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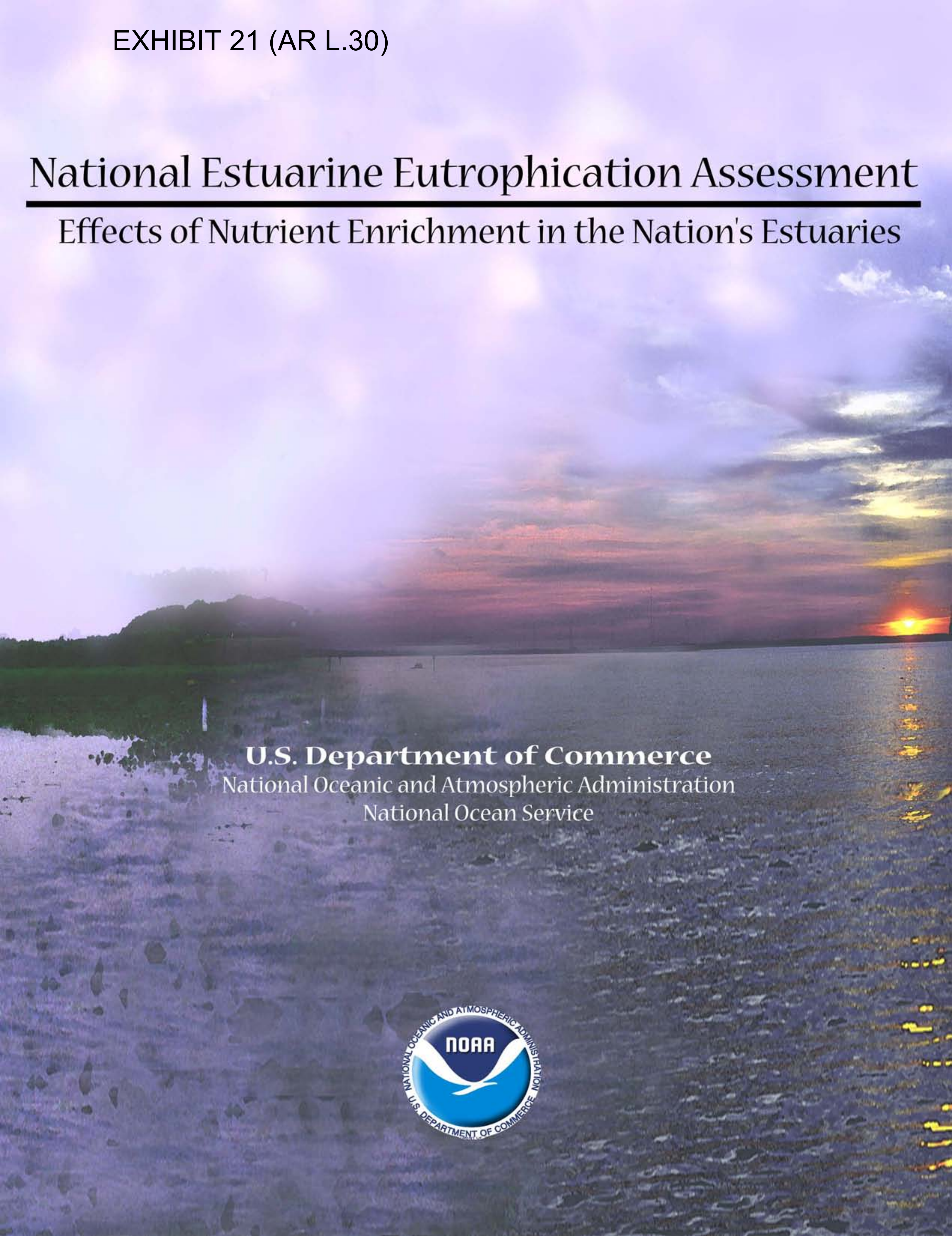

National Estuarine Eutrophication Assessment

Effects of Nutrient Enrichment in the Nation's Estuaries

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Ocean Service

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The National Ocean Service: Working for America's Coasts

The National Ocean Service (NOS) approaches the 21st century with a clear vision–that our coasts and oceans enjoy robust health, provide a rich bounty of resources, and are wisely managed to endure competing uses. As the nation's principal advocate for coastal and ocean stewardship, the National Ocean Service develops the national foundation for coastal and ocean science, management, response, restoration, and navigation. This report, developed by the NOS Special Projects Office and the National Centers for Coastal Ocean Science, strengthens this foundation, helping to bridge the gap between science, management, and public policy.

The Special Projects Office works to increase the effectiveness of coastal management in the United States, thereby ensuring continued economic prosperity and environmental well-being throughout the nation's coastal regions. A main objective of the Special Projects Office is to provide expertise, products, and services that assist the NOS in designing and implementing an effective program of coastal stewardship throughout the agency. This effort includes exploring ways to leverage the agency's considerable expertise into a force that more directly supports and influences the sound management and protection of coastal areas. Special Projects is in a unique position to bridge the gap between NOS scientific efforts and coastal management policy issues.

The National Centers for Coastal Ocean Science (NCCOS) works to understand the ocean and coastal environment, and the influences of human activities, by conducting research, monitoring, and assessments of these delicate and important areas. NCCOS activities include understanding and predicting impacts of pollution and coastal development on sensitive habitats and resources; helping to protect coastal property and residents from storms and other natural hazards; understanding the causes and consequences of harmful algal blooms, such as red tides and toxic *Pfiesteria piscicida*; understanding how climate change may affect our lives; and determining the complex factors that affect fish populations.

More information or access to data, products, and services can be obtained from our Web sites:

Special Projects Office
http://spo.nos.noaa.gov

National Centers for Coastal Ocean Science
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National Estuarine Eutrophication Assessment

Effects of Nutrient Enrichment in the Nation's Estuaries

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September 1999

Special Projects Office
and the
National Centers for Coastal Ocean Science

National Ocean Service
National Oceanic and Atmospheric Administration
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Acknowledgments

We would like to thank all of the estuarine research scientists and coastal resource managers whose contributions of data, information, and expertise were the key to making this report possible (Appendix C). The Core Group was instrumental in developing methods for aggregating the data and, along with the other participants in the National Assessment Workshop, reviewed and analyzed the results and made recommendations for a national-level response to eutrophication problems in the nation's estuaries.

This report is the result of the dedication and cooperation of many individuals who remained committed during the long duration of the project. Special thanks go to Daniel J. Basta, Director of NOS Special Projects, for his vision and unflagging support, and to Richard Alexander and Richard Smith of the U.S. Geological Survey for use of their SPARROW model results prior to publication. We also thank our NOS colleagues Charles Alexander and C. John Klein for technical advice; Alison Hammer, John Hayes, Percy Pacheco, and Scot Frew for invaluable support provided for the National Assessment Workshop; Denise Yver for designing the report cover; and Pam Rubin for reviewing and editing the manuscript.

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Foreword

This report is the culmination of almost seven years of effort to assess comprehensively the scale, scope, and characteristics of nutrient enrichment and eutrophic conditions in the nation's estuaries. It provides the most comprehensive assessment of this issue ever assembled for our nation's estuaries, and the results represent a significant contribution to the development of a national strategy to control nutrient enrichment problems affecting U.S. coastal waters. With this information, we have the opportunity to make a real difference in the actions this nation takes to address this important issue.

These results provide a valuable context for a host of ongoing and planned activities addressing estuarine eutrophication, including reauthorization of the Coastal Zone Management Act, particularly section 6217; reauthorization of the Clean Water Act; the states' development of Unified Watershed Assessments and Watershed Restoration Priorities as part of the Clean Water Action Plan; the Report on the Status of the Nation's Ecosystems; the Committee on Environment and Natural Resources Gulf of Mexico Hypoxia Study; and NOAA's National Dialogues on Coastal Stewardship.

As important as the results themselves is the process used to acquire this information. The approach explicitly recognized that much of what is known about these problems resides within the knowledge and experience of experts around the nation. Hence, a process was developed to systematically obtain information from more than 300 experts on estuarine eutrophication. Those interested in this innovative approach to information synthesis can review the Appendices to learn more about these methods and how to apply them.

During the past year, the National Ocean Service (NOS) has undergone a reorganization, and is emerging with a new focus on coastal stewardship. One of the new roles for NOS is as a catalyst to ensure that scientific results are targeted to providing solutions to environmental problems and to preserving the nation's coastal and ocean resources. This report is also an example of the type of activity that is needed to better bridge the gap between scientists and resource managers. I encourage you to use this work to stimulate further efforts to protect our natural resources.

Nancy Foster, Ph.D.
Assistant Administrator for Ocean Services
and Coastal Zone Management
National Ocean Service, NOAA

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Executive Summary

The National Assessment

This report presents the results of a National Assessment Workshop held in August 1998 to address the problem of estuarine eutrophication. The assessment was based primarily on the results of the National Estuarine Eutrophication Survey, conducted by NOAA from 1992 to 1997, but was supplemented by information on nutrient inputs, population projections, and land use drawn from a variety of sources. It covers 138 estuaries, representing over 90 percent of the estuarine surface area of the coterminous United States, plus the Mississippi River Plume. The final assessment presented here was undertaken at the National Assessment Workshop by a select group of experts, all of whom participated in the eutrophication survey. The Workshop was structured around answering seven key questions regarding the severity and extent of eutrophication in the nation's estuaries. All results presented in this report were reviewed by the Workshop participants.

About Estuarine Eutrophication

Eutrophication is the accelerated production of organic matter, particularly algae, in a water body. It is usually caused by an increase in the amount of nutrients being discharged to the water body. As a result of accelerated algal production, a variety of impacts may occur, including nuisance and toxic algal blooms, depleted dissolved oxygen, and loss of submerged aquatic vegetation. These impacts are interrelated and usually viewed as having a negative effect on water quality and ecosystem health. Eutrophication has been recognized as a problem in freshwater systems for many years, but only in the past three decades has concern grown about the widespread occurrence of eutrophic conditions in estuarine systems. Due to the complexity of the phenomena and the lack of consistent national data sets, the severity and extent of the problem had never been adequately characterized at the national scale.

Key Questions

1. **What are the severity and extent of eutrophic conditions exhibited within the estuaries of the United States?**

2. **To what extent are eutrophic conditions in the nation's estuaries caused by human activities?**

3. **To what extent do eutrophic conditions impair the use of estuarine resources, and what are the important impaired uses?**

4. **Where should management efforts be targeted to achieve the greatest benefit toward remediation and protection from degradation?**

5. **To what extent can the severity and extent of eutrophic conditions be expected to increase by the year 2020, given the natural susceptibility of estuaries and the potential for increasing nutrient inputs?**

6. **Which data gaps and research and monitoring needs are most critical in terms of improving the ability to assess and respond to eutrophication symptoms?**

7. **How can the results of this assessment be translated into a national strategy?**

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Key Findings

1 Eutrophication Severity and Extent

Symptoms of eutrophication are prevalent in the nation's estuaries.

