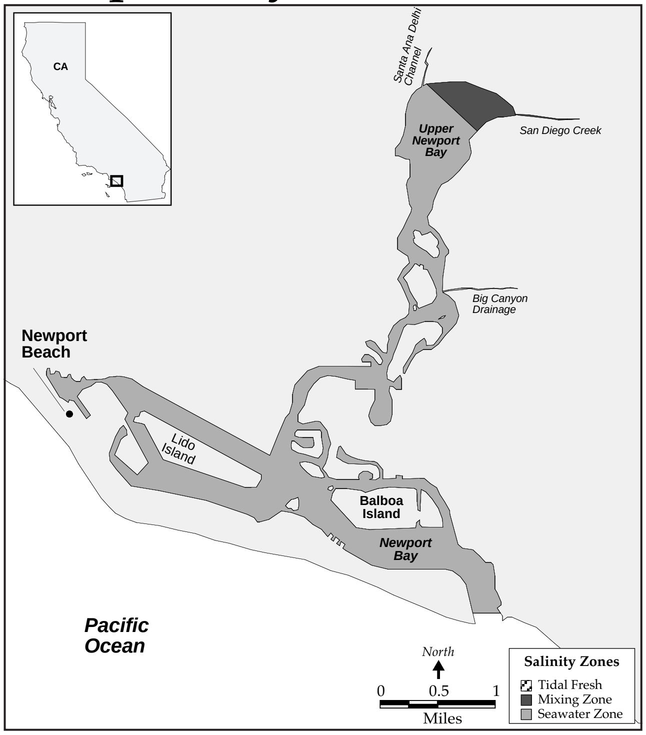
Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater
Anoxia			N / ?
Hypoxia			N / ?
Bio. Stress			N / ?

Increase in duration and spatial coverage of dissolved oxygen events attributed to non-point sources.

Key on page 23

Newport Bay



In Newport Bay, chlorophyll *a* concentrations are medium and turbidity is high. Nuisance blooms occur in the seawater zone. Concentrations of nitrogen and phosphorus are high. Anoxia is not observed, but hypoxia is observed in the mixing zone, and biological stress is observed throughout the system. SAV coverage ranges from none to very low.

Trends for most parameters are unknown. SAV coverage in the seawater zone has declined. There were no changes in nuisance and toxic bloom occurrences.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **149** Avg. Daily Inflow *(cfs)* **23**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi^2)*	2.1		0.3	1.8
Average Depth *(ft)*	8.0		5.0	8.0
Volume *(billion cu ft)*	0.5		0.04	0.4

A modified lagoonal system consisting of Newport Bay and various small channels and tributaries that flow into the main system. Water conditions are governed by the coastal water regime between the southern California mainland and the Channel Islands, known as the Southern California Bight. Waters within the bay are influenced by solar heating and storm runoff. High salinities persist throughout the lower portions of the bay. Tides range approximately 3.8 ft.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyll a			M 50-100%	?	M 0-10%	?
Turbidity			H 50-100%	?	H 50-100%	?
Nuisance Algae			N	- - -	Y	- - -
Toxic Algae			N	- - -	N	- - -

Chl-*a* maximums speculated to occur periodically July to October with limiting factor of macroalgal competition in mixing zone, with nitrogen and phosphorus in seawater zone. Turbidity occurs with storms October to March. Nuisance *Procrocentrum micans* occurs in spring and *Gonyaulax polyhedra* episodicallyApril to November.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV			NS	- - -	VL	↓

Primary productivity dominated by benthic community in mixing and north seawater zones, and by pelagic community in south seawater zone. Pelagic community dominated by diatoms in mixing zone and north seawater zones; benthic community dominated by annelids and mollusks. Intertidal wetland coverage is high. Decrease in SAV and wetlands attributed to development.

Nutrients

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

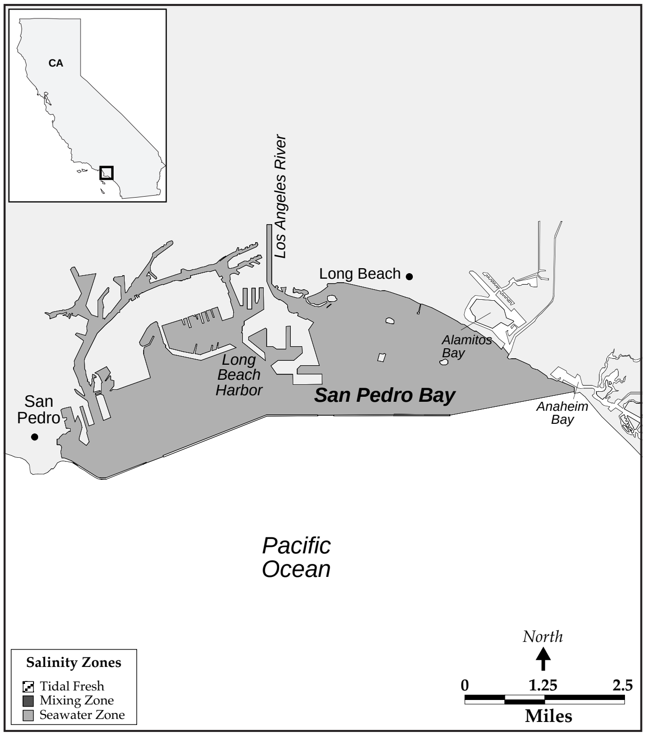
High nitrogen and phosphorus concentrations occur throughout the year. Phosphorus reported as total phosphorus.

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia			N	?	N	?
Hypoxia			Y 50-100%	?	N	?
Hypoxia			Y 50-100%	?	Y 0-10%	?

Dissolved oxygen events speculated to occur periodically. In mixing zone, hypoxia occurs October to November throughout water column.

San Pedro Bay



In San Pedro Bay, chlorophyll *a* concentrations are low, turbidity is high and nuisance and toxic blooms occur. Nitrogen concentrations are low and phosphorus is medium. Anoxia, hypoxia and biological stress are not observed, and there is no SAV in the system.

Chlorophyll *a*, turbidity, and nitrogen concentrations have decreased. Anoxia and hypoxia occurrences have decreased also. There has been no change in nuisance and toxic blooms occurrences or SAV coverage.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **1,726** Avg. Daily Inflow *(cfs)* **300**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi^2)*	23.2			23.2
Average Depth *(ft)*	38.9			38.9
Volume *(billion cu ft)*	25.2			25.2

A modified, fairly open system consisting of San Pedro Bay, Long Beach Harbor and other subsystems to the main bay. Water conditions are highly governed by the coastal water regime between the southern California mainland and the Channel Islands, the area called the Southern California Bight. High salinities persist throughout the bay. Lowest salinities occur near the mouth of the Los Angeles River. Tides range approximately 3.8 ft.

Algal Conditions

	Tidal Fresh	Mixing	Seawater
Chlorophyll a			L ↓?
Turbidity			H 25-50% ↓
Nuisance Algae			Y – – –
Toxic Algae			Y – – –

Chl-*a* limiting factor is nitrogen. Decreasing trend in Chl-*a* associated with point and nonpoint sources during storms. Highest turbidity occurs periodically November to March. Nuisance *Gonyaulax polyhedra* and *Gymnodinium* spp. occur episodically January to August. Toxic *Pseudo-nitschia* spp. and *Alexandrium catenella* observed episodically.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater
SAV			NS – – –

Primary productivity dominated by pelagic community. Pelagic community dominated by diatoms and benthic community dominated by annelids. Intertidal wetland coverage is very low with a high magnitude decrease due to development and dredge and fill activities.

Nutrients

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

Decrease in nitrogen attributed to changes in point sources. Medium phosphorus occurs November to January.

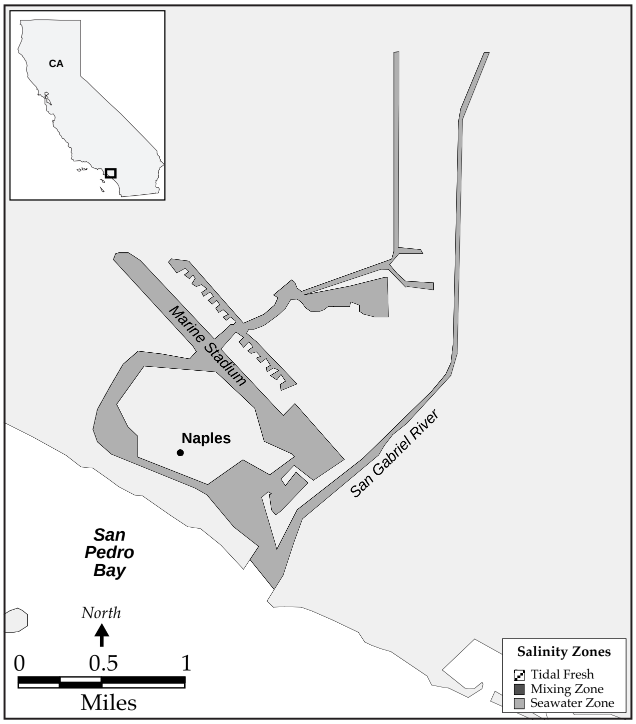
Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater
Anoxia			N ↓
Hypoxia			N ↓
Bio. Stress			N ↓

Decrease in duration, frequency, and spatial coverage of dissolved oxygen events attributed to changes in point sources.

Key on page 23

Alamitos Bay



In Alamitos Bay, chlorophyll *a* concentrations are unknown and turbidity is speculatively medium. Nuisance blooms occur, but toxic blooms do not. Concentrations of nitrogen and phosphorus are medium. Anoxia, hypoxia, and biological stress are observed in this system. SAV spatial coverage is very low.

Trends for chlorophyll *a*, turbidity, nitrogen, and phosphorus are unknown. There were no changes in nuisance and toxic bloom occurrences, SAV spatial coverage, or dissolved oxygen events.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **29** Avg. Daily Inflow *(cfs)* **4**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi^2)*	0.8			0.8
Average Depth *(ft)*	12.6			12.6
Volume *(billion cu ft)*	0.3			0.3

A small, highly modified system consisting of the main bay, Marine Stadium and the San Gabriel River. Water conditions are highly governed by the coastal water regime between the southern California mainland and the Channel Islands, the area called the Southern California Bight. High salinities persist throughout the system. Waters within the bay are influenced by solar heating and storm runoff. Tides range approximately 4 ft.

Algal Conditions

	Tidal Fresh	Mixing	Seawater	
Chlorophyll a			?	?
Turbidity			M* ?	?
Nuisance Algae			Y	– – –
Toxic Algae			N	– – –

Elevated turbidity occurs throughout the year. Nuisance *Gonyaulax polyhedra* and *Gymnodinium* spp. occurs episodically in September.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater	
SAV			VL	– – –*

Primary productivity dominated by pelagic community. Pelagic community speculated to be dominated by diatoms; benthic community is diverse. Intertidal wetland coverage is very low.

Nutrients

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

Medium nutrient concentrations occur throughout the year.

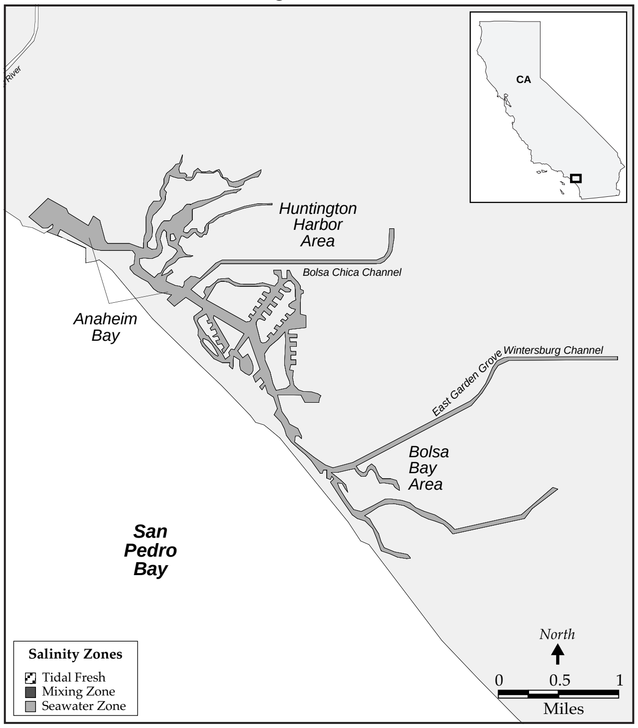
Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater	
Anoxia			Y 50-100%	– – –
Hypoxia			Y 50-100%	– – –
Bio. Stress			Y 50-100%	– – –

Dissolved oxygen events observed episodically April to November throughout the water column.

Key on page 23

Anaheim Bay



In Anaheim Bay, chlorophyll *a* concentrations are unknown. Turbidity is high and nuisance blooms occur, but toxic blooms do not. Nitrogen concentrations are medium and phosphorus is high. Biological stress is observed in this system, but anoxia and hypoxia are not. SAV spatial coverage is very low.

Trends for most parameters are unknown. Turbidity concentrations have declined and there have been no changes in toxic bloom occurrences.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **79** Avg. Daily Inflow *(cfs)* **10**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	**1.2**			**1.2**
Average Depth *(ft)*	**15.5**			**15.5**
Volume *(billion cu ft)*	**0.5**			**0.5**

A small, highly modified system consisting of the main bay, two smaller bay areas and smaller channels. Water conditions are highly governed by the coastal water regime between the southern California mainland and the Channel Islands, the area called the Southern California Bight. High salinities persist throughout the system. Waters within the bay are influenced by solar heating and storm runoff. Tides range approximately 4 ft.

Algal Conditions

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

Highest turbidity occurs episodically October to March. Nuisance *Gonyaulax polyhedra* and *Gymnodinium* spp. occurs episodically June to August.

Nutrients

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

Phosphorus reported as total phosphorus. Highest nitrogen and phosphorus concentrations occur October to March.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater	
SAV			VL	?

Primary productivity dominated by benthic in Anaheim and Bolsa Bays, and by pelagic in Huntington Harbor (shift from benthic) and the turning basin. Benthic community dominated by annelids. Intertidal wetland coverage is medium with low magnitude decrease attributed to marinas.

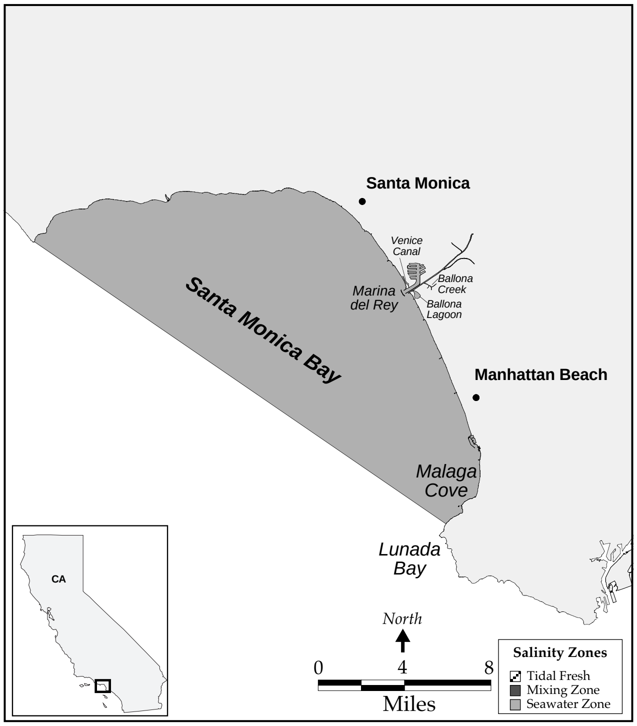
Dissolved Oxygen

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

Biological stress in bottom waters observed episodically with storms October to March.

Key on page 23

Santa Monica Bay



In Santa Monica Bay, nuisance and toxic blooms occur. There is no SAV in Ballona Creek. Information for all other parameters is unknown.

Trends for all parameters are unknown, except for SAV coverage in Ballona Creek, which is unchanged.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **565** Avg. Daily Inflow *(cfs)* **900**

	Estuary	TF	Mixing	Seawater	
				Ballona Creek	In General
Surface Area *(mi^2)*	**203.1**			**0.1**	**203.0**
Average Depth *(ft)*	**313.5**			n/a	n/a
Volume *(billion cu ft)*	**1800**			n/a	n/a

A broad, relatively shallow, unprotected bay consisting of the main bay, Marina del Rey, Ballona Creek, and Venice Canal. The entire system is bounded by submarine canyons to the north and south. Water conditions are highly governed by the coastal water regime between the southern California mainland and the Channel Islands. The warmer ocean waters from the south are generally of higher salinity than waters to the north. Tides range approximately 4 ft.

Algal Conditions

	Tidal Fresh	Mixing	Seawater			
			Ballona Creek		In General	
Chlorophyll a			?	?	?	?
Turbidity			?	?	?	?
Nuisance Algae			?	?	Y	?
Toxic Algae			?	?	Y	?

Nuisance *Gonyaulax polyedra* occurs throughout year. *Prorocentrum micans*, *Chaetoceros* spp., *Gymnodinium splendens*, and *Skeletonema costatum* also are observed. Toxic *Alexandrium catenella* occurs at highest abundance in August and *Pseudo-nitzschia* spp. occur infrequently throughout year.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater			
			Ballona Creek		In General	
SAV			NS	- - -	?	?

Primary productivity in Ballona Creek is benthic. Benthic community dominated by mollusks. Intertidal wetland coverage is medium in Ballona Creek with a decrease due to development and flood control structures.