- High expressions of eutrophic conditions are exhibited in 44 estuaries, representing 40% of the total estuarine surface area studied. An additional 40 estuaries exhibit moderate conditions. When considered together, the estuaries with moderate to high conditions represent 65% of estuarine surface area in the study.
- High conditions occur in estuaries along all coasts, but are most prevalent in estuaries along the Gulf of Mexico and Middle Atlantic coasts.
- 82 estuaries, representing 67% of estuarine surface area, exhibit moderate to high expressions of at least one of the following symptoms: depleted dissolved oxygen, loss of submerged vegetation, and nuisance/toxic algal blooms.

Assessment Data: National Estuarine Eutrophication Survey

Description: rigorous multi-year effort to synthesize the best available information about eutrophic conditions

Characteristics:

- consistent and comparable national data set was produced through survey of over 300 estuarine scientists and managers
- includes spatial and temporal information about eutrophication symptoms, including chlorophyll *a*, macroalgae, epiphytes, dissolved oxygen, submerged aquatic vegetation, and nuisance/toxic algae
- survey data aggregated by estuary and final results reviewed by experts at the Assessment Workshop
- collection, evaluation, and review of the survey data was most rigorous of all evaluations in the National Assessment

2 Human Influence on Eutrophication

Human influence on the expression of eutrophic conditions is substantial.

- A high level of human influence is associated with a majority (36) of the 44 estuaries with high eutrophic conditions.
- Only six (14%) of the 44 estuaries with high-level eutrophic conditions have corresponding high-level nitrogen inputs. An additional 22 of the 44 estuaries have moderate-level nitrogen inputs.
- Of the 44 estuaries with high-level eutrophic conditions, more than half (25) exhibit a high susceptibility to retaining nutrients.

Assessment Data:

- Watershed monitoring data from the U.S. Geological Survey provided first-order estimates of nitrogen inputs.
- U.S. Census Bureau population estimates and Department of Agriculture Agricultural Census data were used as potential nutrient pressure indicators.
- Estuarine susceptibility was determined using NOAA data on freshwater inflow, tide, and estuarine geometry.

Description: provides estimates of human-related nutrient inputs, estuarine susceptibility, and human influence

Characteristics: assessment based on data less rigorously evaluated and reviewed than for eutrophic conditions

3 Impaired Uses of Estuaries

Impairments to estuarine resources, and fisheries in particular, are of great concern.

- 69 estuaries were identified by workshop participants as having human-use impairments related to eutrophication.
- Compared to other impaired uses, commercial/recreational fishing and shellfisheries were identified as impaired for human use in the greatest number of estuaries, 43 and 46, respectively.

Assessment Data: expert evaluations at Workshop

Description: Experts identified impaired uses they judged to be related to estuarine eutrophic conditions.

Characteristics: Although the information is not supported by a comprehensive national data set, it does provide a rough insight into the extent of problems stemming from eutrophic conditions.

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4 Potential Management Concerns

Management requirements are dependent on eutrophic conditions and susceptibility.

- The 23 estuaries with high expressions of eutrophic conditions and high susceptibility are likely to require greater management effort and longer response time for results than those estuaries with low susceptibility. These estuaries represent approximately 10% of the national estuarine surface area.
- There are 10 estuaries that have low eutrophic conditions and high susceptibility; accordingly, they should be priorities for preventive management. These estuaries represent approximately 3% of the national estuarine surface area.
- All of the typical point and nonpoint pollution sources were identified at the Workshop as important to target in order to manage nutrient problems. However, there are some important regional differences in nutrient sources, such as combined sewer overflows in the North Atlantic.

Assessment Data: NOAA susceptibility and Eutrophication Survey data plus expert evaluations at Workshop

Description: In addition to evaluating eutrophic conditions and susceptibility (see numbers 1 and 2), experts identified pollution sources important for managing nutrient inputs in each watershed.

Characteristics: Although the pollutant source information is not based on a comprehensive national data set, the expert evaluation of important point and nonpoint sources is useful for gaining a first-order understanding at the national level of the types of actions, and the level of effort, that will be required to address the problem.

5 Future Eutrophic Conditions

Without preventive efforts, eutrophic conditions can be expected to continually worsen.

- Eutrophic conditions will most likely worsen in 86 estuaries by the year 2020.
- Of the 86 estuaries expected to worsen, 43 exhibit only low to moderate eutrophic conditions.
- The 10 estuaries that exhibit low eutrophic conditions and have high susceptibility are most at risk of future degradation if human-related nutrient inputs increase.

Assessment Data: projected population growth estimates adapted from the U.S. Census Bureau and NOAA susceptibility data

Description: Experts at the National Workshop used population growth and estuarine susceptibility estimates, along with their knowledge of the estuarine watersheds, to project the direction and magnitude of change in current eutrophic conditions.

Characteristics: The reliability of this information is inherently vulnerable to unforeseen changes in input levels from nutrient pollution sources.

6 Data Gaps and Research Needs

Much remains to be done to better characterize and understand estuarine eutrophication.

- Given all of the monitoring and research done to date, information and knowledge is still inadequate in 48 estuaries (low confidence or inadequate data for assessment). These estuaries represent approximately 25% of the nation's estuarine surface area.
- All participants in the National Assessment process agreed that research is needed to clarify the linkages between eutrophication and impacts on estuarine resources, including fisheries, recreation and tourism, and risks to human health.

Assessment Data: expert experience and knowledge, in combination with data completeness and reliability analysis of the Eutrophication Survey results

Description: Experts at the National Assessment Workshop identified data gaps and research needed to improve the assessment of the severity, human influence, impacts, and appropriate responses to eutrophication problems in estuaries.

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Key Findings, continued

6 Data Gaps and Research Needs, continued

- The National Assessment process confirms that much remains to be done to adequately characterize nutrient pressure on estuaries. Better quantification is needed of total nutrient inputs, inputs by source, and estimators of nutrient pressure (e.g., population, land use). Atmospheric and groundwater inputs are least well quantified.

- Better characterization of physical factors is needed, including basic circulation patterns, effects of weather patterns, climate change, changing land use, and resultant effects on nutrient delivery, circulation, and eutrophic conditions.

- Other research needs include defining the relationship between nutrient inputs and toxic blooms, better characterization of assimilative capacity, and characterization of the effects of seasonal population changes.

7 Toward A National Strategy

Assessment results will be valuable in setting national priorities.

- A national strategy, which incorporates the results of this assessment, should be developed to help set priorities and support decision-making at the national level.

- The strategy should focus on management, monitoring, and research, and should effectively integrate with regional, state, and local programs.

- For estuaries in serious condition, priorities should focus on management action; for those in less serious condition but at risk, the focus should be on monitoring and prevention.

- Estuaries for which there is insufficient information for evaluation should undergo basic monitoring and assessment activities.

Assessment Data: expert experience and knowledge base

Description: These recommendations were developed at the National Assessment Workshop from facilitated discussions with the participating estuarine eutrophication experts.

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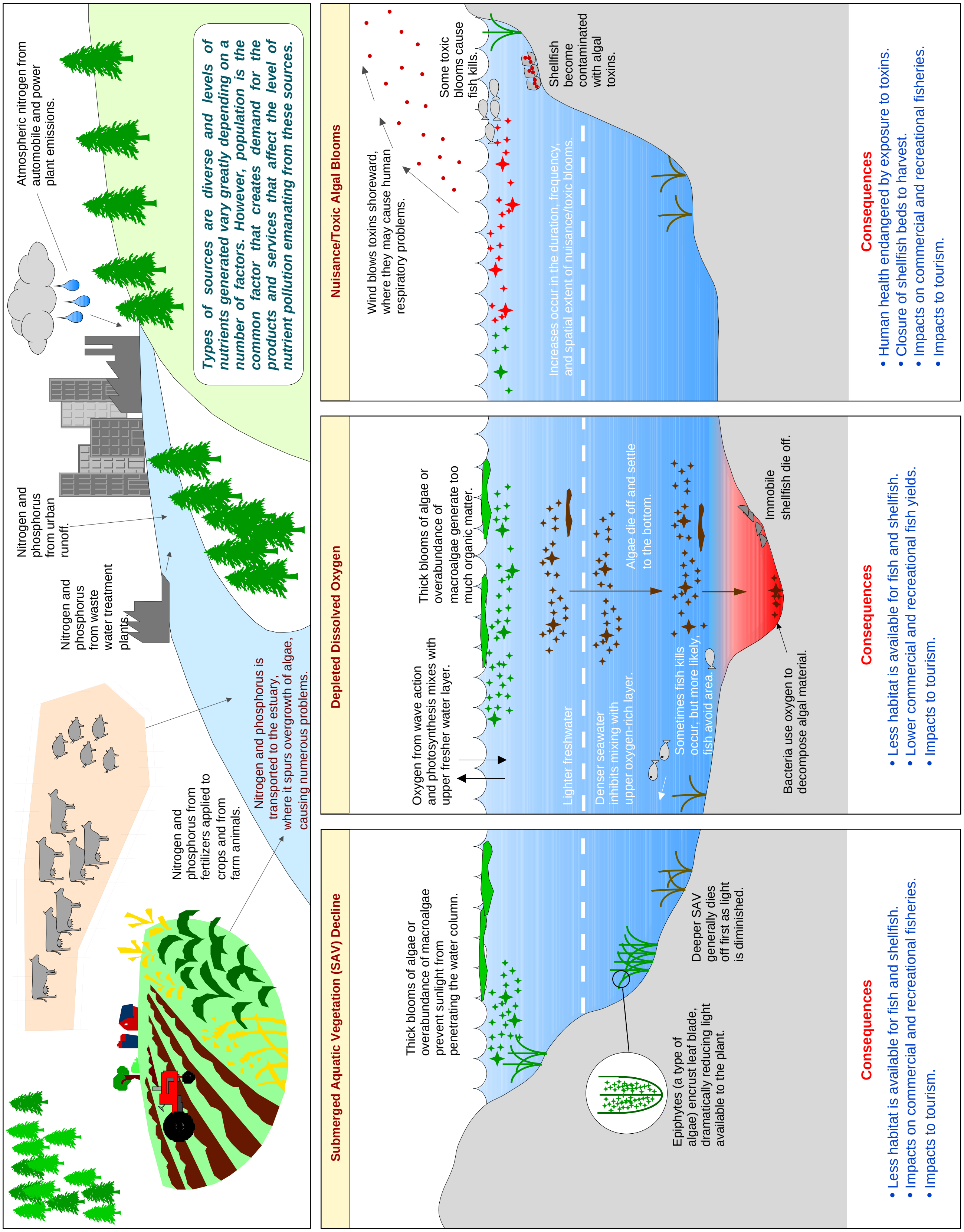
Estuarine Eutrophication: Nutrient Sources and Effects in Estuaries

Eutrophication is a process in which the addition of nutrients to water bodies stimulates algal growth. Under natural conditions, this is usually a slow process that results in healthy and productive ecosystems. In recent decades, however, a variety of human activities has greatly accelerated nutrient inputs to estuarine systems, causing excessive growth of algae and leading to degraded environmental conditions.