Nutrients

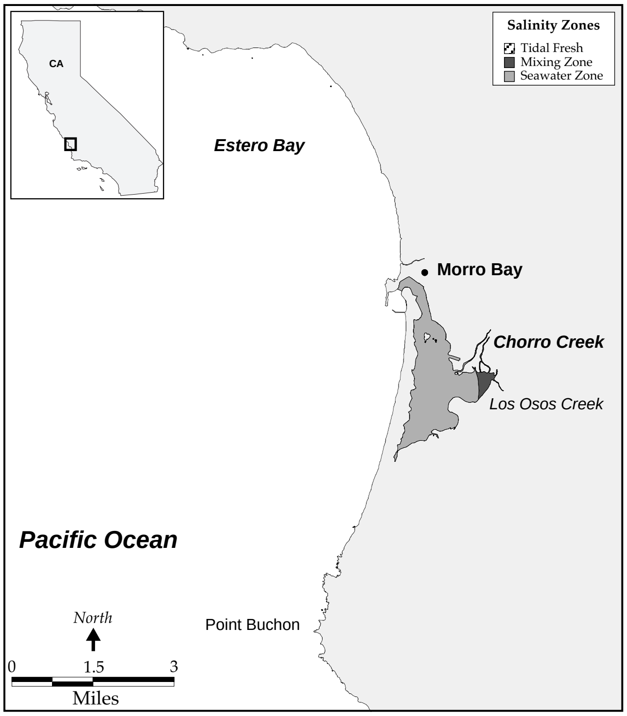
	Tidal Fresh	Mixing	Seawater			
			Ballona Creeek		In General	
Nitrogen			?	?	?	?
Phosphorus			?	?	?	?

Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater			
			Ballona Creek		in General	
Anoxia			?	?	?	?
Hypoxia			?	?	?	?
Bio. Stress			?	?	?	?

Key on page 23

Morro Bay



In Morro Bay, chlorophyll *a* concentrations are unknown, turbidity is high, and nuisance and toxic blooms occur in the seawater zone. Nitrogen concentrations are high and phosphorus ranges from low to high. Biological stress is observed, but anoxia and hypoxia are not. SAV coverage ranges from none to low.

Trends for chlorophyll *a* are unknown. There were no changes in turbidity concentrations or nuisance and toxic bloom occurrences. Nitrogen and phosphorus concentrations have increased; trends for anoxia and hypoxia were unknown. SAV coverage has decreased in the seawater zone.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **93** Avg. Daily Inflow *(cfs)* **34**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	3.2		0.2	3.0
Average Depth *(ft)*	2.6		2.0	2.6
Volume *(billion cu ft)*	0.2		0.01	0.2

A shallow lagoon sheltered by a long sand spit which forms a bar across the lagoon mouth. The bay contains extensive mudflats and is partially filled with sand off the bar. Freshwater inflow is from two streams, the Chorro and Los Osos creeks. Tidal range is 2.5 ft within the bay and salinities are fairly uniform.

Algal Conditions

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

Highest turbidity occurs periodically December to February. Unknown nuisance species speculated to occur periodically June to October, and unknown toxic species occurs periodically April to October. Nuisance Prorocentrum micans, Chaetoceros spp., *Gymnodinium splendens*, *Gonyaulax polyedra*, *Ceratium fuca*, and *Skeletonema costatum* all observed. Toxic *Pseudo-nitzschia* spp. occur throughout year with highest abundance August to September, and *Alexandrium catenella* occurs infrequently throughout year. Resource impacts from macroalgal species *ulva* and *enteromorpha* occur June to October.

Ecosystem/Community Responses

	Tidal Fresh	Mixing		Seawater	
SAV		NS	?	L	↓

Primary productivity dominated by benthic community. Pelagic community is diverse; benthic community dominated by annelids. Intertidal wetland coverage is high in mixing zone, and very low in seawater zone. Decrease in SAV and increase in intertidal wetlands associated with sediment load.

Nutrients

	Tidal Fresh	Mixing		Seawater	
Nitrogen		H 25-50%	↑*	H 10-25%	↑*
Phosphorus		H 25-50%	↑*	L	?

High nitrogen and phosphorus concentrations occur all year. Increase in nitrogen and phosphorus in mixing zone attributed to point and/or non-point sources.

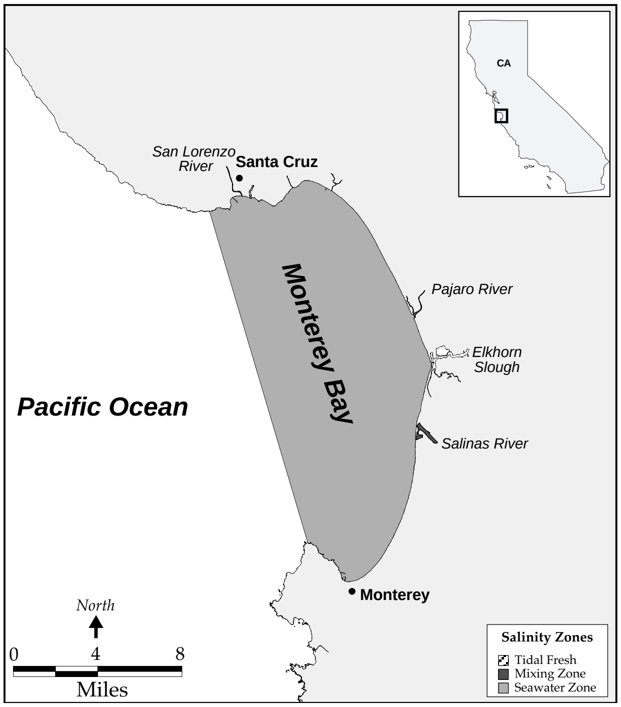
Dissolved Oxygen

	Tidal Fresh	Mixing		Seawater	
Anoxia		N	?	N	?
Hypoxia		N	?	?	?
Bio. Stress		Y 50-100%	?	Y 25-50%	?

Bottom-water biological stress observed periodically June to October in mixing zone and speculatively in seawater zone, attributed to blooms of *ulva* and *enteromorpha*.

Key on page 23

Monterey Bay



In Monterey Bay, chlorophyll *a* concentrations range from low to medium and turbidity ranges from low to high. Nuisance and toxic blooms occur. Nitrogen concentrations range from medium to high and phosphorus from low to high. Anoxia, hypoxia, and biological stress are observed in the mixing zone. SAV coverage ranges from very low to low.

Most parameters have remained unchanged. Nuisance bloom occurrence and nitrogen and phosphorus concentrations have increased, but only in the mixing zone.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **5,317** Avg. Daily Inflow *(cfs)* **1,200**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	224.1		0.6	223.5
Average Depth *(ft)*	257.3		10.2	257.3
Volume *(billion cu ft)*	1607.6		0.02	1603.3

A large, deep system consisting of the main bay and Monterey Canyon, directly offshore. The close proximity of deep, cold water from the coast allows tidal mixing and promotes upwelling of water at the head of the canyon. A fairly uniform salinity structure exists throughout the bay. Tidal range is 3.5 ft near Point Santa Cruz.

Algal Conditions

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

In mixing zone, Chl-*a* occurs periodically March to November with limiting factor of light. Highest turbidity occurs periodically November to February. Nuisance Prorocentrum micans, Gymnodinium splendens, *Gonyaulax polyedra*, *Ceratium fuca*, *Chaetoceros* spp., and *Skeletonema costatum* all observed. Toxic *Pseudo-nitzschi*a spp. and *Alexandrium catenella* occur periodically throughout year with highest abundance of *Pseudo-nitzschi*a August to September and of *Alexandrium catenella* in early spring. Increase in nuisance bloom associated with non-point sources.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV			VL	?	L	---

Primary productivity speculated to be diverse in mixing zone and dominated by pelagic community in seawater zone. Pelagic community speculatively dominated by diatoms; benthic community is diverse in seawater zone. Intertidal wetland coverage is medium in mixing zone with an increase due to mitigation, and very low in seawater zone.

Nutrients

	Tidal Fresh		Mixing		Seawater	
Nitrogen			H 50-100%	↑	M 50-100%	---
Phosphorus			H 25-50%	↑ ? *	L	---

Highest nitrogen concentrations occur all year in mixing zone and March to August in seawater zone. High phosphorus concentration occurs November to February. Increase in nitrogen and phosphorus in mixing zone attributed to non-point sources.

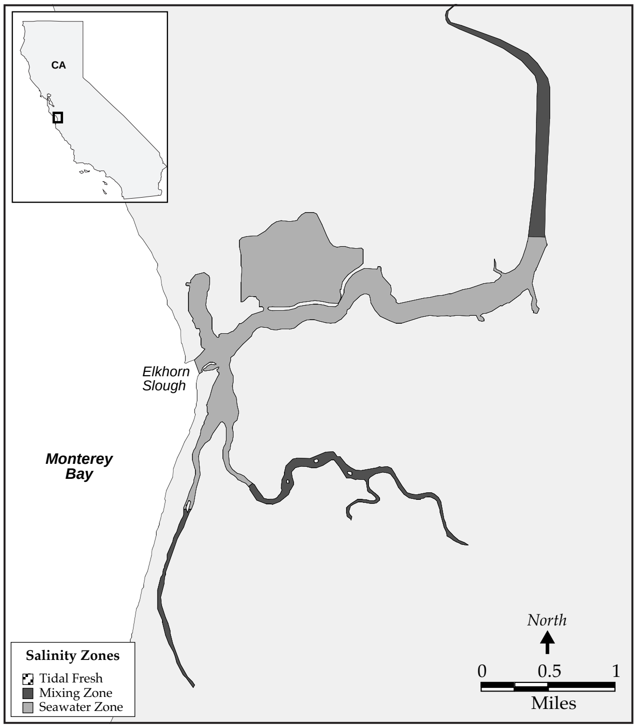
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia			Y 10-25%	---	N	---
Hypoxia			Y 10-25%	---	N	---
Bio. Stress			Y 50-100%	↑	N	---

Anoxia (throughout water column) and hypoxia (in bottom waters) observed episodically August to October. An increase in biological stress in mixing zone attributed to temperature change and non-point sources, and decrease in duration of anoxic and hypoxic events attributed to changes in hydrology.

Key on page 23

Elkhorn Slough



In Elkhorn Slough, chlorophyll *a* concentrations range from high to hypereutrophic, and turbidity is high. Nuisance and toxic blooms occur in the seawater zone. Nitrogen concentrations are high and phosphorus ranges from medium to high. Hypoxia is observed in the seawater zon,e and biological stress occurs throughout the system. SAV spatial coverage ranges from very low to low.

There were no changes in turbidity concentrations or nuisance and toxic bloom events. Chlorophyll *a*, nitrogen, and phosphorus concentrations, and SAV spatial coverage, have increased. Anoxia decreased in both zones and hypoxia decreased in the mixing zone.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **305** Avg. Daily Inflow *(cfs)* **133**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	1.2		0.2	1.0
Average Depth *(ft)*	8.0		7.5	8.1
Volume *(billion cu ft)*	0.3		0.04	0.2

A wide slough system and marshland located in a U-shaped valley cut into up-raised coastal terraces. The head of the slough receives freshwater from an intermittent stream which meanders through its valley to the mouth of Monterey Bay. Broad tidal mudflats are located at the mouth. Salinity structure is determined primarily by oceanic influences. Tidal range is 3.5 ft near the estuary mouth.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyll *a*			H 50-100%	↑ *	E 0-10%	↑
Turbidity			H 50-100%	---	H 50-100%	---
Nuisance Algae			N	--- *	Y	---
Toxic Algae			N	--- *	Y *	---

Chl-*a* blooms speculated to occur episodically throughout year with limiting factor of light, and increasing trend attributed to non-point sources. High turbidity occurs all year. Nuisance *P*rorocentrum micans, Gymnodinium splendens and *Chaetoceros* spp. all observed. Toxic *Pseudo-nitzschi*a spp. and *Alexandrium catenella* occur periodically throughout year with highest abundance for *Pseudo-nitzschi*a August to September and for *Alexandrium catenella* in early spring

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV			VL	---	L	⇧

Primary productivity speculatively dominated by pelagic in mixing zone (shift from diverse), and is diverse in seawater zone (shift from benthic). Pelagic community dominated by diatoms; benthic community by annelids (speculated mixing zone was diverse). SAV increase due to watershed alterations and non-point sources. Intertidal wetland coverage is medium with decreases reported due to dredging or watershed alterations.

Nutrients

	Tidal Fresh		Mixing		Seawater	
Nitrogen			H 25-50%	↑	H 10-25%	↑
Phosphorus			H 25-50%	↑	M 25-50%	↑

Highest nitrogen and phosphorus concentrations occur November to March, with increase attributed to non-point sources.

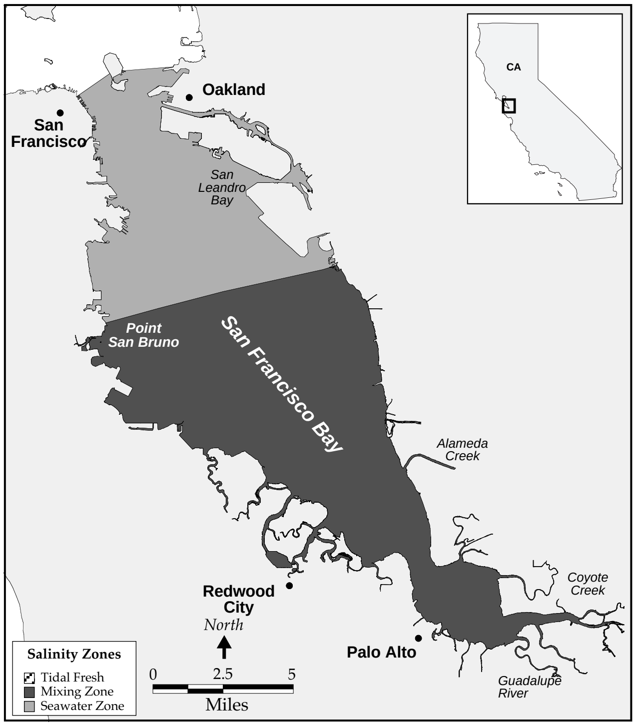
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia			N	↓	N	↓
Hypoxia			N	↓	Y 25-50%	---
Bio. Stress			Y 10-25%	⇧	Y 25-50%	---

Hypoxic events occur periodically June to October throughout water column. Decrease in duration, frequency, spatial coverage of anoxia and hypoxia (consequently, an increase in biological stress) attributed to changes in point sources.

Key on page 23

San Francisco Bay



In San Francisco Bay, chlorophyll *a* concentrations are hypereutrophic and turbidity ranges from medium to high. Nuisance blooms occur in the mixing zone. Nitrogen concentrations range from medium to high, and phosphorus is high. Anoxia, hypoxia, and biological stress are not observed. SAV coverage ranges from none to very low.

There were no changes in chlorophyll *a* concentrations, occurrences of nuisance or toxic blooms, or dissolved oxygen events. Turbidity, nitrogen, and phosphorus concentrations have decreased. SAV spatial coverage has also decreased.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **6,618** Avg. Daily Inflow *(cfs)* **37,036**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi^2)*	**195.6**		**67.6**	**127.5**
Average Depth *(ft)*	**20.9**		**11.5**	**21.7**
Volume *(billion cu ft)*	**113.8**		**21.6**	**77.0**

Consists of the main bay proper and several small tributaries. Freshwater inflow dominated by the Sacramento/San Joaquin Delta (90% of total inflow to bay). Forcing mechanisms such as tides, winds and density gradients are variable and are important for salinity structure and overall circulation. Wind and tides are more dominant in shallow areas of the bay. Tidal range is 4.6 ft near San Leandro Bay.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyll *a*			E 50-100%	- - -	E 50-100%	- - -
Turbidity			H 50-100%	↓	M 50-100%	↓
Nuisance Algae			N	- - -	Y	- - -
Toxic Algae			N	- - -	N	- - -

Chl-*a* blooms occur episodically between February and April with limiting factors speculated to be grazing and silica or nitrogen depletion. Elevated turbidity occurs throughout the year due to tidal and wind induced resuspension. Nuisance *Gymnodinium splendens* occur.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV			NS	↓	VL	↓

Primary productivity is diverse in mixing zone and dominated by pelagic community in seawater zone. Pelagic community is diverse; benthic community dominated by mollusks in mixing zone and is diverse in seawater zone. Decrease in SAV due to dredging in seawater zone and dredging and non-point sources in mixing zone. Intertidal wetland coverage is very low.

Nutrients

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

Highest nitrogen and phosphorus concentrations occur throughout the year with decrease associated with changes in point sources.

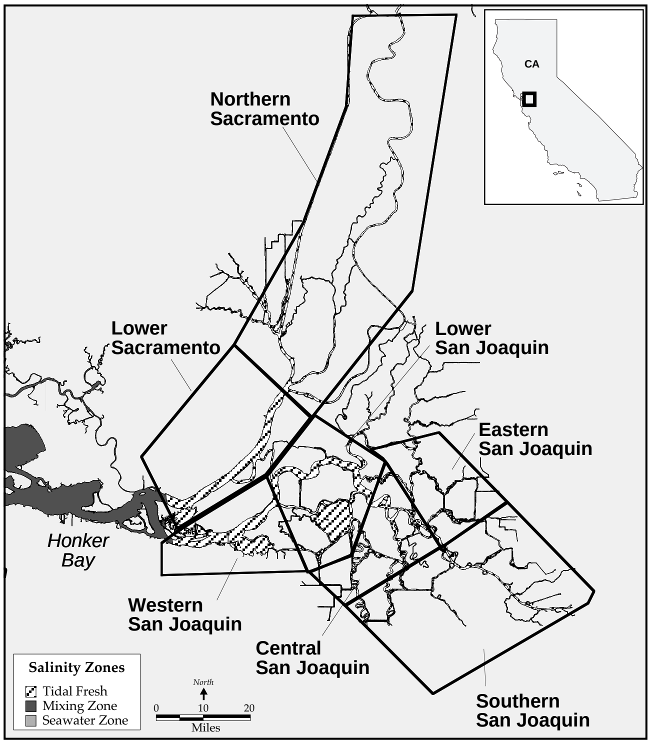
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia			N	- - -	N	- - -
Hypoxia			N	- - -	N	- - -
Bio. Stress			N	- - -	N	- - -

Periodic biological stress observed throughout the water column in 0-10 percent of tidal fresh zone

Key on page 23

North/Central San Francisco Bays: Tidal Fresh Zone



In the tidal fresh zone of the North/Central San Francisco Bay system, chlorophyll *a* concentrations range from high to hypereutrophic, and turbidity is high. Nuisance algal blooms occur in the San Joaquin River but toxic blooms do not occur. Nitrogen and phosphorus concentrations range from medium to high. Hypoxia and biological stress are observed in the southern San Joaquin River. SAV spatial coverage ranges from low to nonexistent.