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Introduction

This report presents the results of a comprehensive National Assessment to address the problem of estuarine eutrophication. The assessment includes evaluations of eutrophic conditions, human influence, impaired estuarine uses, future conditions, data gaps and research needs, and recommendations for a national strategy to respond to the problem.

Estuarine Eutrophication: Background to the Problem

Eutrophication refers to a process in which the addition of nutrients to water bodies, primarily nitrogen and phosphorus, stimulates algal growth. This is a natural process, but it has been greatly accelerated by human activities. Estuaries have always received nutrients from natural sources in the watershed and from the ocean. In recent decades, however, population growth and related activities, such as various agricultural practices, wastewater treatment plants, urban runoff, and the burning of fossil fuels, have increased nutrient inputs by many times the levels that occur naturally.

Increased nutrient inputs promote a complex array of symptoms, beginning with the excessive growth of algae, which, in turn, may lead to other, more serious symptoms. In addition to the rate of algal growth, nutrient inputs may also affect which algal species are favored. This process is poorly understood, but some unfavorable species (e.g., *Pfiesteria*) appear to be linked to nutrient inputs.

A red tide causes a fish kill.
Photo courtesy of Woods Hole Oceanographic Institution

> ***Eutrophication refers to a process in which the addition of nutrients to water bodies stimulates algal growth. In recent decades, human activities have greatly accelerated nutrient inputs, causing the excessive growth of algae and leading to degraded water quality and associated impairments of estuarine resources for human use.***

In recent decades, eutrophication problems have been reported globally, from the Baltic, Adriatic, and Black Seas, to the estuaries and coastal waters of Japan, China, and Australia. Eutrophic symptoms have also been observed in the United States, including the Chesapeake Bay, Long Island Sound, and the northern Gulf of Mexico. More recently, it has become clear that nearly all U.S. estuaries exhibit some level of eutrophic symptoms, although the scale, intensity and impacts vary widely, as do the levels of nutrient inputs that produce these symptoms.

Whether nutrient additions result in degraded water quality depends on the extent of additional input and on natural characteristics that affect estuarine susceptibility to nutrients. In some estuaries, nutrients cause dense algal blooms to occur for months at a time, blocking sunlight to submerged aquatic vegetation. Decaying algae from the blooms uses oxygen that was once available to fish and shellfish. In other estuaries, these or other symptoms may occur, but less frequently, for shorter periods of time, or over smaller spatial areas. In still other estuaries, the assimilative capacity, or ability to absorb nutrients, may be greatly reduced, though no other symptoms are apparent. These eutrophic symptoms are indicative of degraded water quality conditions that can adversely affect the use of estuarine resources, including commercial and recreational fishing, boating, swimming, and tourism. Eutrophic symptoms may also cause risks to human health, including serious illness and death, that result from the consumption of shellfish contaminated with algal toxins, or from direct exposure to waterborne or airborne toxins.

It should be noted that although nutrients cause eutrophic symptoms, other human and natural influences may cause or affect the expression of such

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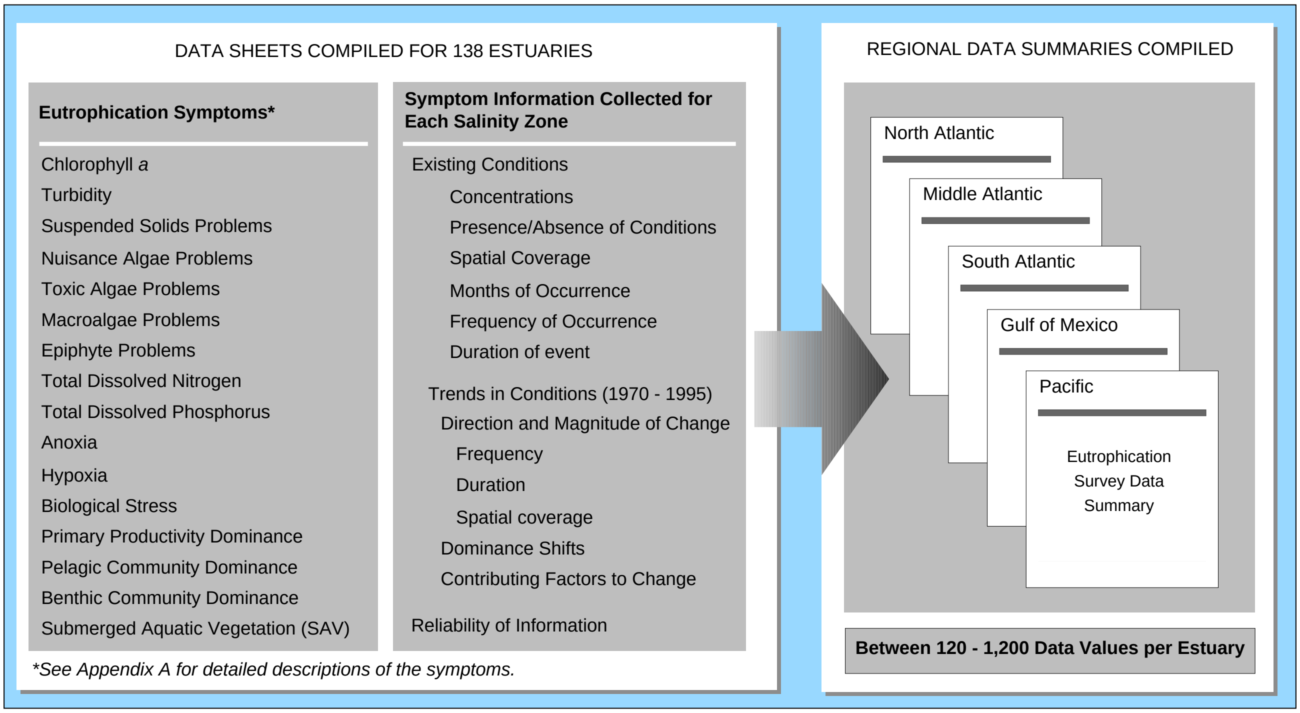
symptoms. These influences include engineered water flow, which decreases estuarine flushing rates; and development, dredging, and disease, which change nutrient assimilative capacity through losses of wetlands, sea grasses, oysters, and other filter feeders. In addition to nitrogen and phosphorus, there are other nutrients (e.g., silica) and trace elements that may be important under certain conditions, but their role is less understood.

Climate changes may also be significant for future conditions. Global warming may result in increased water temperatures, causing lower dissolved oxygen with no changes in nutrient inputs. At the same time, flushing times and exchange rates might increase with rising sea levels, which could possibly offset these effects.

For more than 40 years, scientists and natural resource managers have worked to understand, document, and resolve the complex issues associated with eutrophication in the nation's estuaries. Nonetheless, information concerning algal blooms, low dissolved oxygen, and other eutrophic symptoms was slow to capture the attention of the public, administrators, and legislators. Recently, the consequences of these symptoms have become more apparent, helping to raise awareness of nutrient-related environmental problems. For instance, extensive losses of submerged aquatic vegetation and the associated loss of fish habitat have occurred, many coastal water bodies have suffered worsening episodes of low dissolved oxygen, and blooms of nuisance and toxic algae have been occurring in new areas. For example, *Pfiesteria* was first identified as a major fish-killing agent in the Neuse and Pamlico River estuaries of North Carolina in 1992; in 1997, outbreaks occurred in tributaries of the Chesapeake Bay, where they had previously not been observed.

Given the rising concern of the scientific community and the public at large, NOAA began to investigate and evaluate the need for a more deliberate national response to the problem of estuarine eutrophication. In order to determine the national extent of this problem and to provide a basis for an appropriate and effective national response, it was necessary to survey the overall symptoms of eutrophication within the nation's estuaries. Historical information and ongoing field programs offered the raw materials, but the task remained to construct a comprehensive and consistent characterization of the symptoms of eutrophication. In addition, it was essential to present the results of the survey within the context of everyday use impairments (e.g., swimming, fish consumption) that are important to the American public. In fact, the population of U.S. coastal and upstream areas is projected to increase by more than 13 percent by 2010, suggesting that nutrient-related problems are likely to get worse. This underscores the need to stimulate additional public involvement by presenting and publicizing the best available information to concerned citizens, resource managers, and policy makers alike.

Figure 1. *Data characteristics of NOAA's Estuarine Eutrophication Survey*



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The Nation's First Comprehensive Estuarine Eutrophication Assessment

Since its inception in 1992, NOAA's National Estuarine Eutrophication Survey has synthesized the best available information on eutrophication-related symptoms from more than 300 scientists and environmental managers. Recently published in five regional reports, the data characterize the spatial domain, severity, duration, frequency and past trends of 16 eutrophication related conditions in estuaries of the coterminous United States (NOAA 1996, 1997a, 1997b, 1997c, 1998).

The 138 estuaries characterized in this study represent more than 90 percent of both the total estuarine water surface area and the total number of major U.S. estuaries. Although not an estuary, the Mississippi River Plume is also included because of its importance to the Gulf of Mexico and associated estuaries to the west. Alaska, Hawaii and U.S. territories were not included in this assessment due to limited resources.

Experts interpret survey results at the National Assessment Workshop.

A common spatial framework (salinity zones representing tidal fresh, mixing, and saltwater environments) and predefined data categories were used to consistently characterize the information on conditions and trends for each estuary. In all, this survey produced an array of data containing more than 40,000 data values (120 to 1,200 per estuary; Figure 1). While providing the best possible information on the problem, this array of data was also challenging to interpret.

The National Report: A Challenge to Interpret the Data

NOAA worked with a "Core Group" of 15 scientists and resource managers (see Acknowledgments) to develop and apply methods that would best integrate the survey data for each estuary. It seemed reasonable that eutrophication symptoms and their time/space characteristics could be combined in a way that provided a single value to represent the status of eutrophication symptoms in each estuary. Moreover, this index would allow comparisons, ranking, and priority-setting among estuaries, as well as facilitate summaries of national and regional results. To accomplish this, two obstacles—data quality and a lack of methodology for combining numerous parameters into a single value—would have to be overcome.

Data Quality. An analysis of data completeness and the reliability of symptom data was performed for all estuaries so that confidence levels could be estimated for the data. For 17 estuaries, symptom data were so limited that an assessment of overall eutrophic conditions could not be made. Most of these were on the Pacific Coast. For 31 other systems, some of the symptom data provided by the experts was rated as "speculative" because it was based on spatially or temporally limited field observations. The overall confidence levels for these estuaries was therefore assessed as low. The evaluations for each symptom were carried through the assessment process to provide a basis for assigning a confidence rating to the overall assessment of eutrophic conditions. This confidence evaluation is important, because incomplete or uncertain data were sometimes included in the overall assessment because it was the best information available.

Developing a Methodology to Aggregate Symptom Data. There was no method available for combining symp-

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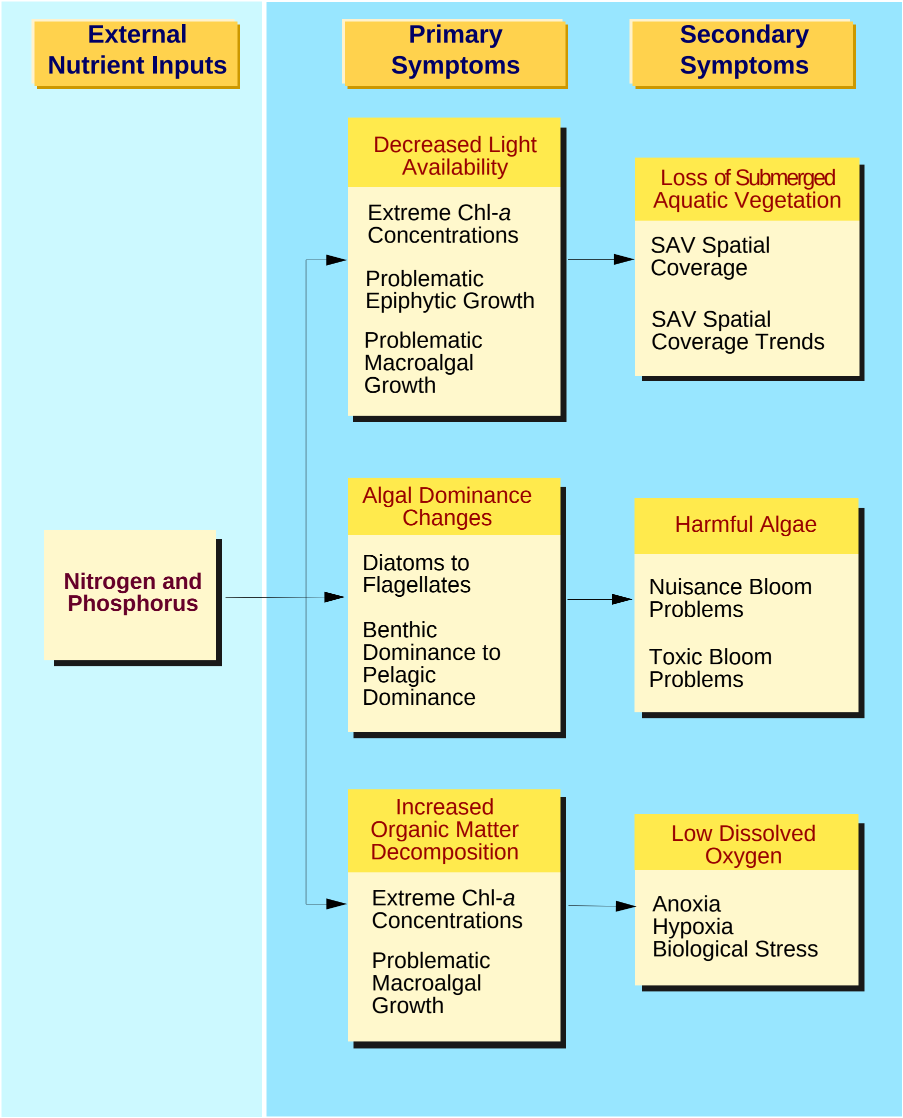
tom data into a single assessment for each estuary; therefore, the Core Group had to address several questions while determining the best way to integrate the existing data:

- Are all eutrophic symptoms and their characteristics equally important? Should all 16 symptoms be considered in the national assessment? Do certain symptoms logically group or occur in a linear sequence?
- Do all eutrophic symptoms have the potential to exist in all estuaries?
- Is the threshold for symptoms the same in all estuaries? For example, does a given concentration of chlorophyll *a* represent "high" eutrophic symptoms in all estuaries?

The Eutrophication Model. To help overcome these obstacles and properly interpret the information, the Core Group participated in two work sessions to develop and test several analytical and numerical methods. Ultimately, a single model was developed that made maximum use of the survey data. While this model does not account entirely for the complexity of this issue, it uses available information to best describe the sequence and severity of eutrophic conditions (Figure 2). The model used six symptoms that were most directly related to nutrient inputs. Three primary symptoms, algal abundance (using chlorophyll *a* as an indicator), epiphyte abundance, and macroalgae, represent the first possible stage of water-quality degradation associated with eutrophication. Although nitrogen and phosphorus concentrations in the water column are related to nutrient inputs, they are also influenced by other biological and chemical processes. As a result, elevated concentrations do not necessarily indicate that eutrophic symptoms are present, nor do low concentrations necessarily indicate that eutrophication is not present. As an example, chlorophyll *a* concentrations may be very high while dissolved nutrient concentrations are low. This scenario is common during peak phytoplankton production because these organisms assimilate the nutrients very efficiently. Thus, nutrient concentrations in the water column were not included as primary symptoms in the model.

In many estuaries, the primary symptoms lead to secondary symptoms, such as submerged aquatic vegetation loss, nuisance and toxic algal blooms (although for toxic forms the linkage is not well established), and low dissolved oxygen. In some cases, secondary symptoms can exist in the estuary without originating from the primary symptoms. This occurs, for instance, in many North Atlantic estuaries where toxic algal blooms are transported from the coastal ocean. In other places, disease or suspended sediments have contributed to declines in submerged aquatic vegetation.

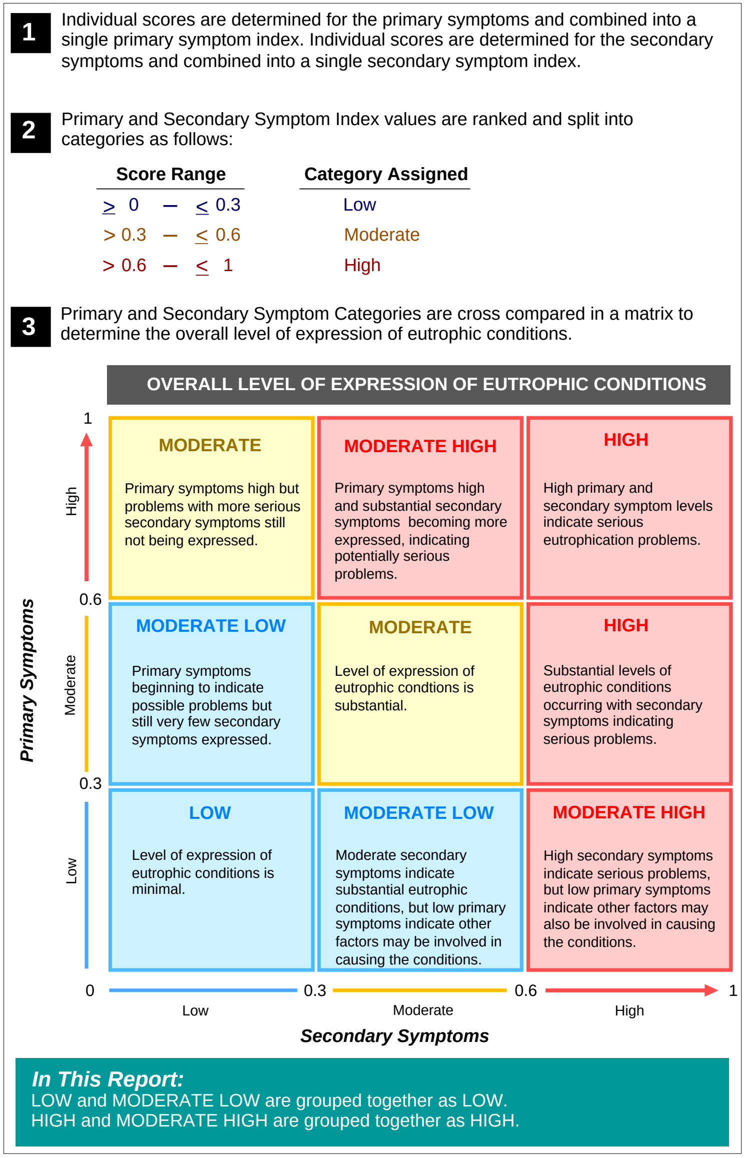
Figure 2. *The simplified eutrophication model used for the National Assessment*



Determining Overall Eutrophic Conditions. A numerical scoring system was developed to integrate information from all six primary and secondary symptoms to determine the overall status of eutrophic symptoms in each estuary. This scoring system was implemented in three phases according to the methods described in Figure 3 (see Appendix A for a detailed description).

First, a single index value was computed from all primary symptoms. The scoring system gave equal weight to all three symptoms and considered the spatial and temporal characteristics of each. The scores for the three symptoms were then averaged, resulting in the highest values being assigned to estuaries having multiple primary symptoms that occur with great frequency, over large spatial areas of the estuary, and for extended periods of time. Likewise, the lowest scores indicate estuaries that exhibit few, if any, characteristics of the primary symptoms.

Figure 3. *Steps followed in determining the overall level of expression of eutrophic conditions in estuaries*



1 Individual scores are determined for the primary symptoms and combined into a single primary symptom index. Individual scores are determined for the secondary symptoms and combined into a single secondary symptom index.

2 Primary and Secondary Symptom Index values are ranked and split into categories as follows:

Score Range	Category Assigned
≥ 0 – ≤ 0.3	Low
> 0.3 – ≤ 0.6	Moderate
> 0.6 – ≤ 1	High

3 Primary and Secondary Symptom Categories are cross compared in a matrix to determine the overall level of expression of eutrophic conditions.

OVERALL LEVEL OF EXPRESSION OF EUTROPHIC CONDITIONS

	Low	Moderate	High
High	**MODERATE** Primary symptoms high but problems with more serious secondary symptoms still not being expressed.	**MODERATE HIGH** Primary symptoms high and substantial secondary symptoms becoming more expressed, indicating potentially serious problems.	**HIGH** High primary and secondary symptom levels indicate serious eutrophication problems.
Moderate	**MODERATE LOW** Primary symptoms beginning to indicate possible problems but still very few secondary symptoms expressed.	**MODERATE** Level of expression of eutrophic condtions is substantial.	**HIGH** Substantial levels of eutrophic conditions occurring with secondary symptoms indicating serious problems.
Low	**LOW** Level of expression of eutrophic conditions is minimal.	**MODERATE LOW** Moderate secondary symptoms indicate substantial eutrophic conditions, but low primary symptoms indicate other factors may be involved in causing the conditions.	**MODERATE HIGH** High secondary symptoms indicate serious problems, but low primary symptoms indicate other factors may also be involved in causing the conditions.