Most chlorophyll *a* and turbidity concentrations, and occurrences of nuisance or toxic blooms, have decreased. Nitrogen and phosphorus concentrations have increased in most areas. Anoxia and hypoxia observations, and SAV spatial coverage, have not changed.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi²)* **4,596** Avg. Daily Inflow *(cfs)* **32,400**

	Estuary	Tidal Fresh: Sacramento River	Tidal Fresh: San Joaquin River	Mixing	Seawater
Surface Area *(mi²)*	319.7	18.6	39.2	see following page	
Average Depth *(ft)*	20.6	n/a	n/a		
Volume *(billion cu ft)*	183.6	n/a	n/a		

Consists of the Sacramento/San Joaquin delta and tributaries of Central San Francisco Bay.

Algal Conditions

Tidal Fresh

	Sacramento River: Northern	Sacramento River: Lower	San Joaquin River: Western	San Joaquin River: Lower	San Joaquin River: Central	San Joaquin River: Southern
Chlorophyll a	H ↓ 50-100%	H ↓ 50-100%	H ↓ 50-100%	E ↑ 25-50%	H ↓ 25-50%	E ↑ 50-100%
Turbidity	H ↓ 50-100%	H ↑ 50-100%	H ↓ 50-100%	H ↑ 50-100%	H ↓ 50-100%	H --- 50-100%
Nuisance Algae	N ---	N ---	N ↓	Y ↓	Y ↓	Y ↓
Toxic Algae	N ---	N ---	N ---	N ?	? ?	N ?

Chl-*a* blooms occur in the Lower Sacramento R., periodically March to November with grazing limiting; in N. Sacramento and E. San Joaquin R., episodically March to May with light limiting; in Lower San Joaquin R., episodically in September with light limiting; in S. San Joaquin R. episodically April to October with light limiting; and in W. San Joaquin R. periodically May to September with light & grazing limiting. Elevated turbidity observed throughout year. An unknown nuisance species observed in San Joaquin R. episodically April to October. Trends in Chl-*a*, nuisance, and toxic algae attributed to changes in non-point sources or hydrology.

Ecosystem/Community Responses

Tidal Fresh

	Sacramento River: Northern	Sacramento River: Lower	San Joaquin River: Western	San Joaquin River: Lower	San Joaquin River: Central	San Joaquin River: Southern
SAV	VL ---	NS ---	NS ---	L ---	L ---	L ↑

Primary productivity dominated by pelagic community. Pelagic community dominated by diatoms in Lower San Joaquin R. and was diatom dominated elsewhere but now is diverse. Benthic community dominated by annelids, except in Lower San Joaquin R. where arthropods dominate. Lower Sacramento R., and W. San Joaquin R. historically were arthropod-dominated, and Lower San Joaquin R. was annelid dominated. SAV increase in S. San Joaquin River due to hydrology changes and increased light. Intertidal wetlands are non-existent in tidal fresh zone.

Nutrients

Tidal Fresh

	Sacramento River: Northern	Sacramento River: Lower	San Joaquin River: Western	San Joaquin River: Lower	San Joaquin River: Central	San Joaquin River: Southern
Nitrogen	M ↑ 50-100%	H ↓ 50-100%	M ↑ 50-100%	H ↓ 50-100%	M ↑ 50-100%	H ↓ 50-100%
Phosphorus	M ↑ 50-100%	H ↓ 50-100%	M ↑ 50-100%	H ↓ 50-100%	M ↑ 50-100%	H ↓ 50-100%

Elevated nitrogen concentrations occur all year, except in West San Joaquin R., where they occur December to March. Elevated phosphorus concentrations occur all year except in East/South San Joaquin R., where they occur December to May. Nitrogen and phosphorus trends associated with changes in non-point sources and/or hydrology.

Dissolved Oxygen

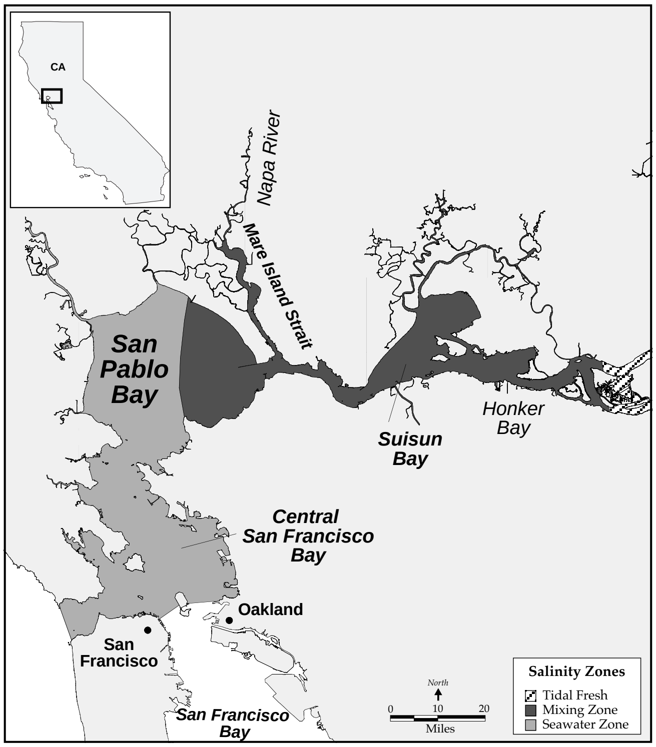
Tidal Fresh

	Sacramento River: Northern	Sacramento River: Lower	San Joaquin River: Western	San Joaquin River: Lower	San Joaquin River: Central	San Joaquin River: Southern
Anoxia	N ---	N ---	N ---	N ---	N ---	N ---
Hypoxia	N ---	N ---	N ---	N ---	N ---	Y --- 0-10%
Bio. Stress	N ---	N ---	N ---	N ---	N ---	Y --- 10-25%

In S. San Joaquin R., bottom-water hypoxic events observed periodically September to November, and biological stress periodically February to November throughout water column. Water column stratification is a highly significant factor.

Key on page 23

North/Central San Francisco Bays: Mixing & Seawater Zones



In the mixing and seawater zones of the North/Central San Francisco Bay system, chlorophyll *a* concentrations range from medium to hypereutrophic, and turbidity ranges from medium to high. Nuisance algal blooms occur in the tidal fresh and seawater zones; toxic blooms do not occur. Nitrogen and phosphorus concentrations range from medium to high. Hypoxia and biological stress are observed in the tidal fresh zone. SAV spatial coverage ranges from non-existent to low.

Most chlorophyll *a* and turbidity concentrations, and occurrences of nuisance or toxic blooms, have decreased. Nitrogen and phosphorus concentrations have increased in most areas. Anoxia and hypoxia observations, and SAV spatial coverage, have not changed.

Algal Conditions

	Mixing		Seawater	
	Suisun Bay	San Pablo Bay	San Pablo Bay	Central San Fran. Bay
Chlorophyll a	E 25-50% ↓	M 50-100% ↓	M 50-100% ↓	E 0-10% ---
Turbidity	H 50-100% ↓	H 50-100% ↓	H 50-100% ↓	M 50-100% ---
Nuisance Algae	N ---	N ---	N ---	Y ---
Toxic Algae	? ---	N ↓	N ↓	N ---

Chl-*a* blooms occur in Central San Fran. Bay episodically in April with silica speculated as limiting factor; in San Pablo Bay, periodically April to August with light & grazing limiting; and in Suisun Bay, episodically in July with light & grazing limiting. Elevated turbidity occurs all year. In Central San. Fran. Bay, nuisance *Mesodinium* spp. occurs episodically April to May and *Gymnodinium sanguineum* once in August. Chl-*a*, nuisance, and toxic algae trends attributed to changes in non-point sources or hydrology.

Ecosystem/Community Responses

	Mixing		Seawater	
	Suisun Bay	San Pablo Bay	San Pablo Bay	Central San Fran. Bay
SAV	L ---	L ---	L ---	VL ↓

Primary productivity dominated by pelagic community except in Suisun Bay, which was pelagic but now benthic. Pelagic community was diatom dominated but is now diverse. Benthic community dominated by mollusks in Suisun and San Pablo Bays and crustaceans and annelids in Central San. Fran. Bay. Suisun Bay was historically arthropod-dominated. The spatial coverage of intertidal wetlands is low in both salinity zones.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **4,596** Avg. Daily Inflow *(cfs)* **32,400**

	Estuary	Tidal Fresh	Mixing		Seawater	
			Suisun Bay	San Pablo Bay	San Pablo Bayl	Central SF Bay
Surface Area *(mi²)*	319.7	See Previous Page	67.7	37.2	60.4	96.6
Average Depth *(ft)*	20.6		n/a	n/a	n/a	n/a
Volume *(billion cu ft)*	183.6		n/a	n/a	n/a	n/a

Consists of Central San Francisco Bay, San Pablo Bay and several smaller embayments. Freshwater inflow dominated by the Sacramento/San Joaquin rivers. Forcing mechanisms such as tides, winds, and density gradients are important for salinity structure and overall circulation and are variable depending on season. Wind and tides are more dominant in shallow areas of the system. Tidal range is 3.5 ft within San Pablo Bay.

Nutrients

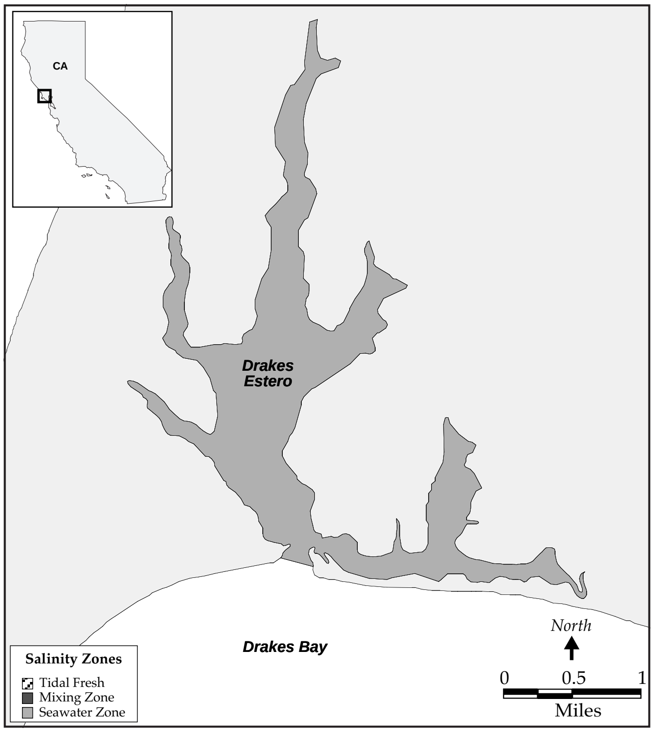
	Mixing		Seawater	
	Suisun Bay	San Pablo Bay	San Pablo Bay	Central San Fran. Bay
Nitrogen	H 0-10% ↑	M 50-100% ↑	M 50-100% ↑	M 50-100% ---
Phosphorus	M 25-50% ↑	M 50-100% ↑	M 50-100% ↑	M 50-100% ↑

Elevated nitrogen and phosphorus concentrations occur throughout year. Nitrogen and phosphorus trends associated with changes in non-point sources and/or hydrology.

Dissolved Oxygen

	Mixing		Seawater	
	Suisun Bay	San Pablo Bay	San Pablo Bay	Central San Fran. Bay
Anoxia	N ---	N ---	N ---	N ---
Hypoxia	N ---	N ---	N ---	N ---
Bio. Stress	N ---	N ?	N ?	N ?

Drakes Estero



In Drakes Estero, nuisance and toxic algal blooms are observed. All other parameters are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **30** Avg. Daily Inflow *(cfs)* **30**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	**3.8**			**3.8**
Average Depth *(ft)*	**2.5**			**2.5**
Volume *(billion cu ft)*	**0.3**			**0.3**

A semi- enclosed small, shallow system near Point Reyes, CA. Oceanic salinities persist throughout the system. Waters within the bay are influenced by solar heating and storm runoff.

Algal Conditions

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

Nuisance *Prorocentrum micans* and *Gymnodinium splendens* occur late summer to late fall, *Skeletonema costatum* most abundant during spring upwelling. *Chaetoceros* spp. also observed. Toxic *Alexandrium catenella* observed in highest abundance early spring, August and December and *Pseudo-nitzschi*a spp. in late spring and late summer .

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater
SAV			? ?

Nutrients

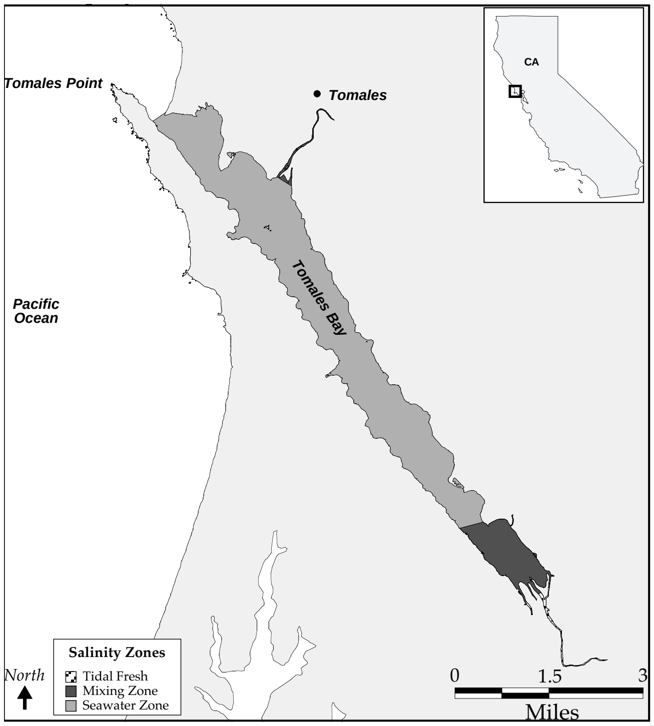
	Tidal Fresh	Mixing	Seawater
Nitrogen			? ?
Phosphorus			? ?

Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater
Anoxia			? ?
Hypoxia			? ?
Bio. Stress			? ?

Key on page 23

Tomales Bay



In Tomales Bay, chlorophyll *a* concentrations are unknown and turbidity concentrations range from low to medium. Nuisance and toxic algal blooms occur. Concentrations of nitrogen and phosphorus, and observations of hypoxia or anoxia, are unknown. Biological stress is not observed. SAV spatial coverage ranges from low to medium.

Spatial coverage of SAV has not changed. All other trends are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **233** Avg. Daily Inflow *(cfs)* **260**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	11.4	0.1	1.4	9.9
Average Depth *(ft)*	5.6	1.0	1.0	6.1
Volume *(billion cu ft)*	1.8	0.03	0.04	1.7

A long , narrow system. Freshwater input is highly seasonal, with the wet season occurring between October and March. Evaporation is highest in June and September. Extreme seasonality of both freshwater input and system salinity is apparent within the estuary. Tides range approximately 4.2 ft within the bay.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyll a			?	?	?	?
Turbidity			M ?	?	L	?
Nuisance Algae			Y	?	Y	?
Toxic Algae			Y	?	Y	?

Nuisance *Prorocentrum micans* and *Gymnodinium splendens* most abundant during late summer to fall, *Skeletonema costatum* occur during spring upwelling. *Chaetoceros* spp. and *Scrippsiella* spp. also observed. Toxic *Alexandrium catenella* and *Pseudo-nitzschia* spp. occur periodically throughout year but *Alexandrium* observed in highest abundance July to August and December and *Pseudo-nitzschia* in spring and late summer.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV			L	– – –	M*	– – –

Pelagic community dominated by diatoms; benthic community dominated by crustaceans in mixing zone and mollusks in seawater zone.

Nutrients

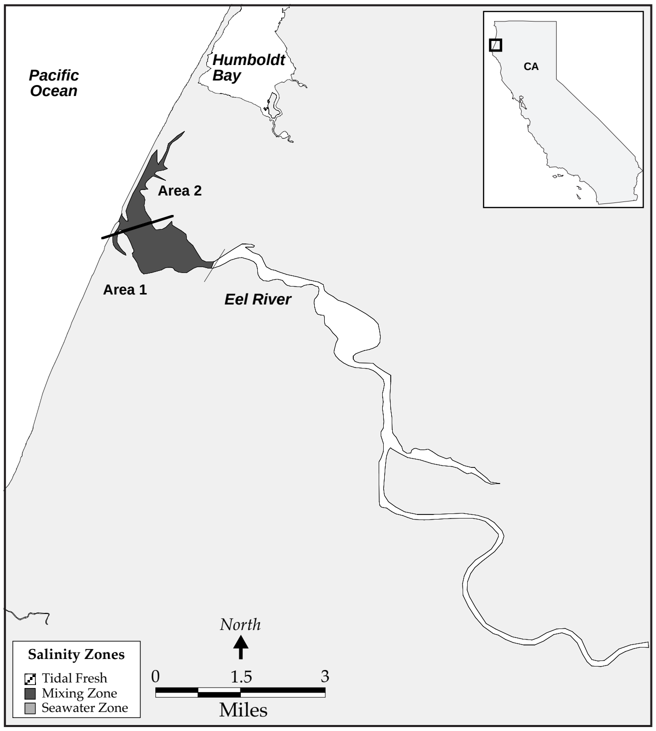
	Tidal Fresh		Mixing		Seawater	
Nitrogen			?	?	?	?
Phosphorus			?	?	?	?

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia			?	?	?	?
Hypoxia			?	?	?	?
Bio. Stress			N	?	N	?

Key on page 23

Eel River



In Eel River, chlorophyll *a* concentrations are low and turbidity ranges from medium to high. Nuisance or toxic algal blooms do not occur. Concentrations of nitrogen and phosphorus are low. Anoxia, hypoxia and biological stress are not observed in this system. SAV also is not present.

All trends for this system are reported as stable, except changes in anoxia and hypoxia, which are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **1,503** Avg. Daily Inflow *(cfs)* **9,700**

	Estuary	TF	Mixing Area 1	Mixing Area 2	SW
Surface Area *(mi²)*	7.0		1.1	2.7	3.2
Average Depth *(ft)*	5.4		n/a	n/a	5.4
Volume *(billion cu ft)*	1.1		n/a	n/a	0.5

The Eel River delta rests upon a valley, the Eel River syncline, filled with thousands of feet of sediment. The watershed is composed of a steeply eroded terrain that has been heavily logged in past 80 years. Reduced tidal prisms and impaired sediment flushing potential are consequences of significant winter discharges. Is highly stratified during high flow period. Tidal range is 4.4 ft near the river mouth.

Algal Conditions

	Tidal Fresh	Mixing Area 1		Mixing Area 2		Seawater
Chlorophyll a		L	- - -	L	- - -	
Turbidity		M 50-100%	- - -	H 50-100%	- - -	
Nuisance Algae		N	- - -	N	- - -	
Toxic Algae		N	- - -	N	- - -	

Turbidity occurs periodically June to October.

Ecosystem/Community Responses

	Tidal Fresh	Mixing Area 1		Mixing Area 2		Seawater
SAV		NS	- - -	NS	- - -	

Primary productivity dominated by pelagic community in Area 1 and is diverse in Area 2. Pelagic community dominated by diatoms; benthic community dominated by crustaceans. Intertidal wetland coverage is very low in Area 1 and medium in Area 2, with low magnitude increases due to reclamation.

Nutrients

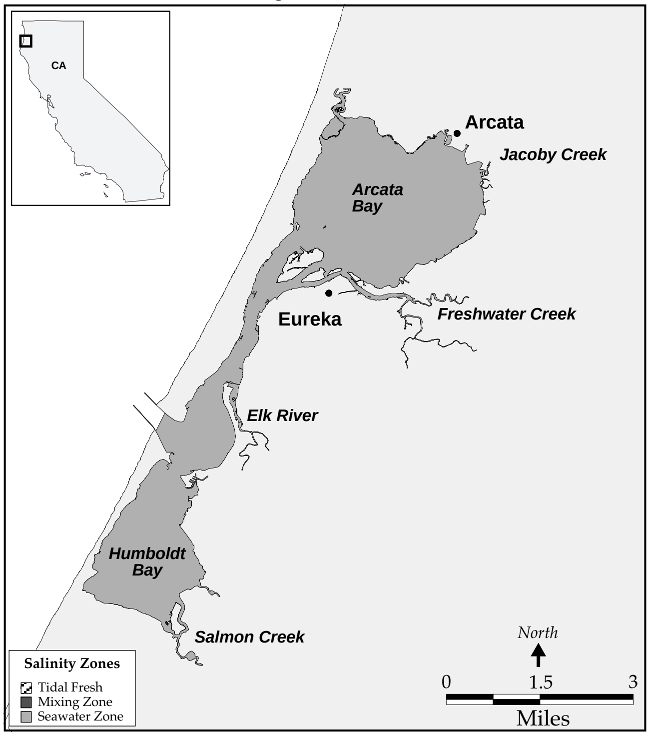
	Tidal Fresh	Mixing Area 1		Mixing Area 2		Seawater
Nitrogen		L	- - -	L	- - -	
Phosphorus		L	- - -	L	- - -	

Dissolved Oxygen

	Tidal Fresh	Mixing Area 1		Mixing Area 2		Seawater
Anoxia		N	?	N	?	
Hypoxia		N	?	N	?	
Bio. Stress		N	?	N	?	

 Key on page 23

Humbolt Bay



In Humbolt Bay, chlorophyll *a* concentrations are low and turbidity is high. Nuisance and toxic blooms occur. Concentrations of nitrogen and phosphorus are low. Anoxia, hypoxia, and biological stress are not observed in this system. SAV spatial coverage is low.

Concentrations of chlorophyll *a* and turbidity, occurrences of nuisance algal blooms, and SAV spatial coverage have all remained the same. Nitrogen and phosphorus concentrations have decreased; dissolved oxygen trends are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **223** Avg. Daily Inflow *(cfs)* **700**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi^2)*	25.2			25.2
Average Depth *(ft)*	11.1			11.1
Volume *(billion cu ft)*	7.8			7.8

A bar-built estuary consisting of South Bay, Entrance Bay and Arcata Bay. Both South and Arcata Bays consist of extensive mud flats interspersed with drainage channels. Entrance Bay is a relatively narrow and deeper bay than other two. Within Arcata and South Bay mixing is limited while Entrance Bay water is well-mixed. Circulation is predominantly tidally driven. Tidal range is 5.5 ft near North Spit.

Algal Conditions

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

High turbidity can occur any time during the year. Nuisance *Chaetoceros* spp. and *Skeletonema costatum* occur all year. Toxic *Pseudo-nitzschia* spp. occur early spring and late fall and *Alexandrium catenella* occur early spring and late summer.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater
SAV			L / - - -

Primary productivity is diverse. Pelagic community dominated by diatoms; benthic community is diverse. Intertidal wetland coverage is low with a high magnitude increase from restoration.

Nutrients

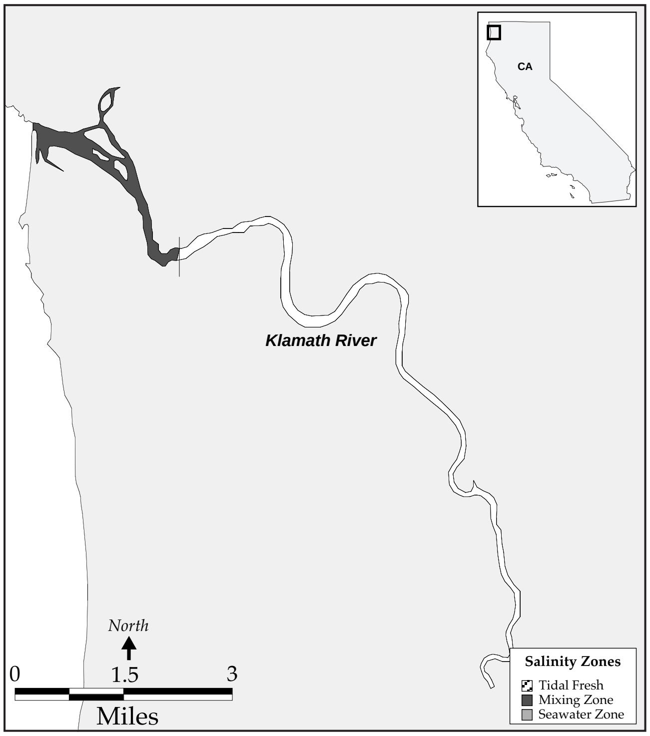
	Tidal Fresh	Mixing	Seawater
Nitrogen			L / ↓ *
Phosphorus			L / ↓ *

Decrease in nitrogen and phosphorus attributed to changes in point sources.

Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater
Anoxia			N / ?
Hypoxia			N / ?
Bio. Stress			N / ?

Klamath River



In Klamath River, chlorophyll *a* concentrations are low and turbidity is medium. Nuisance or toxic algal blooms do not occur. Concentrations of nitrogen and phosphorus are low. Anoxia, hypoxia, and biological stress are not observed in this system. SAV spatial coverage is medium.

All trends for this system are reported as stable, except changes in anoxia and hypoxia, which are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **1,541** Avg. Daily Inflow *(cfs)* **n/a**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	**1.0**		**1.0**	
Average Depth *(ft)*	**22.8**		**22.8**	
Volume *(billion cu ft)*	**0.6**		**0.6**	

The Klamath River estuary has distinctive outflow differences between summer and winter. When snowmelt ends, flow rates diminish to where no tidal exchange exists and a lagoon forms. When runoff dominates in winter, the estuary is thoroughly flushed. The estuary exhibits vertically stratified conditions.

Algal Conditions

	Tidal Fresh	Mixing	Seawater
Chlorophyll a		L / - - -	
Turbidity		M ? / - - -	
Nuisance Algae		N / - - -	
Toxic Algae		N / - - -	

Turbidity occurs episodically November to February.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater
SAV		M / - - -	

Benthic community dominated by crustaceans.

Nutrients

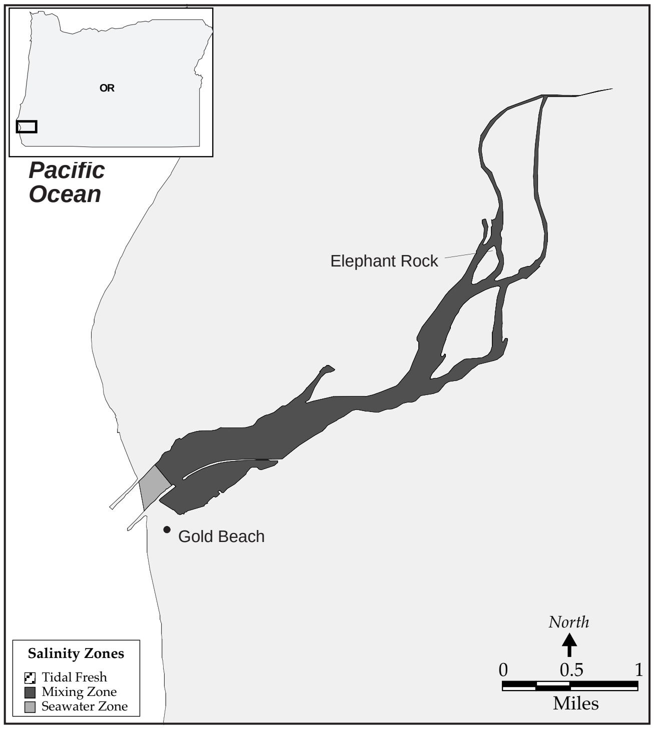
	Tidal Fresh	Mixing	Seawater
Nitrogen		L / - - -	
Phosphorus		L / - - -	

Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater
Anoxia		N / ?	
Hypoxia		N / ?	
Bio. Stress		N / ?	

Key on page 23

Rogue River



In Rogue River, all information on algal conditions is unknown. Concentrations of nitrogen are medium in the mixing zone, and phosphorus concentrations are unknown. There are no observations of anoxia, hypoxia, or biological stress in this system. SAV spatial coverage is low in the seawater zone.

SAV spatial coverage has decreased in the seawater zone. All other trends are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **904** Avg. Daily Inflow *(cfs)* **10,561**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	**1.0**		**0.9**	**0.1**
Average Depth *(ft)*	**10.9**		**12.0**	**4.0**
Volume *(billion cu ft)*	**0.3**		**0.3**	**0.01**

A small estuary with a large drainage area. Lacks tidal flats and marshes. Seasonal variations in freshwater inflow strongly influence the characteristics and processes of the estuary. Salinity stratification is generally high, especially in winter. Structure is dependent on river flow, tides and formation of sand spit near the mouth. Tidal range is 4.9 ft at the mouth of the River.

Algal Conditions

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

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV			?	?	L	↓

Benthic community dominated by epiphytes on gravel in seawater zone. SAV decrease associated with non-point sources. Intertidal wetland coverage is very low in mixing zone.

Nutrients

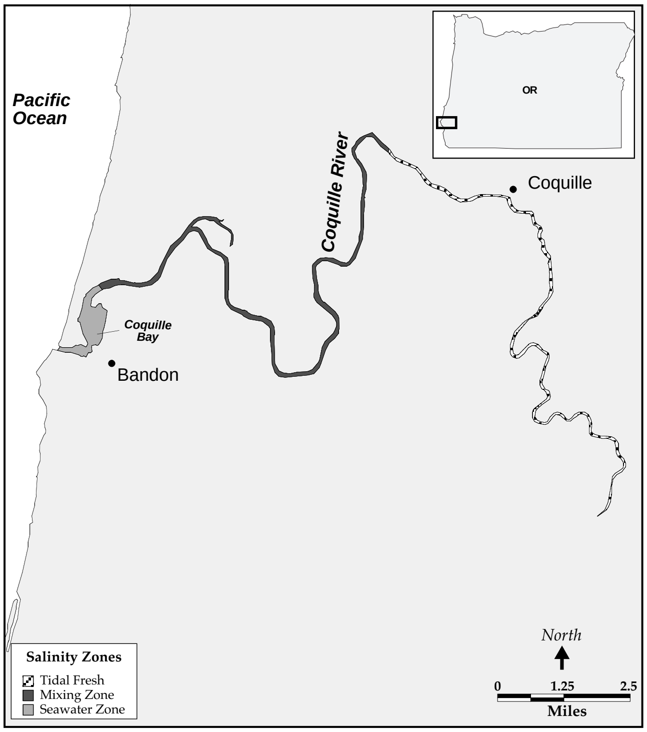
	Tidal Fresh		Mixing		Seawater	
Nitrogen			M ?	?	?	?
Phosphorus			?	?	?	?

Nitrogen reported as total inorganic nitrogen. Highest concentrations occur July to September.

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia			N	?	N	?
Hypoxia			N	?	N	?
Bio. Stress			N	?	N	?

Coquille River



In Coquille River, chlorophyll *a* concentrations are high in the seawater zone, and turbidity is high in all zones. Nuisance or toxic bloom events are unknown. Concentrations of nitrogen and phosphorus are medium. There are no observations of anoxia, hypoxia, or biological stress. SAV spatial coverage is very low.

Chlorophyll *a* and dissolved oxygen concentrations, and SAV spatial coverage, have all remained the same. Turbidity concentrations have declined. All other trends are unknown.

Physical and Hydrologic Characteristics

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

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi^2)*	3.6	1.0	1.8	0.8
Average Depth *(ft)*	n/a	n/a	n/a	n/a
Volume *(billion cu ft)*	n/a	n/a	n/a	n/a

A long, narrow estuary among the smallest in Oregon. The estuary is fully exposed to waves and tidal influences at the the mouth. Tidal influence can be felt 36 to 40 miles upstream. Salinity stratification occurs, especially during winter months. Tidal range is 5.2 ft near the river mouth.

Algal Conditions

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

In seawater zone, Chl-*a* blooms occur periodically April to October. Elevated turbidity occurs throughout the year.

Ecosystem/Community Responses

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

Pelagic community dominated by diatoms in the seawater zone. Benthic community is diverse in the seawater zone.

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%*	?

Nitrogen concentrations occur July to December in tidal fresh and mixing zones and speculatively June to August in seawater zone. Phosphorus concentrations occur July to December in tidal fresh and mixing and speculatively June to August in the seawater zone.

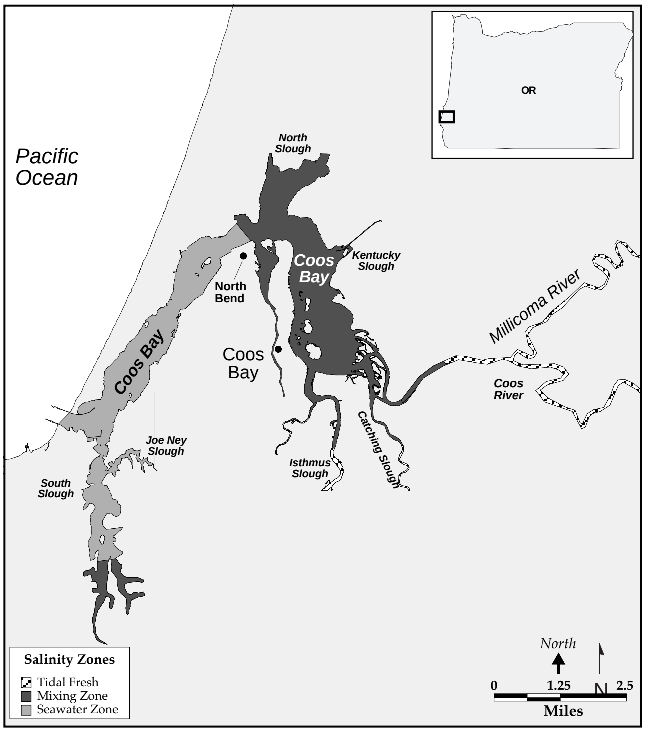
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	N	---	N	---	N	---
Hypoxia	N	---	N	---	N	---
Bio. Stress	N	---	N	---	N	---

D.O. trends reported for 1970 -1991.

Key on page 23

Coos Bay



In Coos Bay, chlorophyll *a* concentrations are high in the seawater zone, and turbidity is high in the mixing and seawater zones. Nuisance or toxic bloom events are unknown. In the seawater zone, nitrogen concentrations are medium and phosphorus concentrations are high. Anoxia, hypoxia, and biological stress are not observed in this system. SAV spatial coverage ranges from very low to low.

Dissolved oxygen observations and SAV spatial coverage have not changed. All other trends are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **588** Avg. Daily Inflow *(cfs)* **2,900**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	18.3	0.2	10.4	7.7
Average Depth *(ft)*	14.2	10.0	14.6	11.5
Volume *(billion cu ft)*	7.3	0.06	4.2	2.5

A drowned river valley estuary consisting of Coos Bay and several tributaries. Extensive filling and diking in the main bays and sloughs have changed the form of the estuary. The estuary is considered well mixed for almost all months of the year. Receives majority of freshwater inflow from the Coos River. Tidal range is 5.7 ft near the mouth of the estuary.

Algal Conditions

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

In seawater zone, Chl-*a* blooms occur periodically April to June with nitrogen limiting. High turbidity occurs throughout the year.