In This Report:
LOW and MODERATE LOW are grouped together as LOW.
HIGH and MODERATE HIGH are grouped together as HIGH.

Next, a single index value was computed from all secondary symptoms. The scoring system again gave equal weight to all symptoms and their spatial and temporal characteristics. The highest score of any of the three symptoms was then chosen as the overall secondary value for the estuary. This weights the secondary symptoms higher than the primary symptoms, because the secondary symptoms take longer to develop, thereby indicating a more chronic problem, and being more indicative of actual impacts to the estuary.

Finally, the range of numeric scores assigned to primary and secondary symptoms was divided into categories of high, moderate, and low. Primary and secondary scores were then compared in a matrix so that overall categories could be assigned to the estuaries (Figure 3). Estuaries having high scores for both primary and secondary conditions were considered to have an overall "high" level of eutrophication. Likewise, estuaries with low primary and secondary values were assigned an overall "low" level of eutrophication. The Core Group members, using the matrix as a guide, then assigned scores to the remaining estuaries based on their interpretations of each estuary's combined values.

Interpreting the Model Results. While the model offered a potentially wide scale over which to define the severity of the problem, few of the 138 estuaries or the Mississippi River Plume actually fell at either extreme of this continuum, where the numerical scoring systems are more easily interpreted. Logically, estuaries with few primary symptoms and low numeric scores were considered to be relatively unaffected by nutrient-related conditions when compared to estuaries with both primary and secondary symptoms and higher numeric scores.

Most estuaries showed varying degrees of both primary and secondary symptoms, so that the meaning of these scores was more difficult to determine. This was particularly true for two conditions, for which these general guidelines for interpretation were offered:

High or moderate primary symptoms and low secondary symptoms. These estuaries have rela-

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tively well developed conditions associated with algal blooms, epiphytes, and/or macroalgae, which suggests that they are in the early stages of eutrophication and may be on the edge of developing more serious conditions. These systems may be susceptible to additional nutrient inputs and could begin to develop secondary symptoms of eutrophication.

High or moderate secondary symptoms and low primary symptoms. For these estuaries, advanced secondary symptoms exist, even though the "prerequisite" primary symptoms (as suggested by the model) may not be well developed. Three possible interpretations are offered to describe these conditions. For some estuaries, the secondary conditions were transported from offshore coastal areas, rather than originating within the estuary. This occurs, for example, with toxic bloom conditions in North Atlantic estuaries. Alternatively, it is possible that nutrient-related water quality conditions have recently improved, but the response time to reduce secondary symptoms is longer than it is for primary symptoms. The secondary symptoms that remain may be residual conditions that also may improve as nutrient concentrations continue to decrease. Finally, it is possible that secondary conditions in an estuary are related only partially, or not at all, to nutrient enrichment. For example, submerged aquatic vegetation losses in Long Island Sound have been attributed to both disease and nutrient enrichment.

Through the use of a simple model, a framework was established to help understand the sequence, processes, and symptoms associated with nutrient enrichment. Despite its limitations (e.g., the model does not account for changes in assimilative capacity from losses of wetlands), the model represents the first attempt to synthesize large volumes of data and to derive a single value for eutrophication in each estuary. With this foundation, the next steps are to (1) expand understanding of the relationship between eutrophication and nutrient sources, and (2) evaluate appropriate responses to the problem.

Extending the Assessment: Toward a National Strategy

This National Assessment focuses on the data in NOAA's Estuarine Eutrophication Survey, the fundamental goal of which was to describe the scale, scope, and severity of nutrient enrichment conditions nationwide, and to compare the various expressions of eutrophic symptoms in individual estuaries. In a sense, the model represents a form of environmental triage—separating estuaries that are in serious condition, but could potentially improve, from those that presently do not experience many symptoms, but are seemingly at risk. In turn, this represents a starting point for understanding why these conditions exist, how and why conditions differ across estuaries, whether certain problematic conditions may respond to remedial actions, and which of these actions would best protect estuaries from further degradation.

To do so means to go beyond the survey data. At the very least, more information is needed about the magnitude and sources of nutrient inputs, the natural ability of estuaries to flush or assimilate incoming nutrients, and the relative influence of both of these factors on the expression of eutrophication. Moreover, these results need to be associated with use impairment and public health issues that bring the message to the public and help to set priorities for management and research activities. With the guidance of the Core Group, the National Assessment was expanded to include additional data sets that begin to examine these linkages.

Expanding the Model. To accommodate the additional analyses, the original eutrophication model was expanded (Figure 4) so that eutrophic symptoms could be compared with other national data sets, specifically estuarine transport (i.e., flushing, also referred to as susceptibility), nutrient inputs and sources, and eutrophication-related estuarine use impairments. The data for these assessments were derived from a variety of sources, described below. These assessments were intended to allow general observations about the linkages between symptoms, nutrient loading and susceptibility, and between eutrophic conditions and use impairments. Recommendations for potential responses to the problem were developed from conclusions based on these observations.

Susceptibility. Estimates were made of the natural tendency of an estuary to retain or export nutrients. The rate at which water moves through the estuary was determined by examining tidal action and the volume of freshwater flowing in from rivers. In general, if the water (and nutrients) are flushed quickly, there is not sufficient time for problems to develop and the estuary is not particularly susceptible. If the estuary acts more like a bathtub, with nutrient-rich water sitting in the system for a long time, then there is time for nutrients to be taken up by algae. These estuaries are more susceptible to developing eutrophic symptoms.

Although only dilution and flushing were included in this susceptibility estimate, biological processes may also affect susceptibility. For instance, filter feeders raise an estuary's capacity to assimilate more

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nutrients before showing symptoms. Wetlands, which retain nutrients that might otherwise enter estuarine waters, also improve an estuary's ability to fend off eutrophic symptoms.

Nutrient Inputs. The level of nutrients entering estuaries is a critical factor in determining the level to which they will develop symptoms. Excess nutrient inputs are mainly human-related and are due to high coastal population density, various agricultural practices (e.g., fertilizer applications, animal feedlot operations), the burning of fossil fuels, and sewage treatment effluents.

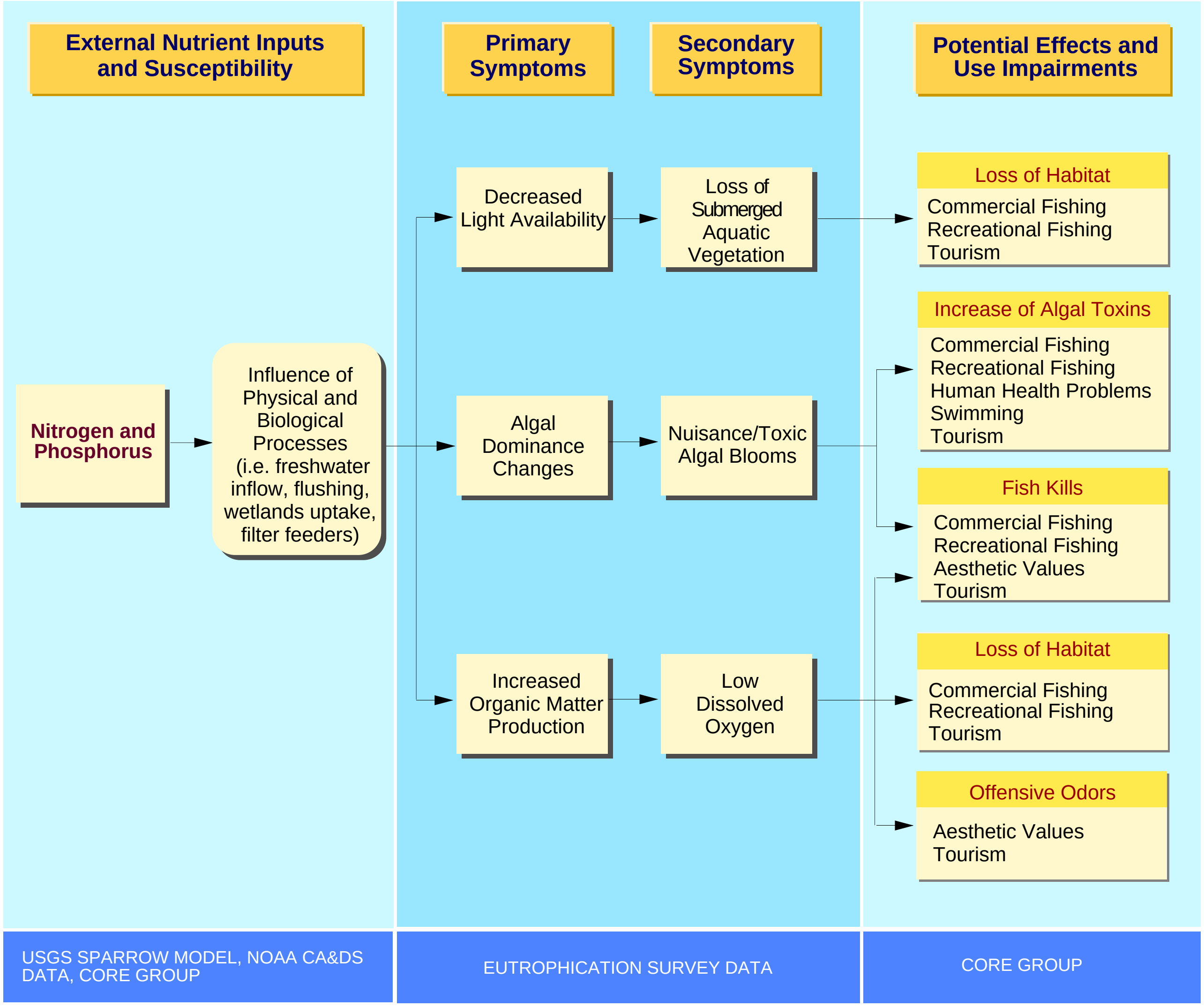
Estuarine Use Impairments. Impaired resources (in terms of human use) were evaluated to gain a basic understanding of the level of negative impacts occurring in the nation's estuaries. These include impacts to recreational activities, such as swimming and boating, as well as to commercial operations, such as fishing and shellfishing.

Potential Management Concerns. Evaluations were also made of the most important sources to target in order to manage nutrient inputs into estuaries.

Data Sets and Data Quality. NOAA had access to national data sets that were used for characterizations; however, the assessments were largely based on the knowledge and experience of the Core Group and other Workshop participants.