Ecosystem/Community Responses

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

Primary productivity dominated by pelagic community. Pelagic community dominated by diatoms in mixing and seawater zones; benthic community dominated by annelids in mixing zone and is diverse in seawater zone. Intertidal wetland coverage is high in tidal fresh zone and medium in mixing and seawater zones, with low magnitude decreases due to development.

Nutrients

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

Nitrogen reported as total inorganic nitrogen and phosphorus reported as total phosphorus. Highest concentrations for both parameters occur April to June.

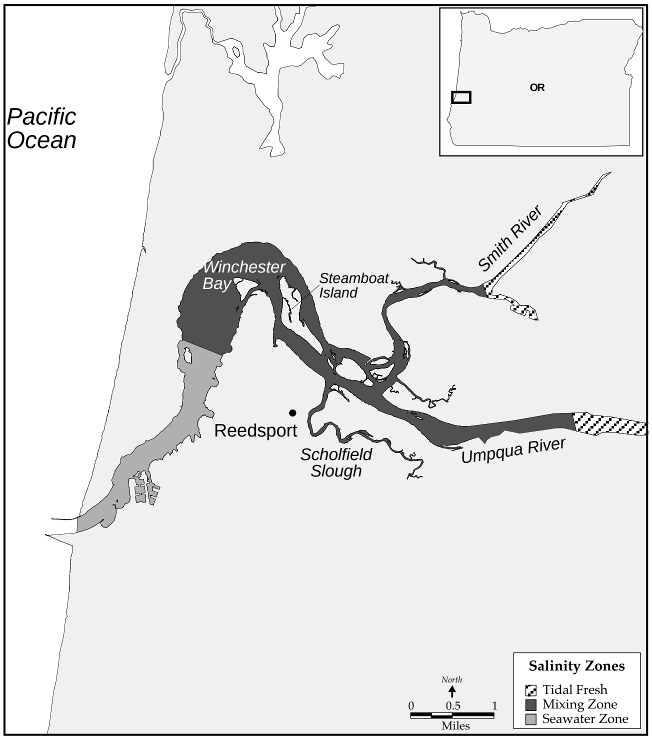
Dissolved Oxygen

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

D.O. trends reported for 1970-1984.

Key on page 23

Umpqua River



In Umpqua River, chlorophyll *a* concentrations are high in the seawater zone and turbidity concentrations are unknown. Nuisance or toxic bloom events are unknown, as are nitrogen and phosphorus concentrations. Anoxia, hypoxia, and biological stress are not observed in this system. SAV spatial coverage ranges from very low to low.

Observations of anoxia, hypoxia, and biological stress have not changed. All other trends are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **1,509** Avg. Daily Inflow *(cfs)* **9,300**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi^2)*	9.3	0.6	6.4	2.3
Average Depth *(ft)*	13.5	12.6	13.8	9.7
Volume *(billion cu ft)*	3.5	0.21	2.5	0.6

A large and moderately deep estuary. Depth to width ratios are high and are accentuated by dredged navigation channels. Seasonal and daily variation in freshwater flow is most significant factor in affecting the salinity structure. Umpqua Bay is classified as two-layered during high flow, partially-mixed during low flow. Mean tidal range is 5.1 ft near the entrance to the river.

Algal Conditions

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

Nutrients

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

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	?	?	L	?	VL	?

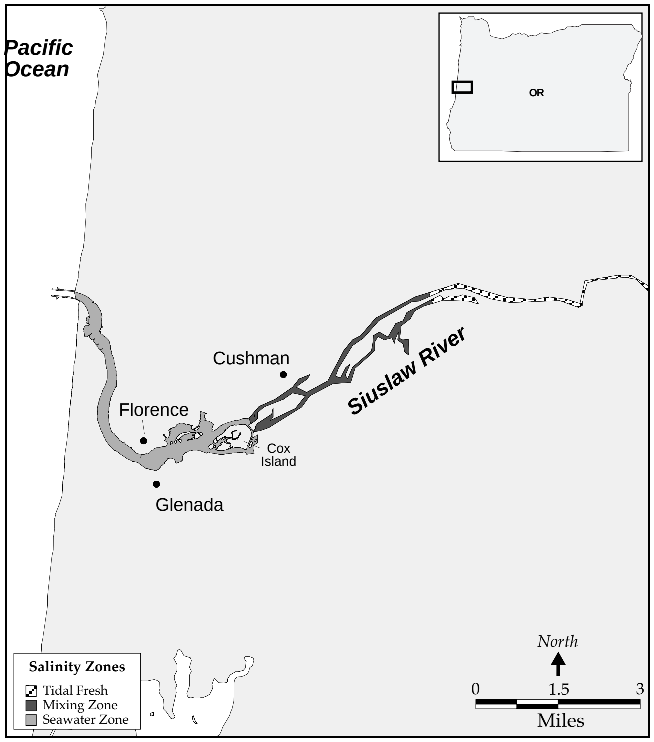
Benthic community is diverse in mixing and seawater zones. Intertidal wetland coverage is very low in tidal fresh zone, medium in mixing zone, and low in seawater zone.

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	N	---	N	---	N	---
Hypoxia	N	---	N	---	N	---
Bio. Stress	N	---	N	---	N	---

Key on page 23

Siuslaw River



In Siuslaw River, chlorophyll *a* concentrations are high in the seawater zone and turbidity concentrations are unknown. Nuisance or toxic bloom events are unknown, as are nitrogen and phosphorus concentrations. Biological stress is observed in this system, but anoxia and hypoxia arenot. SAV spatial coverage ranges from very low to low.

SAV spatial coverage has not changed. All other trends are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* 776 Avg. Daily Inflow *(cfs)* 3,013

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	3.7	0.5	1.0	2.2
Average Depth *(ft)*	9.3	6.0	9.2	11.6
Volume *(billion cu ft)*	1.0	0.08	0.3	0.7

A riverine-type estuary consisting of the main channel of the Siuslaw River. Seasonal and daily variation in freshwater flow is the most significant factor affecting salinity structure. The degree of mixing can vary from completely mixed (October) to an almost fully stratified system (January and May). Mean tidal range is 5.5 ft near the entrance to Siuslaw River.

Algal Conditions

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

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	?	?	L	– – –	VL	– – –

Pelagic community dominated by diatoms in seawater zone; benthic community is diverse in mixing and seawater zones. Intertidal wetland coverage is very low in tidal fresh zone, medium in mixing zone, and low in seawater zone.

Nutrients

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

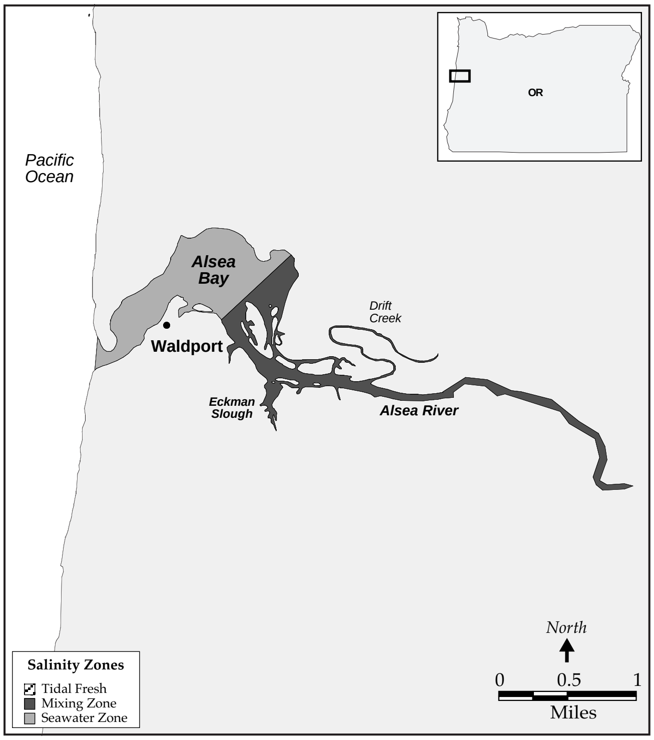
Dissolved Oxygen

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

Periodic biological stress observed during summer in mixing zone.

Key on page 23

Alsea River



In Alsea River, chlorophyll *a* concentrations are high in the seawater zone and turbidity concentrations are unknown. Nuisance or toxic bloom events are unknown, as are nitrogen and phosphorus concentrations. Anoxia, hypoxia and biological stress are not observed in this system. SAV spatial coverage ranges from low to medium.

Dissolved oxygen observations and SAV spatial coverage have not changed. All other trends are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **483** Avg. Daily Inflow *(cfs)* **2,250**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	3.6		1.6	2.0
Average Depth *(ft)*	6.6		9.7	4.3
Volume *(billion cu ft)*	0.7		0.4	0.2

A shallow estuary consisting of Alsea Bay and several tidal creeks. The estuary is usually stratified during the winter and well mixed during the summer. Seasonal and daily variation in freshwater flow is the most significant factor affecting the salinity structure. Mean tidal range is 5.8 ft near the entrance to Alsea Bay.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyll *a*			?	?	H* (?)	?
Turbidity			?	?	?	?
Nuisance Algae			?	?	?	?
Toxic Algae			?	?	?	?

Nutrients

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

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia			N	– – –	N	– – –
Hypoxia			N	– – –	N	– – –
Bio. Stress			N	– – –	N	– – –

D.O. trends reported for 1970-1983.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV			M	– – –	L	– – –

Pelagic community dominated by diatoms in seawater zone; benthic community is diverse with crustaceans dominating. Intertidal wetland spatial coverage is unknown, but decreases have been reported due to development.

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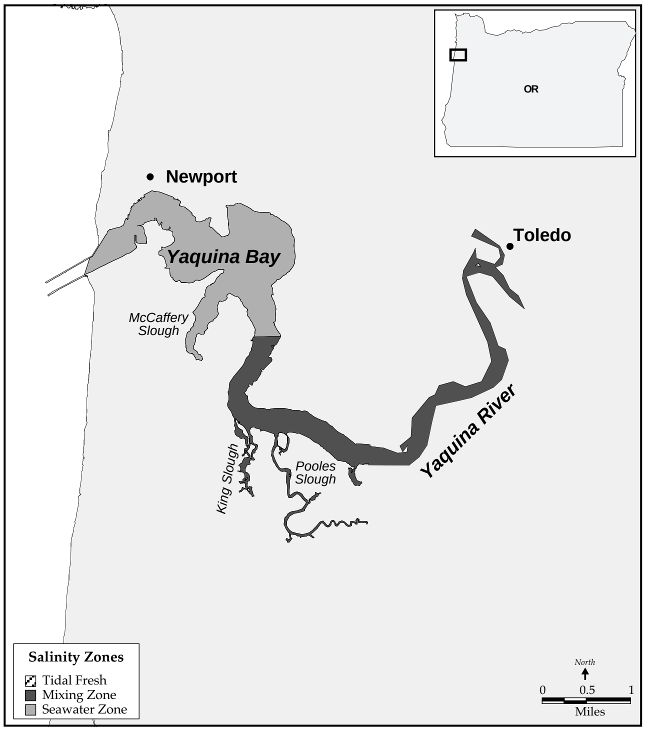
Yaquina Bay



In Yaquina Bay, chlorophyll *a* and turbidity concentrations are medium. Nuisance andtoxic algal bloom events are not observed. Concentrations of nitrogen and phosphorus are medium. Biological stress is observed in the system but not anoxia or hypoxia. SAV spatial coverage is low.

Chlorophyll *a*, turbidity, nitrogen, and phosphorus concentrations have remained unchanged. Anoxia and hypoxia observations and SAV spatial coverage have also remained the same. Nuisance and toxic bloom trends are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area (*mi2*) **246** Avg. Daily Inflow (*cfs*) **950**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area (*mi2*)	5.8		2.5	3.3
Average Depth (*ft*)	9.6		8.5	10.9
Volume (*billion cu ft*)	1.6		0.6	1.0

A drowned river valley estuary greatly influenced by climate patterns of the Pacific Northwest. Seasonal streamflow is highly correlated with seasonal patterns of precipitation. Freshwater inflow is lowest from June to October, when a saltwedge extends fairly far upriver. During this period, significant variations in salinity structure can occur with the onset of upwelling events. Tidal range is 5.9 ft near the head of the estuary.

Algal Conditions

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

Chl-*a* blooms occur episodically May to July with nitrogen and light co-limiting. Elevated turbidity occurs throughout the year.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV			L	– – –	L	– – –

Primary productivity dominated by pelagic community in seawater zone. Pelagic community dominated by diatoms; benthic community is diverse. Intertidal wetland coverage is medium in mixing zone and low in seawater zone, with decreases reported due to development.

Nutrients

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

Highest nitrogen concentrations observed December to January and phosphorus concentrations December to February.

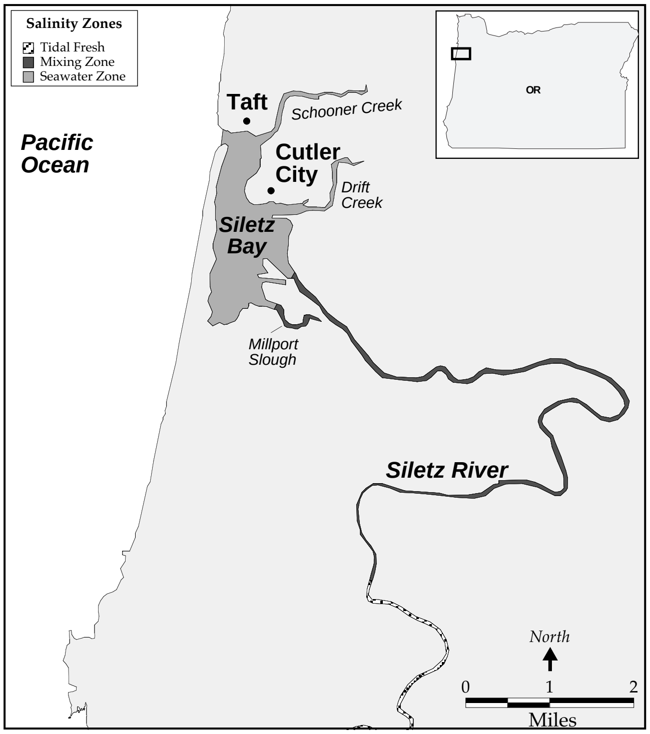
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia			N	– – –	N	– – –
Hypoxia			N	– – –	N	– – –
Bio. Stress			Y 10-25%	?	Y* 10-25%	?

Periodic biological stress observed throughout water column May to September in mixing zone, and speculatively in bottom-waters in seawater zone. Water column stratification is not a factor.

Key on page 23

Siletz Bay



In Siletz Bay, chlorophyll *a* concentrations are unknown and turbidity concentrations are medium. Nuisance and toxic algal bloom events are unknown. Concentrations of nitrogen are medium and phosphorus are high. There are no observations of anoxia, hypoxia or biological stress. SAV spatial coverage is very low.

Dissolved oxygen observations have not changed in the mixing and seawater zones. All other trends are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **372** Avg. Daily Inflow *(cfs)* **2,767**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	2.7	0.3	0.6	1.8
Average Depth *(ft)*	8.1	7.9	8.6	6.0
Volume *(billion cu ft)*	0.6	0.07	0.1	0.3

A small, riverine-type estuary consisting of Siletz Bay and River. Drift Creek and Schooner Creek discharge directly into the bay. Sedimentation rates have increased, and increases in river flow dampen tidal influences within the estuary, especially during fall and winter. The estuary is partially mixed in October, and stratified in January and April. Mean tidal range is 5.8 ft.

Algal Conditions

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

Elevated turbidity occurs throughout the year.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	?	?	VL	?	VL	?

Benthic community is a diverse mixture. Intertidal wetland spatial coverage is medium in mixing and seawater zones.

Nutrients

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

Nitrogen reported as dissolved inorganic nitrogen and phosphorus reported as total phosphorus. Highest concentrations of both parameters are speculated to occur June to August.

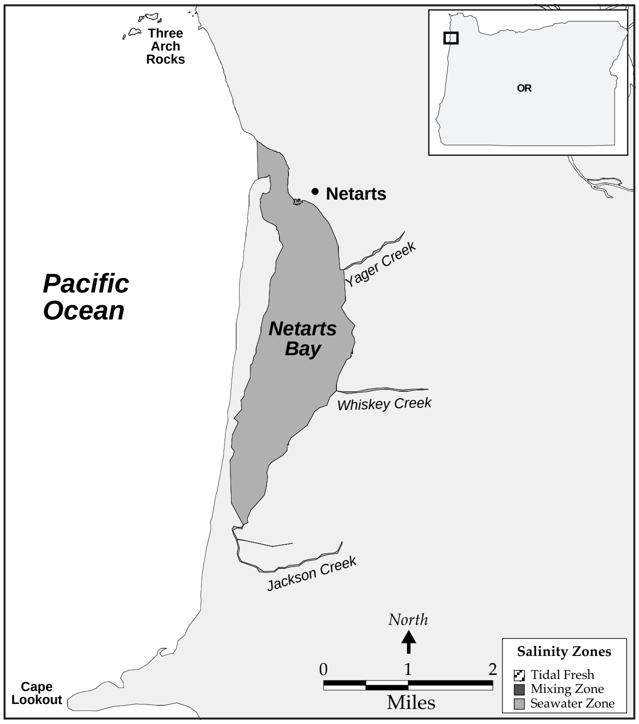
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	?	?	N	– – –	N	– – –
Hypoxia	?	?	N	– – –	N	– – –
Bio. Stress	?	?	N	– – –	N	– – –

D.O. trends reported for 1970-1983.

Key on page 23

Netarts Bay



In Netarts Bay, chlorophyll *a* concentrations are high and turbidity concentrations are medium. Nuisance or toxic bloom events are unknown, as are nitrogen and phosphorus concentrations. There are no observations of anoxia, hypoxia or biological stress. SAV spatial coverage is medium.

Dissolved oxygen observations and SAV spatial coverage have not changed. All other trends are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **16** Avg. Daily Inflow *(cfs)* **98**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	3.6			3.6
Average Depth *(ft)*	4.7			4.7
Volume *(billion cu ft)*	0.5			0.5

A bar-built, shallow estuary shaped like an open lagoon. Only a small percentage (12%) of the bay is subtidal. Inflow of freshwater is small. Salinities generally approach oceanic levels within the bay, and significant mixing usually occurs all year. Tidal range is 5.8 ft near the bay entrance.

Algal Conditions

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

Elevated turbidity occurs throughout the year.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater
SAV			M – – –

Primary productivity speculated to be dominated by pelagic community. Pelagic community dominated by diatoms; benthic community is diverse. Intertidal wetland coverage is high with a low magnitude decrease reported due to development.

Nutrients

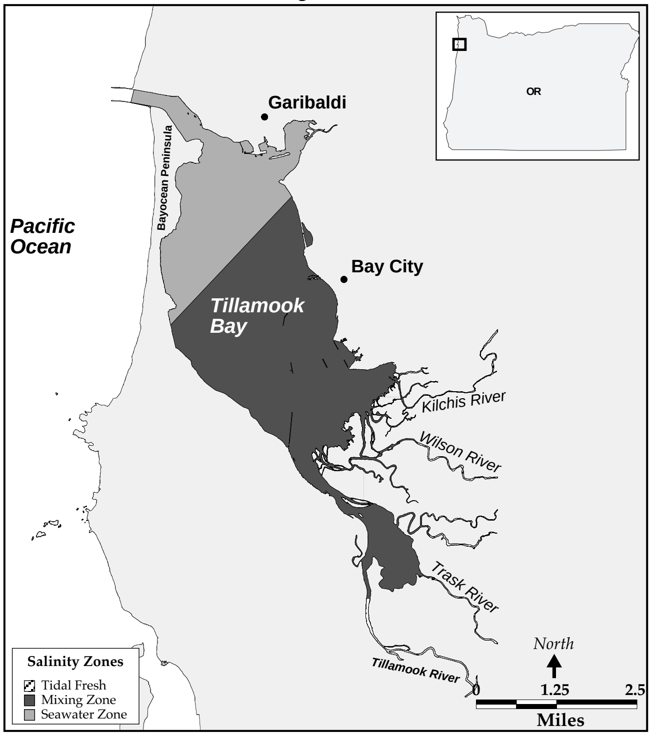
	Tidal Fresh	Mixing	Seawater
Nitrogen			? ?
Phosphorus			? ?

Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater
Anoxia			N – – –
Hypoxia			N – – –
Bio. Stress			N – – –

Dissolved oxygen trends reported for 1980-1984.

Tillamook Bay



In Tillamook Bay, seawater chlorophyll *a* concentration is medium. Turbidity concentrations range from medium to high. Nuisance and toxic bloom events are unknown. Concentrations of nitrogen and phosphorus are high in the seawater zone. Anoxia, hypoxia and biological stress are not observed. SAV spatial coverage ranges from low to medium.

Dissolved oxygen observations and SAV coverage in the mixing and seawater zones have not changed. All other trends are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **553** Avg. Daily Inflow *(cfs)* **3,880**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	14.9	0.5	9.9	4.5
Average Depth *(ft)*	6.0	5.0	5.0	7.7
Volume *(billion cu ft)*	2.5	0.07	1.4	1.0

A shallow estuary consisting of Tillamook Bay and several tributaries discharging into the bay. During high runoff period from November to March, the bay has a two-layered salinity structure but is vertically homogeneous during April through October. Salinity intrusion is greatly reduced during the winter. Tidal range is 5.6 ft near the bay entrance.

Algal Conditions

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

In seawater zone, Chl-*a* blooms speculated to occur periodically May to October. Elevated turbidity occurs throughout the year.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	?	?	M	---	L	---

Primary productivity speculated to be dominated by pelagic community in seawater zone. Pelagic community dominated by diatoms in seawater zone; benthic community is diverse in mixing and seawater zones. Intertidal wetland coverage is medium in mixing zone and low in seawater zone, with low magnitude decreases reported due to development.

Nutrients

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

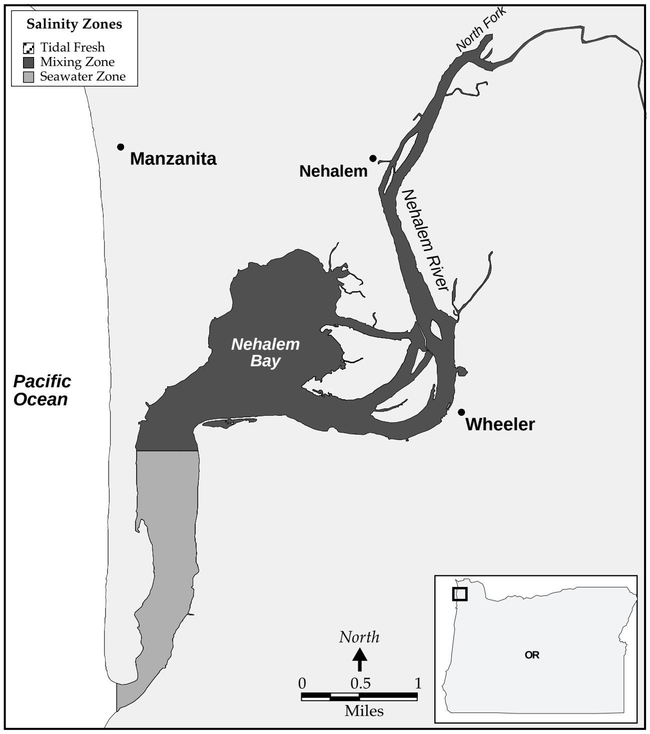
Nitrogen reported as dissolved inorganic nitrogen and phosphorus reported as total phosphorus. Highest concentrations for both parameters occur May to September.

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	N	?	N	---	N	---
Hypoxia	N	?	N	---	N	---
Bio. Stress	N	?	N	---	N	---

Key on page 23

Nehalem River



In Nehalem River, chlorophyll *a* concentration is high and turbidity concentrations range from low to medium. Nuisance and toxic bloom events are unknown, as are concentrations of nitrogen and phosphorus. There are no observations of anoxia, hypoxia or biological stress. SAV spatial coverage is very low.

Dissolved oxygen concentrations and SAV spatial coverage have not changed. All other trends are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **860** Avg. Daily Inflow *(cfs)* **3,420**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	3.0	0.0	2.3	0.7
Average Depth *(ft)*	7.3	8.5	6.6	13.1
Volume *(billion cu ft)*	0.6	0.01	0.4	0.3

Consists of Nehalem Bay and the Nehalem River that discharges into the bay approximately 5 miles from the mouth. Receives majority of freshwater from the Nehalem River (99% of watershed). Classified as a partly-mixed system in January and September and a two-layered system in April. Mean tidal range is 5.9 ft near the entrance to the bay.

Algal Conditions

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

Chl-*a* speculated to occur periodically April to August.

Ecosystem/Community Responses

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

Primary productivity speculatively dominated by pelagic community in seawater zone. Pelagic community dominated by diatoms in seawater zone; benthic community is diverse. Intertidal wetland coverage is very low or low with some decreases reported due to development.

Nutrients

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

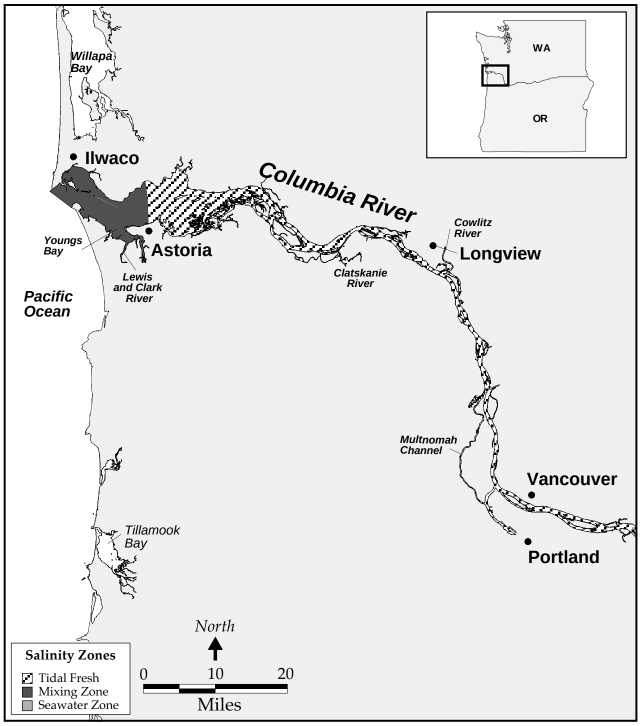
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia			N	- - -	N	- - -
Hypoxia			N	- - -	N	- - -
Bio. Stress			N	- - -	N	- - -

Dissolved Oxygen trends reported for 1970-1993.

Key on page 23

Columbia River



In Columbia River, chlorophyll *a* and turbidity concentrations are high. Nuisance blooms do not occur, but toxic blooms occur in mixing zone. Concentrations of nitrogen and phosphorus are medium. Anoxia, hypoxia and biological stress are not observed in this system. SAV spatial coverage is very low.

All trends are stable except a decrease in phosphorus concentrations and an increase in mixing zone SAV coverage.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **5,609** Avg. Daily Inflow *(cfs)* **272,500**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	**240.7**	**171.4**	**69.3**	
Average Depth *(ft)*	**15.6**	**14.3**	**20.3**	
Volume *(billion cu ft)*	**104.9**	**68.3**	**39.2**	

A highly dynamic estuarine system consisting of the Columbia River and several tributaries. Tidal influence can be felt as far upstream as the Bonneville Dam (not pictured), ~ 65 miles upstream. Wide variations in salinity gradients occur throughout the year. Saltwater intrusion is more pronounced during lower upland flow periods. Mean tidal range is 5.6 ft. at the river mouth.

Algal Conditions

	Tidal Fresh		Mixing		Seawater
Chlorophyll *a*	H 25-50%*	---	H 25-50%*	---	
Turbidity	H 50-100%	---	H 50-100%	---	
Nuisance Algae	N	---	N	---	
Toxic Algae	N	---	Y	?	

Chl-*a* blooms occur periodically May to August with limiting factors of light and retention time. Elevated turbidity occurs all year. Toxic *Alexandrium* spp. occurs periodically September to November and *Pseudo-nitzschia* spp. occurs episodically throughout the year.

Ecosystem/Community Responses

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

Primary productivity dominated by benthic community in intertidal areas, and pelagic in subtidal areas. Pelagic community dominated by diatoms in tidal fresh and seawater zones, except in summers flagellates dominate; benthic community is diverse. SAV increase due to expanding mudflats. Intertidal wetland coverage is low in tidal fresh zone and medium in mixing zone, with decreases reported due to development.

Nutrients

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

Highest nitrogen and phosphorus concentrations occur December to April. Decrease in phosphorus associated with changes in non-point sources.

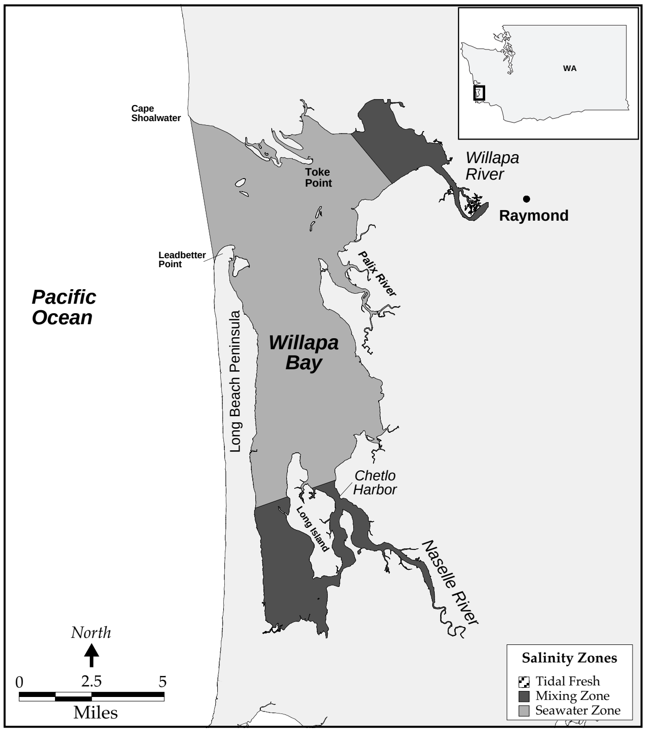
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater
Anoxia	N	?	N	?	
Hypoxia	N	?	N	?	
Bio. Stress	N	?	N	?	

Increase in duration of dissolved oxygen events attributed to non-point sources.

Key on page 23

Willapa Bay



In Willapa Bay, chlorophyll *a* concentrations range from low to medium and turbidity ranges from medium to high. Nuisance and toxic blooms occur in the mixing and seawater zones. Concentrations of nitrogen and phosphorus are medium. Anoxia, hypoxia and biological stress are not observed in this system. SAV spatial coverage is high in the mixing zone, and low or nonexistent in the other zones.

Turbidity has increased and SAV coverage has decreased. All other trends are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area (*mi2*) **1,064** Avg. Daily Inflow (*cfs*) **5,900**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area (*mi2*)	138.2	1.0	32.6	104.6
Average Depth (*ft*)	16.3	18.0	9.6	22.5
Volume (*billion cu ft*)	62.7	0.5	8.7	65.6

A large, complex estuary consisting of the main bay and several medium and small sized river systems. The bay is highly affected by wave action and tidal currents on incoming tide cycles, therefore high tidal prisms and intense erosion rates are common. Most of the bay consists of extensive areas of tidal flats. Considered to be well mixed most of the year. Mean tidal range is 6.2 ft. near the estuary mouth.

Algal Conditions

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

Chl-*a* blooms occur periodically March to October with limiting factors of depth, light, nitrogen and phosphorus. Elevated turbidity occurs all year in mixing zone and periodically April to June in seawater zone. Nuisance *Ceratium* spp. occurs episodically August to November, and toxic *Alexandrium* spp. and *Pseudo-nitzschia* spp. occur episodically/periodically May to October. These blooms are more common during ENSO events and warm-dry years.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	NS	---	H	↓ *	L	↓ *

Primary productivity dominated by benthic community in mixing zone (with increasing trend in pelagic activity) and is diverse in seawater zone. Pelagic community dominated by diatoms, but dinoflagelletes increasing due to changes in freshwater input and increased upwelling. Benthic community dominated by crustaceans in tidal fresh, annelids, mollusks, and crustaceans in mixing, and crustaceans and mollusks in seawater zone. Intertidal wetland coverage ranges from medium to low. SAV decrease and intertidal wetland increase due to invasive species.

Nutrients

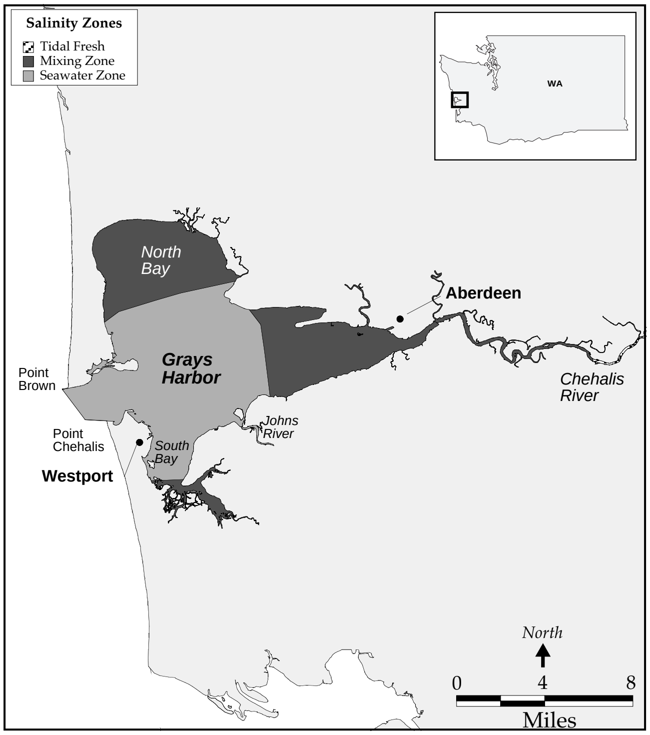
	Tidal Fresh		Mixing		Seawater	
Nitrogen	?	?	M 50-100%	?	M 50-100%	?
Phosphorus	?	?	M 50-100%	?	M 50-100%	?

Highest nitrogen concentrations occur September to March. Highest phosphorus concentrations reported August to April.

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	?	?	N	?	N	?
Hypoxia	?	?	N	?	N	?
Bio. Stress	?	?	N	?	N	?

Grays Habor



In Grays Harbor, chlorophyll *a* concentrations are medium and turbidity concentrations are high. Nuisance bloom events are unknown, but toxic blooms occur. Concentrations of nitrogen and phosphorus are medium. Anoxia, hypoxia, and biological stress are not observed in this system. SAV spatial coverage ranges from low to medium.

All trends are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area (*mi2*) **1,398** Avg. Daily Inflow (*cfs*) **13,500**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area (*mi2*)	**94.3**	**0.5**	**44.0**	**49.8**
Average Depth (*ft*)	**12.9**	**14.8**	**10.3**	**16.6**
Volume (*billion cu ft*)	**33.9**	**0.2**	**12.6**	**23.0**

A triangular-shaped estuary consisting of the main harbor area and several medium and small sized river systems. The bay is highly affected by wave action and tidal currents on incoming tide cycles, therefore high tidal prisms and intense erosion rates are common. Most of the bay consists of extensive areas of tidal flats. Is mixed or moderately stratified much of the year. Mean tidal range is 6.9 ft. near the estuary mouth.