For nutrient-loading estimates, NOAA provided comparative data for 1987 (adapted from the U.S. Geological Survey's SPARROW model; Smith et al., 1997) for five major sources: fertilizer, livestock wastes, point sources, atmospheric deposition, and nonagricultural sources. In addition, NOAA provided information on coastal population and land usage, which were used as comparative estimators of loading. Estuarine susceptibility estimates were based on an estuary's dilution potential and flushing potential, which are calculated from freshwater

Figure 4. *The expanded eutrophication model*



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inflow, tidal prism, and estuary geometry (NOAA's Coastal Assessment & Data Synthesis System, 1998). These data sets were synthesized and interpreted less rigorously than the symptom data, and thus, were more speculative than the data for eutrophic symptoms.

The assessment of estuarine-use impairments and management targets was not based on hard data; rather, it was derived from the expert knowledge of participants at the National Assessment Workshop. Despite the speculative nature of these assessments, the information was still very useful, providing insight into the consequences of eutrophic symptoms in estuaries, and into the most effective management actions for reducing them.

See Appendix A for details on the methods and information sources used in the assessment.

Organizing the Results: Seven Key Questions

Seven questions, which follow the logic sequence of the expanded eutrophication model, were developed to help organize results for the National Assessment. Question 1 examines the results of the model. Questions 2 through 4 examine linkages between these symptoms, pollution sources, and coastal use impairments. Questions 5 through 7 identify priority management, monitoring, and research needs.

1. What are the severity and extent of eutrophic conditions exhibited within the estuaries of the United States?

This analysis is based on the eutrophication data set and its interpretation using the eutrophication model.

2. To what extent are eutrophic conditions in U.S. estuaries caused by human activities?

The U.S. Geological Survey SPARROW model provided first-order estimates of nutrient loads for 1987 from five major sources. Population estimates and Agricultural Census data also were used to represent the potential for nutrient sources. In addition, an indicator of estuarine flushing potential was developed based on freshwater inflow, tide, and estuarine geometry.

3. To what extent do eutrophic conditions impair the use of estuarine resources, and what are the important impaired uses?

Core Group members selected from a list of seven use impairments for each estuary. This list included recreational and commercial fishing, fish consumption, shellfishing, swimming, boating, aesthetics, and tourism.

4. Where should management efforts be targeted to achieve the greatest benefit toward remediation and protection from future degradation, and what are the most important sources to target?

Core Group members selected from a list of 10 point and nonpoint nutrient source targets.

5. To what extent can the severity and extent of eutrophic conditions be expected to increase by the year 2020, given the natural susceptibility of estuaries and the potential for increasing nutrient inputs?

Projected population growth estimates were used to represent the potential for future nutrient inputs and thus, changes in eutrophic conditions. Susceptibility was used to determine the expected severity of change.

6. Which data gaps and research and monitoring needs are most critical in terms of improving the ability to assess and respond to eutrophic conditions?

Core Group members listed these, based on their experience and the findings of Questions 1 through 5 above.

7. How can the results of this assessment be translated into a national strategy?

Recommendations were developed from discussions between members of the Core Group.

Using this Report and the Data

This report contains five sections that are organized according to the seven questions listed above. The report emphasizes the results from the eutrophic symptoms model (i.e., Question 1) as they represent the culmination of the multi-year survey work and provide an unprecedented classification for the nation's estuaries. The results of the expanded assessment model (i.e., Questions 2 through 7) are also provided, but at a more general level consistent with the less rigorous methods of data collection. The most direct responses to the seven questions are provided in the Executive Summary, while the National Overview and Regional Summaries sections are supplemented by mapped and tabular displays of the synthesized results. The Conclusions and Recommendations sections propose next steps, as suggested by the Core Group and other Workshop participants. The data and methods used in this National Assessment are described in the Appendices. The digital data can be accessed on-line at**:**

http://cads.nos.noaa.gov

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National Overview

This assessment characterizes the overall eutrophic conditions and the water-quality problems associated with nutrient enrichment for 138 U.S. estuaries. A Core Group of eutrophication experts collaborated with NOAA and was instrumental in developing methods to assess the results of the National Eutrophication Survey. At a National Assessment Workshop, the Core Group and additional experts reviewed and interpreted the Survey results, and analyzed the factors that influence the development of problematic conditions. They also reported on impairments in estuarine uses, potential management concerns, and the future outlook to the year 2020. Note that the Mississippi River Plume was also characterized, and is counted as an additional "estuary" in the figures, but is not included in surface area statistics.

Eutrophic Conditions

The assessment of overall eutrophic conditions is based on the combined level of expression of six symptoms: chlorophyll *a*, epiphyte abundance, macroalgal abundance, depleted dissolved oxygen, submerged aquatic vegetation loss, and nuisance/toxic algal blooms. The level of expression of each is determined by the concentration, spatial coverage, frequency of occurrence, and/or other factors (refer to Figure 3, page 5).

For each symptom assessment, an evaluation of the level of confidence was made based on the temporal and spatial representativeness of the data. The confidence evaluation is important, because in some cases the data were incomplete or uncertain, but still provided the best information available and the only means of presenting a national picture. These symptom confidence ratings provided the basis for evaluating the confidence of overall eutrophic conditions.

The data for 17 estuaries were too sparse to provide an overall view of eutrophic conditions although limited data existed for certain symptoms in some of these estuaries (see page 18 for list). For an additional 38 estuaries, the overall assessment confidence was rated as low (see Appendix B).

> ***The expression of overall eutrophic conditions is high in 44 U.S. estuaries. These estuaries are located mainly in the Gulf of Mexico and Middle Atlantic regions; however, certain estuaries along all coastlines exhibit high levels of eutrophic conditions.***

Overall Conditions. National Assessment Workshop participants concluded that the expression of overall eutrophic conditions was high in 44 estuaries, representing 40% of the total estuarine surface area studied (Figure 5). These estuaries were located mainly in the Gulf of Mexico and Middle Atlantic regions; however, some estuaries along all coastlines exhibited high levels of eutrophic conditions (Figures 6 and 7). This means that in these estuaries, one or more symptoms occurred at problem levels every year, or persistently, across a major part of each estuary. An additional 40 estuaries exhibited moderate eutrophic conditions. When considered together, the estuaries with moderate to high conditions represent 65% of the estuarine surface area studied. The remaining 38 estuaries exhibited low