Algal Conditions

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

Chl-*a* blooms occurs periodically April to September with limiting factors of depth, light, and speculatively nitrogen. Elevated turbidity occurs periodically June to September and November to February. Toxic *Alexandrium* spp. and *Pseudonitzschia* spp. occur periodically June to October.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	?	?	M	?	L	?

Primary productivity dominated by benthic community in mixing zone and is diverse in seawater zone. Pelagic community dominated by diatoms in mixing and seawater zones, benthic community dominated by crustaceans in mixing zone, and speculatively dominated by annelids in seawater zone. Intertidal wetland spatial coverage is low.

Nutrients

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

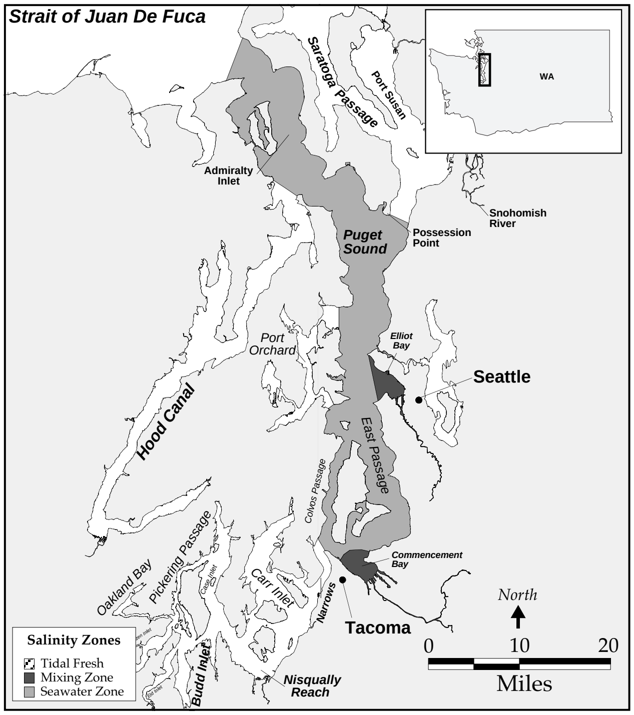
Highest concentrations of nitrogen occur January to May and phosphorus September to May.

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	?	?	N	?	N	?
Hypoxia	?	?	N	?	N	?
Bio. Stress	?	?	N	?	N	?

Key on page 23

Puget Sound (Main Basin)



In Puget Sound, chlorophyll *a* and turbidity concentrations are high. Nuisance and toxic blooms are reported to occur periodically. Nitrogen and phosphorus concentrations are medium. There are no observations of anoxia or hypoxia, however biological stress is observed in the seawater zone. SAV spatial coverage is very low in the seawater zone.

Trends for chlorophyll *a*, turbidity, nitrogen, and phosphorus concentrations are unknown. Nuisance and toxic bloom impacts have increased in the seawater zone. SAV spatial coverage in the seawater zone has decreased.

Physical and Hydrologic Characteristics

Estuarine Drainage Area (*mi2*) **7,813** Avg. Daily Inflow (*cfs*) **51,100**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area (*mi2*)	396.9		24.5	372.4
Average Depth (*ft*)	211.2		323.1	208.8
Volume (*billion cu ft*)	2337.1		220.7	2167.9

A fjord-like estuary connecting through Admiralty inlet to the Strait of Juan de Fuca westward to the Pacific Ocean. The main basin extends southward from Admiralty Inlet near Possession Point to the narrows. The Skagit, Stillaguamish, and the Snohomish rivers are the major sources of freshwater. Seasonally, deepwater replacement occurs when saline waters move into the main basin, eventually replacing less dense, mixed waters. Tides and wind influence circulation and salinity structure within the main basin. Tidal range is approximately 7 ft near the mouth of the main basin.

Algal Conditions

	Tidal Fresh	Mixing	Seawater
Chlorophyll *a*		H (50-100%) ?	H (0-10%) ?
Turbidity		H (50-100%) ?	H (25-50%) ?
Nuisance Algae		Y ?	Y ↑
Toxic Algae		Y ?	Y ↑

Chl-*a* blooms occur periodically March to September with limiting factor of depth. Highest turbidity occurs in Elliot/Commencement Bays periodically April to December and in February, and in Main Basin October to December and February to April. Nuisance *Chaetoseros* spp. and *Heterosigma* spp. occur periodically April to November. Toxic *Alexandrium* spp. occurs periodically all year.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater
SAV		? ?	VL ↓

Primary productivity dominated by pelagic community. Pelagic community dominated by diatoms, except in summer when flagellates dominate; benthic community is a diverse mixture. SAV decrease attributed to macroaglae blooms. Intertidal wetland coverage is very low, with decreases due to development.

Nutrients

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

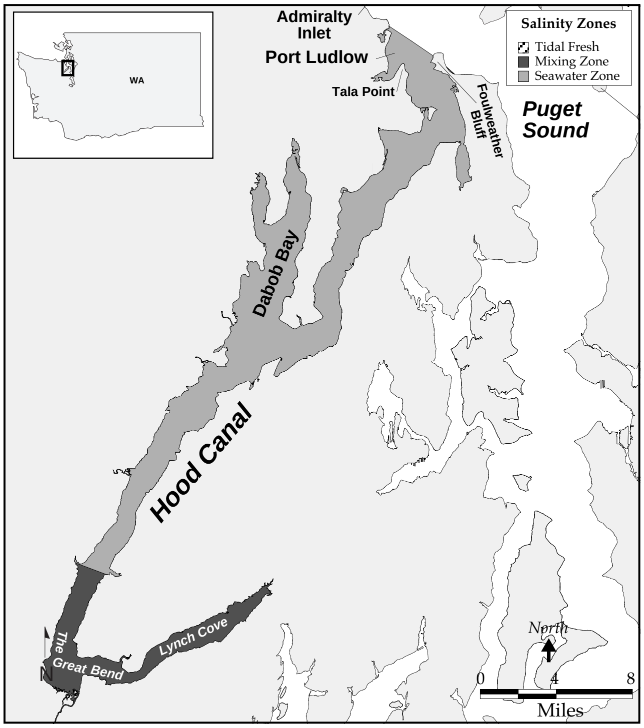
Highest nitrogen concentrations occur throughout year in Elliot and Commencement Bays and January to April in the Main Basin. Highest phosphorus concentrations reported throughout year.

Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater
Anoxia		N ?	N ?
Hypoxia		N ?	N ?
Bio. Stress		N ?	Y (10-25%) ?

Periodic biological stress occurs in bottom waters July to November.

Hood Canal



In Hood Canal, chlorophyll *a* concentrations range from medium to high and turbidity concentrations are medium. Nuisance and toxic blooms are not observed. Concentrations of nitrogen and phosphorus are medium. Anoxia is observed in the mixing zone, and hypoxia and biological stress are observed throughout the system. SAV spatial coverage is very low.

All trends are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **976** Avg. Daily Inflow *(cfs)* **6,500**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	154.1		29.5	124.6
Average Depth *(ft)*	229.9		265.1	213.9
Volume *(billion cu ft)*	987.8		218.0	743.1

Puget Sound subsystem consisting of Hood Canal, Dabob Bay, and several small embayments. Entrance is between Tala Point and Foulweather Bluff. Hood Canal has very limited tidelands compared to other areas of Puget Sound. Mudflats exist in the Lynch Cove area. Tidal range is 7.5 ft near Dabob Bay.

Algal Conditions

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

Chl-*a* blooms occur periodically April to August with limiting factors of nitrogen and light in mixing zone, and nitrogen and depth in seawater zone. Elevated turbidity occurs periodically June to October.

Ecosystem/Community Responses

	Tidal Fresh	Mixing		Seawater	
SAV		VL	?	VL	?

Primary productivity dominated by pelagic community. Pelagic community dominated by diatoms; benthic community dominated by mollusks in mixing zone and is diverse in seawater zone, but historically both zones dominated by annelids. Intertidal wetland coverage is very low with decreases reported due to development.

Nutrients

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

Highest nitrogen concentrations occur November to April and phosphorus concentrations throughout the year.

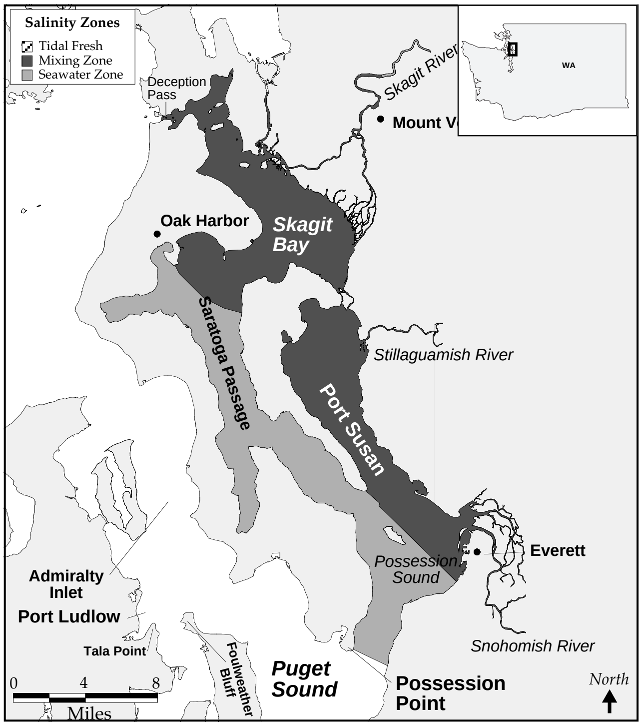
Dissolved Oxygen

	Tidal Fresh	Mixing		Seawater	
Anoxia		Y 50-100%	?	N	?
Hypoxia		Y 50-100%	?	Y 25-50%	?
Bio. Stress		Y 50-100%	?	Y 25-50%	?

Bottom-water anoxia observed episodically in October, bottom-water hypoxia observed all year in mixing zone and periodically July to March in seawater zone, and bottom-water biological stress conditions observed all year. Water column stratification is a highly significant factor.

Key on page 23

Whidbey Basin/Skagit Bay



In Whidbey Basin/Skagit Bay, chlorophyll *a* concentrations are high and turbidity concentrations are high in the mixing zone and medium in the seawater zone. Nuisance blooms are reported in the mixing and seawater zones. Concentrations of nitrogen and phosphorus are medium. Anoxia and hypoxia are observed in the seawater zone and biological stress is reported in the mixing and seawater zones. SAV spatial coverage is very low.

All trends are unknown.

Physical and Hydrologic Characteristics

Estuarine Drainage Area (*mi2*) **1,408** Avg. Daily Inflow (*cfs*) **36,600**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area (*mi2*)	**246.0**		**145.3**	**100.7**
Average Depth (*ft*)	**154.5**		**85.7**	**237.3**
Volume (*billion cu ft*)	**1059.4**		**347.2**	**666.2**

Northeastern subsystem of Puget Sound encompassing water portion from Possession Sound to Deception Pass, a natural outlet to the Juan de Fuca Straight. Skagit Bay is the shallowest area, and Possession Sound is the deepest. Tides are frequently out of phase with other areas within the system and the range is 7.4 ft near the entrance at Deception Pass.

Algal Conditions

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

Chl-*a* blooms occur periodically March to August with co-limiting factors of light and depth. Elevated turbidity occurs periodically December to January and March to July. Nuisance *Heterosigma* spp. occurs episodically.

Nutrients

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

Highest nitrogen concentrations observed November to April and phosphorus concentrations reported throughout the year.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV			VL	?	VL	?

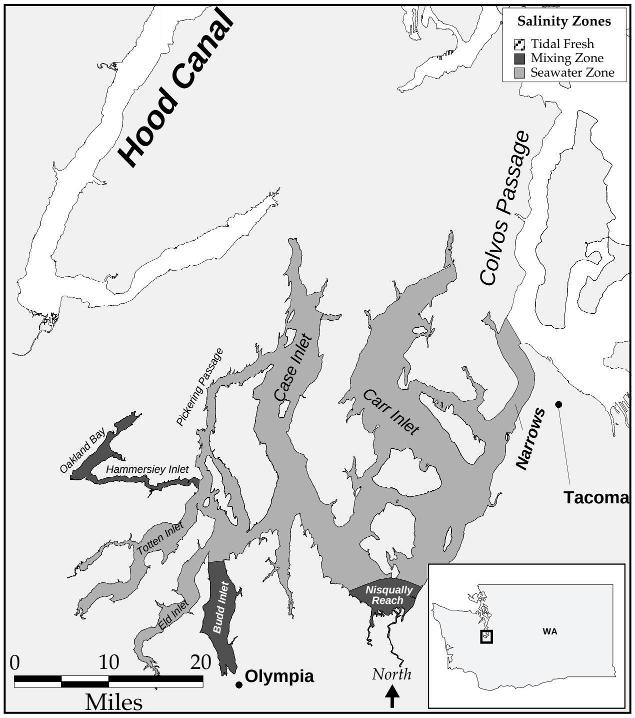
Primary productivity dominated by pelagic community. Pelagic community dominated by diatoms, except in summer when flagellates dominate; benthic community speculatively dominated by annelids. Intertidal wetland coverage is low in mixing zone with increase reported due to invasive species, and very low in seawater zone with speculated decrease due to development.

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia			N	?	Y 0-10%	?
Hypoxia			N	?	Y 0-10%	?
Bio. Stress			Y 10-25%	?	Y 10-25%	?

Bottom-water anoxic events observed in Penn Cove periodically in October, and hypoxia and biological stress observed August to October. Water column stratification is a highly significant factor.

South Puget Sound



In South Puget Sound, chlorophyll *a* and turbidity concentrations range from medium to high. Nuisance and toxic blooms occur periodically. Nitrogen and phosphorus concentrations are medium. Anoxia is not observed, however hypoxia is observed in the mixing zone and biological stress is observed in all zones. SAV spatial coverage ranges from very low to low.

All trends are unknown except a decrease reported in nitrogen concentrations in Budd Inlet.

Physical and Hydrologic Characteristics

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

	Estuary	TF	Mixing: In General	Mixing: Budd Inlet	Seawater
Surface Area (*mi²*)	192.1		19.0	16.9	156.2
Average Depth (*ft*)	n/a		n/a	n/a	n/a
Volume (*billion cu ft*)	n/a		n/a	n/a	n/a

Southernmost portion of Puget Sound. Consists of several passages, inlets, and interconnected waterways and a shoreline that is highly complex and extensive. The entrance is at the Narrows, a short, steep sided passage that provides the only access between South Puget Sound and the Main Basin. The significant tidal range and more gentle sloping shoreline creates abundant intertidal areas.

Algal Conditions

	TF	Mixing: In General		Mixing: Budd Inlet		Seawater	
Chlorophyll a		M 50-100%	?	H 50-100%	?	H 50-100%	?
Turbidity		M 50-100%	?	H 25-50%	?	M 50-100%	?
Nuisance Algae		Y	?	Y	?	Y	?
Toxic Algae		Y	?	Y	?	Y	?

Chl-*a* blooms occur periodically April to October with co-limiting factors of nitrogen and light. Elevated turbidity occurs periodically April to October in seawater zone and all year in mixing zone. Nuisance *Gymnodinium sanguineum* and *Ceratium fusus*, and toxic *Alexandrium* spp. occur periodically June to October.

Ecosystem/Community Responses

	TF	Mixing: In General		Mixing: Budd Inlet		Seawater	
SAV		VL	?	VL	?	L	?

Primary productivity dominated by pelagic community. Pelagic community dominated by diatoms, except in summer flagellates dominate; benthic community is diverse. Intertidal wetland coverage is low in mixing zone and very low in seawater zone.

Nutrients

	TF	Mixing: In General		Mixing: Budd Inlet		Seawater	
Nitrogen		M 50-100%	?	M 50-100%	↓	M 50-100%	?
Phosphorus		M 50-100%	?	M* 50-100%	?	M 50-100%	?

Elevated nitrogen concentrations occur October to June, with decrease reported for 1994-97 attributed to changes in point sources. Elevated phosphorus concentrations occur throughout the year.

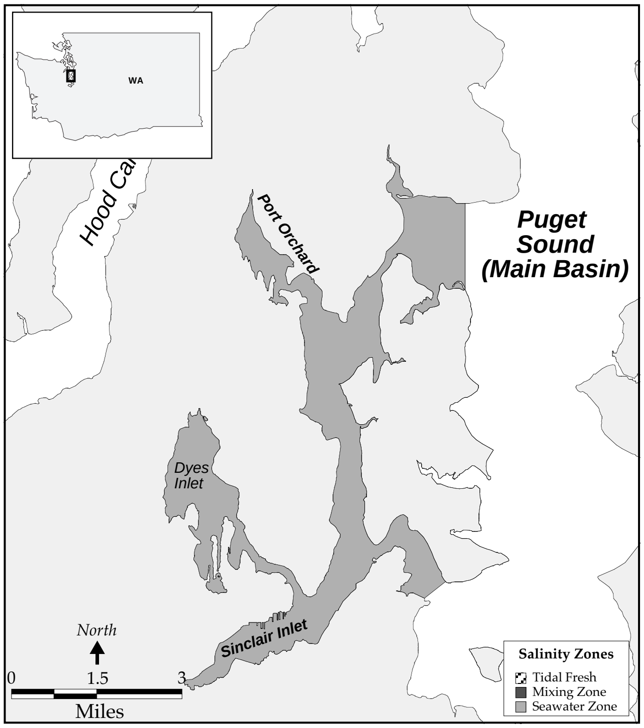
Dissolved Oxygen

	TF	Mixing: In General		Mixing: Budd Inlet		Seawater	
Anoxia		?	?	N	?	N	?
Hypoxia		Y 10-25%	?	Y 25-50%	?	N	?
Bio. Stress		Y 25-50%	?	Y 25-50%	?	Y 25-50%	?

Bottom-water hypoxia and biological stress observed periodically July to October. Water column stratification is a significant factor.

Key on page 23

Port Orchard Sound



In Port Orchard Sound, chlorophyll *a* concentrations are high and turbidity concentrations are medium. Nuisance and toxic blooms occur periodically. Concentrations of nitrogen and phosphorus are medium. Biological stress is observed in the system, but not anoxia or hypoxia. SAV spatial coverage is very low.

All trends are unknown except a speculative decrease in SAV spatial coverage.

Physical and Hydrologic Characteristics

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

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area (*mi²*)	**36.3**			**36.3**
Average Depth (*ft*)	**n/a**			**n/a**
Volume (*billion cu ft*)	**n/a**			**n/a**

Subsystem of Puget Sound consisting of Dyes Inlet, Sinclair Inlet, Port Orchard, and Liberty Bay. Waters in Rich Passage are fairly deep while Agate Passage is shallow and narrow. The entire central portion is moderately shallow and contain extensive tideland areas.

Algal Conditions

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

Chl-*a* blooms occur periodically March to August with light, depth and nitrogen as limiting factors. Elevated turbidity, nuisance *Heterosigma* spp., and toxic *Alexandrium* spp. occur periodically April to October.

Nutrients

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

Elevated nitrogen concentrations occur September to May and phosphorus concentrations throughout the year.

Ecosystem/Community Responses

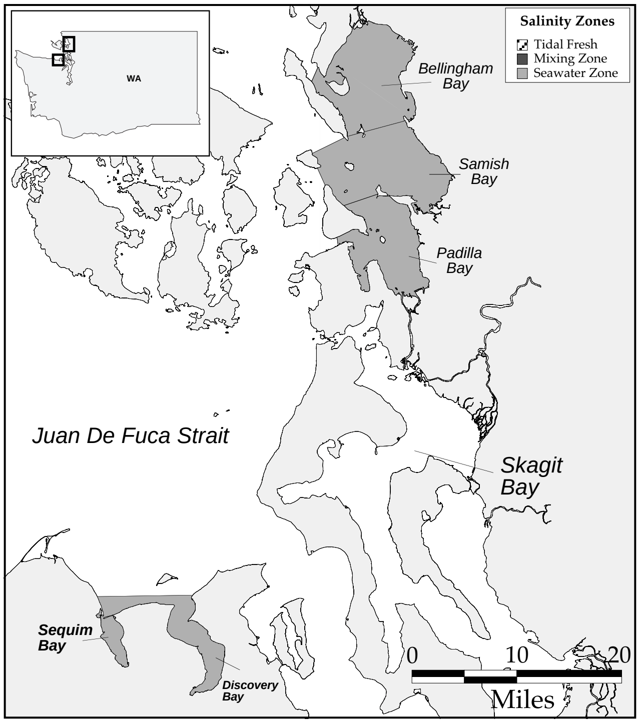
	Tidal Fresh	Mixing	Seawater
SAV			VL ↓*

Primary productivity dominated by pelagic community. Pelagic community dominated by diatoms, except in summer when flagellates dominate; benthic community speculated to be diverse. SAV decrease attributed to macroalgae blooms. Intertidal wetland spatial coverage is very low.

Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater
Anoxia			N ?
Hypoxia			N ?
Bio. Stress			Y (10-25%) ?

Washington Northern Bays



In Washington Northern Bays, chlorophyll *a* concentrations are high and turbidity ranges from low to high. There are no observed nuisance blooms but toxic blooms occur periodically. Concentrations of nitrogen and phosphorus are medium. Biological stress is observed in the system, but not anoxia or hypoxia. SAV spatial coverage ranges from low to medium.

All trends are unknown, except a low magnitude increase in SAV spatial coverage in Bellingham/Padilla/Samish Bays.

Physical and Hydrologic Characteristics

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

	Estuary	TF	Mixing	Seawater: Bellingham/Padilla/Samish	Seawater: Sequim/Discovery
Surface Area (*mi²*)	161.5			135.3	26.2
Average Depth (*ft*)	n/a			n/a	n/a
Volume (*billion cu ft*)	n/a			n/a	n/a

Open embayments to the Strait of Georgia and the Strait of Juan de Fuca. There is little freshwater inflow to these coastal bays. Instead, the bays are dominated primarily by tidal currents.

Algal Conditions

	TF	Mixing	Seawater: Bellingham/Padilla/Samish		Seawater: Sequim/Discovery Bay	
Chlorophyll a			H 25-50%	?	H 25-50%	?
Turbidity			H 10-25%	?	L	?
Nuisance Algae			N	?	?	?
Toxic Algae			Y	?	Y	?

Chl-*a* blooms occur periodically April to October with limiting factors of light, nitrogen and depth. Elevated turbidity occurs periodically April to June and December to February in Bellingham/Padilla/Samish Bays, and April to July in Sequim/Discovery Bays. Toxic *Alexandrium* spp. occurs periodically July to October.

Ecosystem/Community Responses

	TF	Mixing	Seawater: Bellingham/Padilla/Samish		Seawater: Sequim/Discovery Bay	
SAV			M	⇧	L	?

Primary productivity is mix of SAV and pelagic communities in Bellingham/Padilla/Samish Bays and is dominated by pelagic community in Sequim/Discovery Bays. Pelagic community dominated by diatoms, except in summer when flagellates dominate. In Bellingham/Padilla/Samish Bays, SAV increase attributed to increased sediments due to changes in freshwater inflow. Intertidal wetland coverage is very low.

Nutrients

	TF	Mixing	Seawater: Bellingham/Padilla/Samish		Seawater: Sequim/Discovery Bay	
Nitrogen			M 50-100%	?	M 50-100%	?
Phosphorus			M 50-100%	?	M 50-100%	?

Elevated nitrogen concentrations occur August to April and phosphorus concentrations reported throughout the year.

Dissolved Oxygen

	TF	Mixing	Seawater: Bellingham/Padilla/Samish		Seawater: Sequim/Discovery Bay	
Anoxia			N*	?	N	?
Hypoxia			?	?	N	?
Bio. Stress			N	?	Y 10-25%	?

Periodic bottom-water biological stress observed August to October in Sequim Bay.

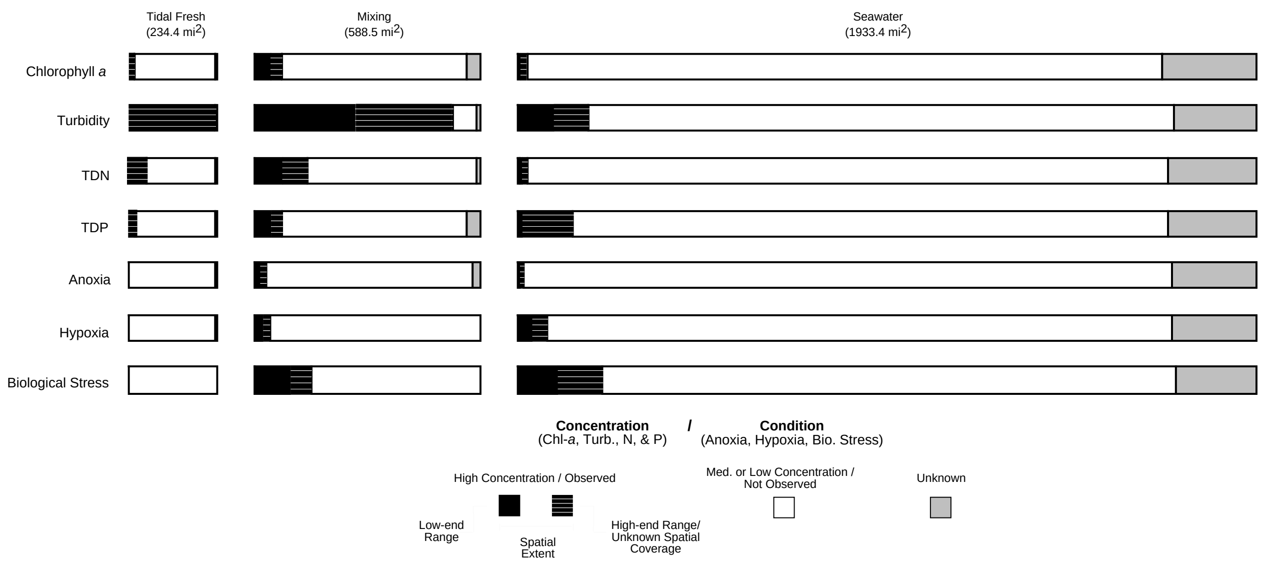
Key on page 23

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.

Pacific Coast Regional Workshop (March 17-21, 1997 San Francisco, CA)

Oregon and Washington

Frank Cox	Washington Department of Health
John A. Johnson	Oregon Fish and Wildlife
Larry Marxer	Oregon Department of Environmental Quality
Greg McMurray	Oregon Department of Environmental Quality
Jan Newton	Washington State Department of Ecology
Curtis Roegner	Oregon Institute of Marine Biology
Randy Shuman	Metropolitan King County Ambient Monitoring
Barbara Sullivan	Oregon State University
Kathy Taylor	CREST
Ron Thom	Battelle/Marine Sciences Laboratory

California

Shirley Birosik	Los Angeles Water Quality Control Board
Karleen Boyle	UCLA
Jane Caffrey	Elkhorn Slough National Estuarine Research Reserve
Brian Cole	US Geological Survey
Scott Dawson	Santa Ana Regional Water Quality Control Board
John Hannum	North Coast Regional Water Quality Control Board
Deborah Johnston	California Department Fish and Game
Katie Kropp	Morro Bay National Estuary Program
Peggy Lehman	Department of Water Resources
Bruce Moore	Orange Co. Environmental Management Agency
Don Reish	California State University
Bruce Thompson	San Francisco Estuarine Institute
Karen Worcester	Morro Bay National Estuary Program

Participated in absentia

Kathleen Sayce	Shoalwater Botanical
Joy Zedler	San Diego State University

Survey/Site Visits

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

Tijuana Estuary

Karleen Boyle*	UCLA
Peggy Fong*	UCLA
Peter Michael•	San Diego Wat. Qual. Con. Bd.
Grieg Peters	San Diego Wat. Qual. Con. Bd.
Joy Zedler•	San Diego State University

San Diego Bay

Peter Michael•	San Diego Wat. Qual. Con. Bd.
Bill Paznokas	Calif. Dept. of Fish & Game
Grieg Peters	San Diego Wat. Qual. Con. Bd.

Mission Bay

Lisa Levin	Scripps Institute of Oceanog.
Peter Michael•	San Diego Wat. Qual. Con. Bd.
Grieg Peters	San Diego Wat. Qual. Con. Bd.
Bill Paznokas	Calif. Dept. of Fish & Game

Newport Bay

Karleen Boyle*	UCLA
Scott Dawson*	Santa Ana Wat. Qual. Con. Bd
Peggy Fong*	UCLA
Christopher Kinner*	Irvine Ranch Water District
Eric Klein*	Orange Co. Env. Mgmt. Ag.
Bruce Moore*	Orange Co. Env. Mgmt. Ag.
Don Reish	California State University
Ken Thompson*	Irvine Ranch Water District
Joy Zedler•	San Diego State University

San Pedro Bay
Shirley Birosik — Los Angeles Water Quality
Don Reish — California State University

Alamitos Bay
Shirley Birosik — Los Angeles Water Quality
Don Reish — California State University

Anaheim Bay
Eric Klein* — Orange Co. Env. Mgmt. Ag.
Bruce Moore* — Orange Co. Env. Mgmt. Ag.
Don Reish — California State University

Santa Monica Bay
Don Reish — California State University
Bruce Thompson — San Francisco Estuarine Inst.

Morro Bay
Michael Martin — Calif. Dept. of Fish & Game
Don Reish — California State University
Karen Worcester — Cen. Coast Wat. Qual. Con. Bd.

Monterey Bay
Deborah Johnston — Calif. Dept. of Fish & Game
Michael Martin — Calif. Dept. of Fish & Game
James Nybakken — Moss Landing Marine Lab

Elkhorn Slough
Andrew DeVogelare — Elkhorn Slough NERR
Deborah Johnston — Calif. Dept. of Fish & Game
Michael Martin — Calif. Dept. of Fish & Game
James Nybakken — Moss Landing Marine Lab
Mark Silberstien — Elkhorn Slough NERR
Bruce Thompson — San Francisco Estuarine Inst.

San Francisco Bay
James Cloern — US Geological Survey
Donald Heinle — CH2M Hill
James Hollibaugh — San Francisco State University
Deborah Johnston — Calif. Dept. of Fish & Game
Michael Martin — Calif. Dept. of Fish & Game
Frederic Nichols — US Geological Survey
Don Reish — California State University
Mary Beth Saffo — University of Calif., Santa Cruz
Larry Shemel — US Geological Survey
Bruce Thompson — San Francisco Estuarine Inst.

North/Central San Francisco Bays
Jim Arthur — Bureau of Reclamation
Randall Brown — CA Dept. of Water Resources
Deborah Johnston — Calif. Dept. of Fish & Game
Michael Josselyn — San Francisco State University
Michael Martin — Calif. Dept. of Fish & Game
Frederic Nichols — US Geological Survey
Harlan Proctor — Calif. Dept. of Fish & Game
Don Reish — California State University
Larry Shemel — US Geological Survey
Bruce Thompson — San Francisco Estuarine Inst.

Drakes Estero
Michael Martin — Calif. Dept. of Fish & Game

Tomales Bay
Deborah Johnston — Calif. Dept. of Fish & Game
Michael Martin — Calif. Dept. of Fish & Game
Greg Ruiz — Smithsonian Env. Research Cn.

Eel River
John Hannum — No. Coast Water Qual. Con. Bd.
William Winchester — No. Coast Water Qual. Con. Bd.

Humbolt Bay
Milton Boyd — Humboldt State University
John Hannum — No. Coast Water Qual. Con. Bd.
Deborah Johnston — Calif. Dept. of Fish & Game
William Winchester — No. Coast Water Qual. Con. Bd.

Klamath River
Barry Collins — Calif. Dept. of Fish & Game
John Hannum — No. Coast Water Qual. Con. Bd.
William Winchester — No. Coast Water Qual. Con. Bd.

Rogue River
Tim Unterwegner — Oregon Dept. Fish & Wildlife

Coos Bay
Barbara Butler* — Oregon Inst. of Marine Biology
Michael Graybill* — South Slough NEER
Jan Hodder* — Oregon Inst. of Marine Biology
John A. Johnson• — Oregon Fish and Wildlife
Lynda Shapiro* — Oregon Inst. of Marine Biology
Steve Rumrill* — South Slough NEER

Umpqua River
John A. Johnson• — Oregon Fish and Wildlife

Siuslaw River
John A. Johnson• — Oregon Fish and Wildlife

Alsea River
John A. Johnson• — Oregon Fish and Wildlife

Yaquina Bay
John Chapman* — Hatfield Marine Science Center
Clayton Creech* — Hatfield Marine Science Center
John A. Johnson• — Oregon Fish and Wildlife
David Specht — US EPA
Janet Webster* — Hatfield Marine Science Center

Siletz Bay
John A. Johnson• — Oregon Fish and Wildlife

Netarts Bay
John A. Johnson• — Oregon Fish and Wildlife

Tillamook Bay

John A. Johnson•	Oregon Fish and Wildlife
Larry Marxer*	Oregon Dept. of Env. Quality
Gregory McMurray*	Oregon Dept. of Env. Quality
Avis Newell*	Oregon Dept. of Env. Quality

Nehalm River

John A. Johnson•	Oregon Fish and Wildlife

Columbia River

Robert Emmet	NOAA/NMFS
Jon Graves	Columbia R. Study Task Force
Larry Marxer*	Oregon Dept. of Env. Quality
Gregory McMurray*	Oregon Dept. of Env. Quality
Kathleen Sayce	Shoalwater Botanical
Lawrence Small	Oregon State University

Willipa Bay

Robert Emmet	NOAA/NMFS
Larry Marxer*	Oregon Dept. of Env. Quality
Gregory McMurray*	Oregon Dept. of Env. Quality
Jan Newton*	Wash. State Dept. of Ecology
Kathleen Sayce	Shoalwater Botanical
Ronald Thom•	Battelle Marine Science Lab

Grays Harbor

Carol Janzen	
Jan Newton*	Wash. State Dept. of Ecology
Jack Word	Battelle Ocean Sciences

Puget Sound

Eugene Collias	NW Consultant Oceanogr. Inc.
Andrea Copping	Washington Sea Grant
Jan Newton*	Wash. State Dept. of Ecology
Frederick Nichols	US Geological Survey
Chris Prescott	Puget Sound Wat. Qual. Auth.
Jack Rensel	University of Washington
Ron Thom•	Battelle Marine Sciences Lab

Hood Canal

Jan Newton*	Wash. State Dept. of Ecology
Chris Prescott	Puget Sound Wat. Qual. Auth.
Pete Striplin	Striplin Environmaental Assoc.
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Whidbey Basin/Skagit Bay

Jan Newton*	Wash. State Dept. of Ecology
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Pete Striplin	Striplin Environmaental Assoc.
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South Puget Sound

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Chris Prescott	Puget Sound Wat. Qual. Auth.
Pete Striplin	Striplin Environmaental Assoc.
Ronald Thom•	Battelle Marine Science Lab

Port Orchard Sound

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Chris Prescott	Puget Sound Wat. Qual. Auth.
Pete Striplin	Striplin Environmaental Assoc.
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Washington Northern Bays

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Chris Prescott	Puget Sound Wat. Qual. Auth.
Pete Striplin	Striplin Environmaental Assoc.
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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 Pacific Coast estuaries. In some cases, the survey results are based directly upon these publications. This list is not comprehensive; some estuaries are not included because no suggestions were received.

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Appendix 3: NEI Estuaries

*One hundred twenty-nine estuaries are included in the National Estuarine Inventory (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 subsystem 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 River
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 (37)

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/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/Whidbey Basin
South Puget Sound
Port Orchard System
Washington Northern Bays

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