Figure 5. *Level of expression of eutrophic conditions*

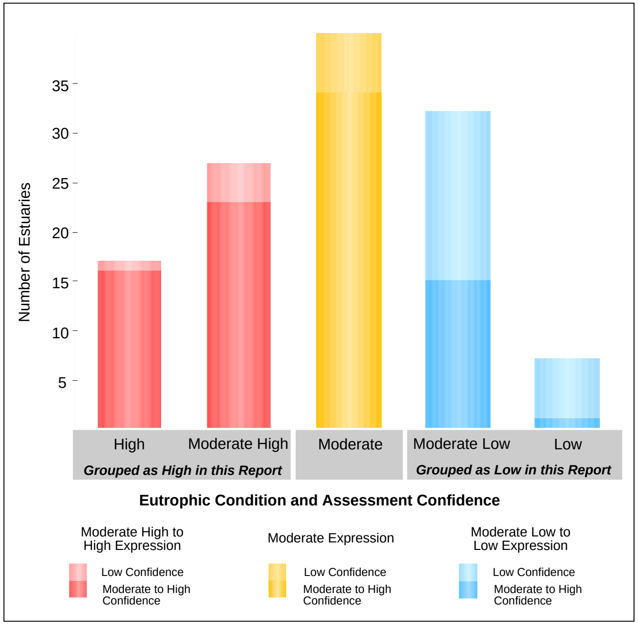

Figure 6 . *Eutrophic conditions by region*

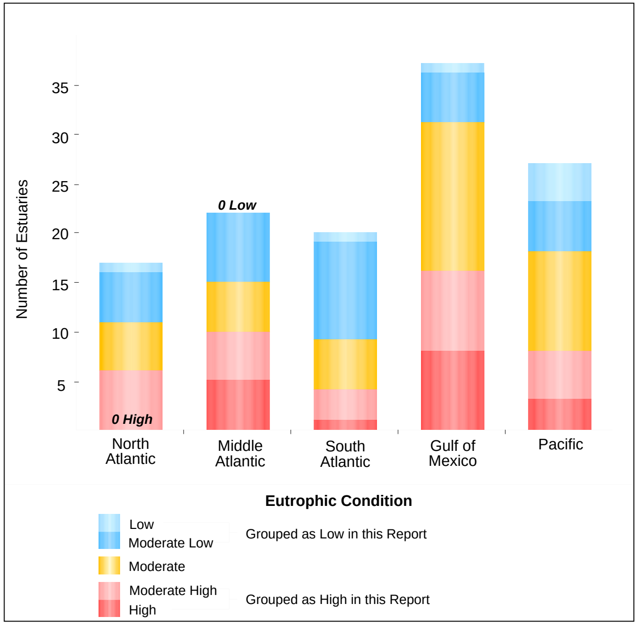

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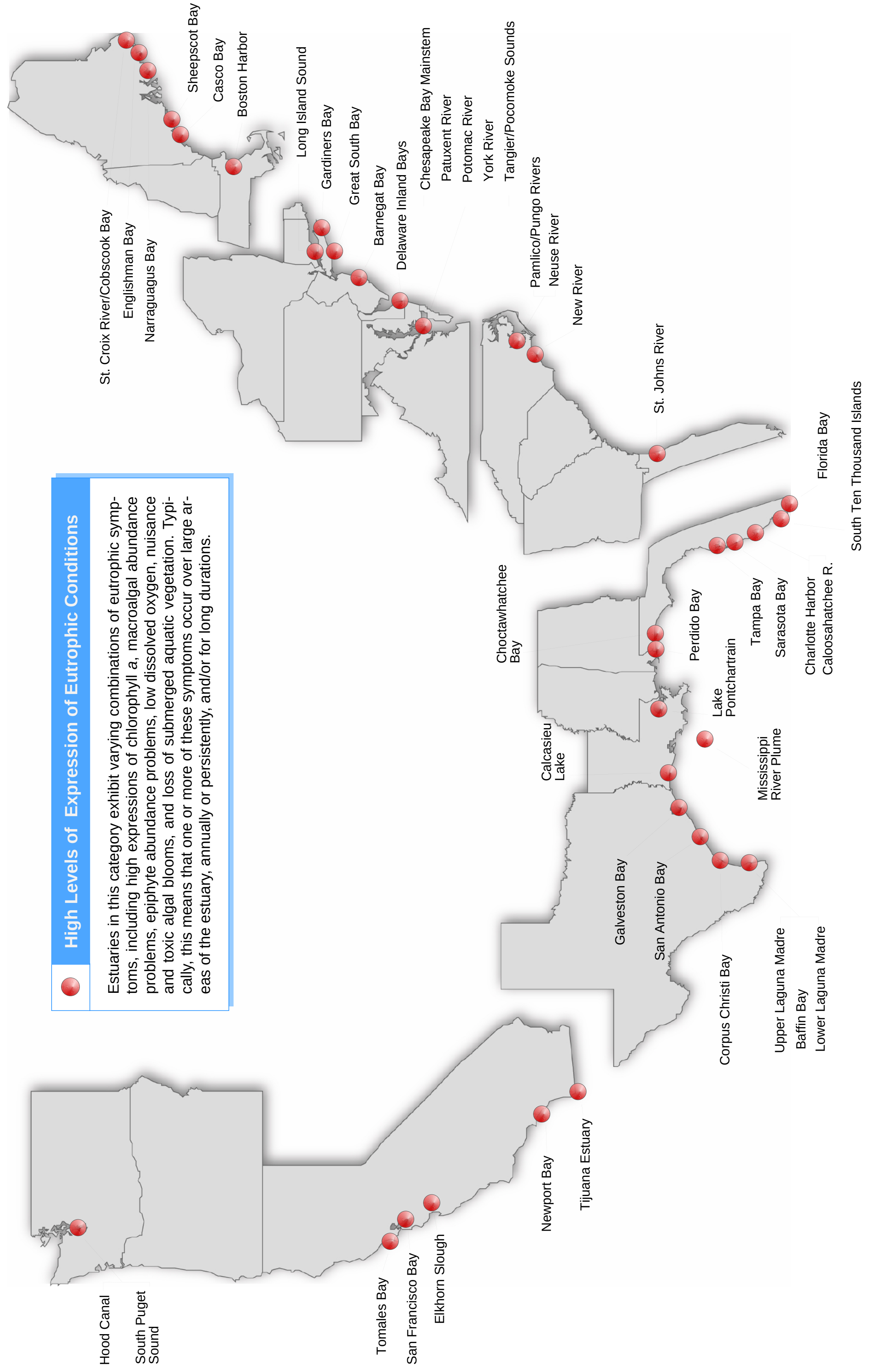
Figure 7. *Estuaries with high levels of expression of eutrophic conditions*

Forty-four estuaries along all of the nation's coasts were assessed by workshop participants as showing high expressions of eutrophic conditions. The Middle Atlantic and Gulf of Mexico have the highest percentages of estuaries with high eutrophic conditions. The Pacific and South Atlantic regions contain the highest percentage of estuaries that lack sufficient information to confidently assess eutrophic conditions. An additional forty estuaries (not shown) have moderate levels of eutrophic conditions.



High Levels of Expression of Eutrophic Conditions

● Estuaries in this category exhibit varying combinations of eutrophic symptoms, including high expressions of chlorophyll a, macroalgal abundance problems, epiphyte abundance problems, low dissolved oxygen, nuisance and toxic algal blooms, and loss of submerged aquatic vegetation. Typically, this means that one or more of these symptoms occur over large areas of the estuary, annually or persistently, and/or for long durations.

Note: Conditions are not necessarily related in whole to human-related eutrophication; to various degrees natural causes and other human disturbances may also play a role. For instance, some estuaries in Maine are typified by natural occurrences of toxic algae, which drift in from the open ocean. Once in the estuary, however, these blooms may be sustained by human nutrient inputs.

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levels of eutrophic conditions, meaning that symptoms were not observed at problem levels or that problem conditions occurred infrequently or only under specific and unusual circumstances. About half of these estuaries were located in the South Atlantic and Pacific regions.

In more than 80 percent of estuaries with high and moderate levels of eutrophic conditions, the assessment confidence was high; conversely, confidence was high in fewer than half of the systems assessed as having low eutrophic conditions. Most of the estuaries with low confidence are located in the Pacific and South Atlantic regions.

Symptoms: Common Signs of Eutrophication. The immediate response to nutrient inputs is the overgrowth of algae. The primary symptoms of increased nutrient concentrations in the water column are high levels of chlorophyll *a*, epiphytes, and/or macroalgae (see sidebar, right). It is thought that once primary symptoms are observed at high levels, an estuary is in the first stages of displaying undesirable eutrophic conditions.

High expressions of chlorophyll *a* occurred in 39 estuaries, high expressions of macroalgal abundance occurred in 24 estuaries, and high expressions of epiphyte abundance occurred in 11 estuaries (see Figure 8 for an accounting of symptom expression broken down by eutrophic condition category). Overall, at least one of these primary symptoms was expressed at high levels in 58 estuaries. In some cases, high levels may be natural, but this observation indicates that 40 percent of the nation's estuaries may be in the first stages of developing problems associated with eutrophication. On a regional basis, epi-

Common Symptoms of Eutrophication

Chlorophyll *a* is a measure used to indicate the amount of microscopic algae, called phytoplankton, growing in a water body. High concentrations are indicative of problems related to the overproduction of algae.

Epiphytes are algae that grow on the surfaces of plants or other objects. They can cause losses of submerged aquatic vegetation by encrusting leaf surfaces and thereby reducing the light available to the plant leaves.

Macroalgae are large algae, commonly referred to as "seaweed." Blooms can cause losses of submerged aquatic vegetation by blocking sunlight. Additionally, blooms may also smother immobile shellfish, corals, or other habitat. The unsightly nature of some blooms may impact tourism due to the declining value of swimming, fishing, and boating opportunities.

Low dissolved oxygen occurs as a result of large algal blooms that sink to the bottom and use oxygen during the process of decay. Low dissolved oxygen can cause fish kills, habitat loss, and degraded aesthetic values, resulting in the loss of tourism and recreational water use.

Losses of submerged aquatic vegetation (SAV) occur when light is decreased due to turbid water associated with overgrowth of algae or as a result of epiphyte growth on leaves. The loss of SAV can have negative effects on the ecological functioning of an estuary and may impact some fisheries because the SAV beds serve as important habitat.

Nuisance and toxic algal blooms are thought to be caused by a change in the natural mixture of nutrients that occurs when nutrient inputs increase over a long period of time. These blooms may release toxins that kill fish and shellfish. Human-health problems may also occur due to the consumption of seafood that has accumulated algal toxins or from the inhalation of airborne toxins. Many toxic algal blooms occur naturally; however, the role of nutrient enrichment is unclear.

Figure 8. *Level of expression of symptoms within each overall category of eutrophic condition*

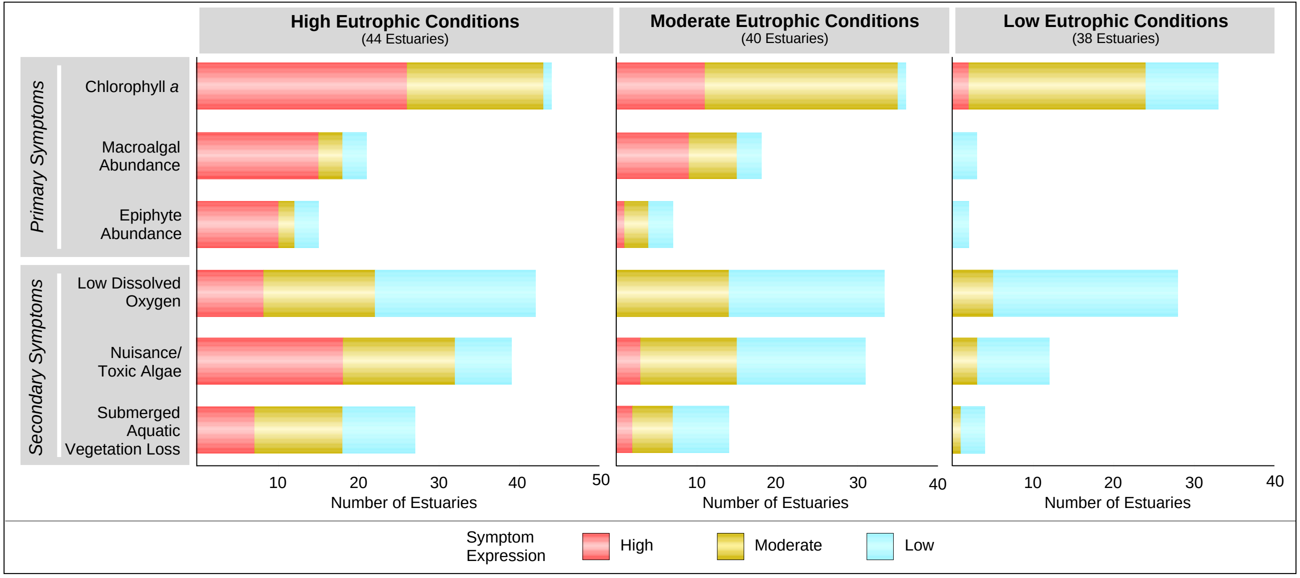

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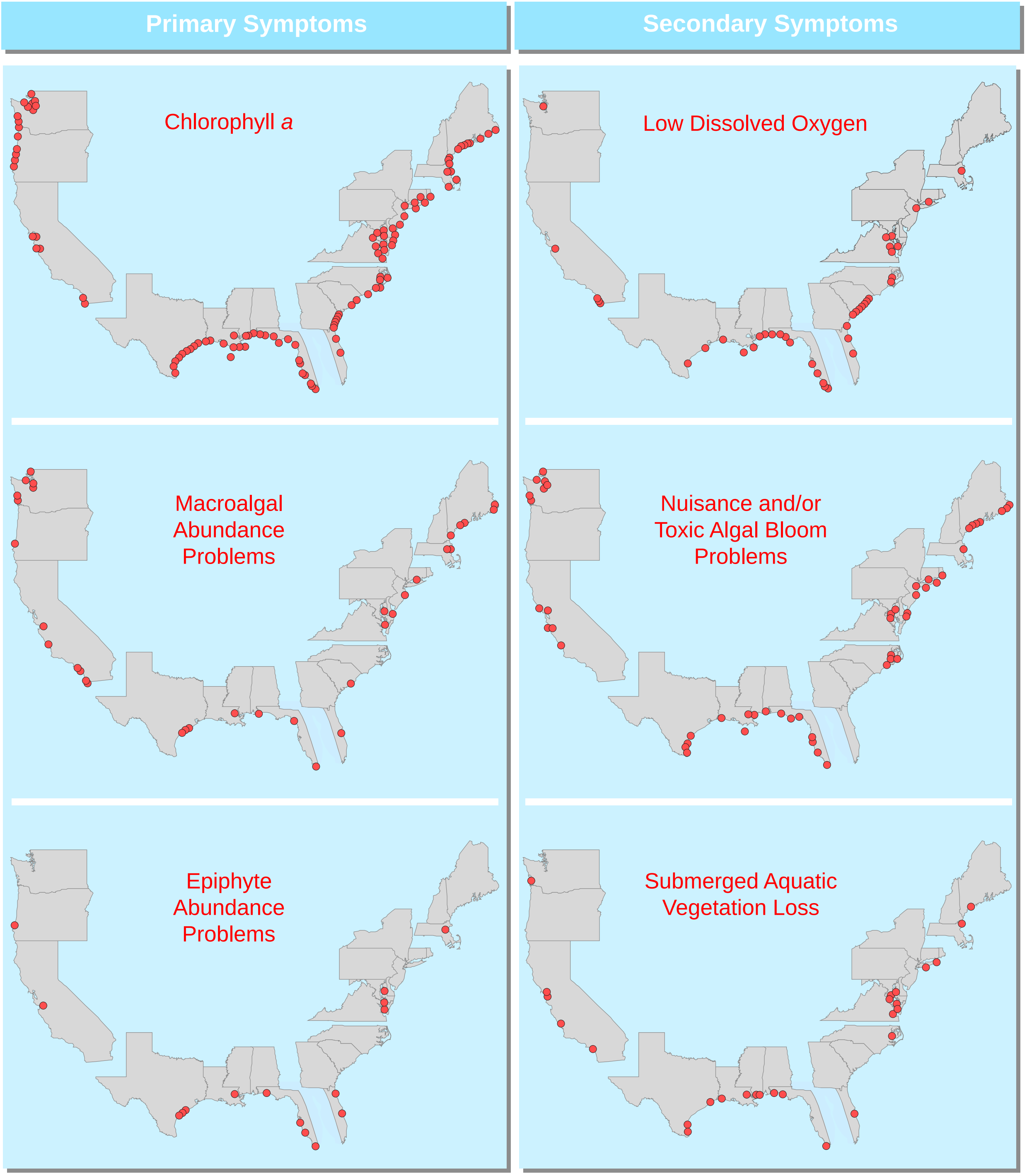
Figure 9. *Expression of eutrophic symptoms*

These maps depict estuaries with moderate to high levels of expression of eutrophic symptoms, indicating areas of possible concern. Note that these symptoms are not necessarily related in whole to human-related nutrient inputs; natural causes and other human disturbances may also play a role, to various degrees, in the expression of symptoms.



phyte problems occurred mainly in Gulf of Mexico estuaries, while higher levels of chlorophyll *a* and macroalgae were observed in estuaries of all regions (Figure 9).

While high levels of primary symptoms are strong indicators of the onset of eutrophication, the secondary symptoms, which include low dissolved oxygen, the loss of submerged aquatic vegetation, and the occurrence of nuisance and toxic blooms, indicate more serious problems, even at moderate levels. Note that while there is a direct causative link between nutrients and primary symptoms, there are many other factors, both natural and human related,

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More than half of U.S. estuaries have moderate to high expressions of at least one of the secondary symptoms. This finding is important because these symptoms can have serious consequences, including negative impacts on commercial fish yields, degraded recreational opportunities, increased risks to human health, and adverse affects on tourism.

that may contribute to the occurrence of secondary symptoms.

Depleted dissolved oxygen was expressed at moderate or high levels in 42 estuaries. Twenty-seven estuaries had moderate or high levels of submerged aquatic vegetation loss, and 51 estuaries exhibited moderate or high nuisance / toxic algal blooms (Figures 8 and 9). Overall, moderate or high levels of at least one secondary symptom was observed in 82 estuaries, representing 67% of the nation's estuarine surface area—an indication that eutrophication is well developed and is potentially causing serious problems in more than half of U.S. estuaries. The secondary symptoms were restricted regionally, with the exception of nuisance and toxic blooms, which were observed in systems along all coasts. Losses of submerged aquatic vegetation were mostly limited to the Gulf of Mexico and Middle Atlantic regions, and low dissolved oxygen was observed mainly in the Gulf of Mexico, Middle Atlantic, and South Atlantic regions. These geographical differences may be useful for developing regionally specific indicators that are more sensitive than the nationally applied model used here.

This crab could not survive in the anoxic zone near the mouth of the Mississippi River. Photo courtesy of Nancy Rabalais, courtesy of the National Undersea Research Program.

Completing the Picture

These results provide a picture of the overall eutrophic conditions in the nation's estuaries and the specific symptoms that occur. Nevertheless, questions remain, such as: What factors influence the development of these symptoms? What types of use impairments do these symptoms cause? What are the management implications? At the National Assessment Workshop, the Core Group used data and information about estuarine susceptibility and human-related nutrient inputs, which, together, provided the basis for evaluating the overall human influence on these conditions. Participants relied heavily on their experience and prior knowledge to evaluate estuarine-use impairments and potential management targets. The data for these ancillary assessments were not as robust, and were less rigorously reviewed, than the Eutrophication Survey data, and some findings were inconclusive. This information was included, however, because it helped to complete the national picture.

Influencing Factors. In an effort to determine the level of human influence on the development of eutrophication, workshop participants considered the overall eutrophic condition with respect to nutrient inputs and estuarine susceptibility to retain nutrients. Figure 10 (next page) shows the input data separately from the susceptibility data, as well as the aggregated results, which represent the overall level of human influence. Although both phosphorus and nitrogen cause nutrient enrichment problems in estuaries, at the time of the Assessment Workshop, national-level information was available only for nitrogen inputs. For this reason, nitrogen values were used as the primary estimates of nutrient inputs, and information on population density and land use was used as a general indicator of nutrient pressure to help account for phosphorus and corroborate nitrogen estimates. The nitrogen input estimates were based on watershed monitoring data from the U.S. Geological Survey, as produced by the SPARROW model (Smith et al., 1997).

While these data were variable and did not show distinct groupings, some generalizations could be made. Many estuaries assessed as having high levels of overall eutrophic conditions also had high susceptibility and moderate to high levels of nutrient

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inputs. These estuaries are very sensitive to nutrient inputs, and as a result, many were assessed as having a high level of human-related influence on the development of eutrophic conditions. The converse also seems to hold true; that is, most estuaries with low susceptibility and low inputs of nutrients had a low overall level of eutrophic conditions. These estuaries are less sensitive to development of eutrophic conditions even with human related nutrient inputs.

The assessment results highlight these generalizations; of the 44 estuaries with high levels of eutrophic conditions, workshop participants assessed 36 as having a high level of human influence on the development of conditions. It is important to note that a common feature of these estuaries was high or moderate susceptibility. It is also noteworthy that most of the 44 estuaries have moderate, not high (as in only six of the estuaries), levels of nutrient inputs. In estuaries with high or moderate susceptibility, even a moderate level of nutrient input may be sufficient to cause serious eutrophic symptoms. In these systems, natural estuarine characteristics, such as low tidal exchange, enhance the expression of symptoms. Most of these estuaries were located in the Gulf, Middle Atlantic, and Pacific regions.

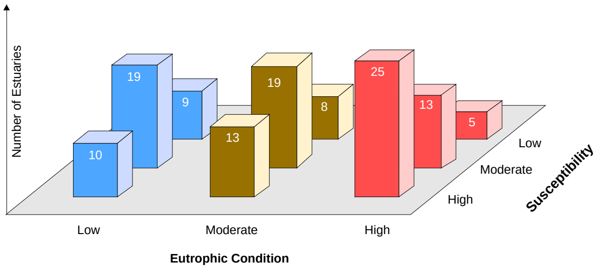
In contrast, 38 estuaries exhibited low overall eutrophic conditions. The common traits of these estuaries were lower susceptibility and lower nitrogen inputs; 31 of these estuaries had moderate or low nitrogen inputs, and 28 had moderate or low susceptibility. In these systems, natural characteris-

Figure 10. *Influencing factors on the expression of eutrophic conditions*

At the National Assessment Workshop, an attempt was made to characterize the natural conditions and human activities that influence the expression of eutrophic conditions in the nation's estuaries. The purpose was to develop an understanding of why eutrophic conditions differ among estuaries and to provide a basis for guiding management responses to problems. These figures indicate that the response to a given level of nutrient is highly variable and is primarily due to differences among estuarine susceptibility to nutrients. Some estuaries are so susceptible that only small amounts of additional nutrients will cause problems, while others can seemingly take in large quantities and still display few eutrophic symptoms (but may pass the nutrients on to other receiving bodies downstream).

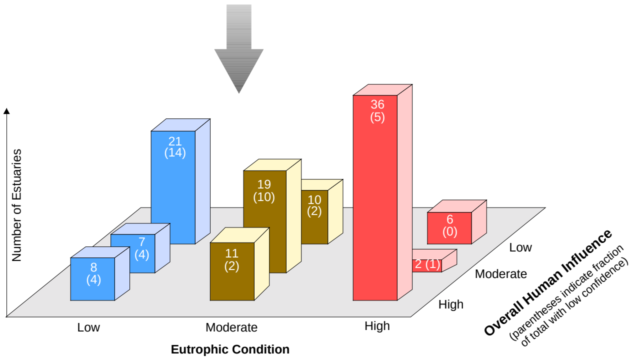
Estuarine Susceptibility

The estuarine susceptibility estimates are based on estuarine flushing and dilution capacity - freshwater inflow, tidal flushing, and degree of stratification. These characteristics influence the transport and fate of nutrients in coastal water bodies, and help to determine the susceptibility of an estuary to retain nutrients. These data were derived from national data sets contained in NOAA's Coastal Assessment and Data Synthesis system.



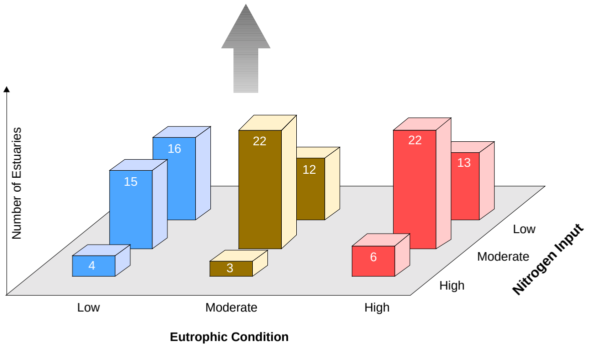
Overall Human Influence

An estimation of the overall level of human influence on the expression of eutrophic conditions was determined for each estuary by combining estuarine susceptibility estimates with indicators of nutrient pressure. Although nitrogen input was used as the primary indicator of nutrient pressure, workshop participants made appropriate modifications to the overall nutrient pressure assessment, based on analysis of population density and land use data as general nutrient pressure indicators.



Nitrogen Inputs

Nitrogen yield estimates, adapted from USGS's SPARROW model, characterize the level of nitrogen inputs to estuaries for five major nutrient source types: point sources, fertilizer, livestock, atmospheric deposition, and nonpoint/nonagricultural. These data provide a rough snapshot estimation of nitrogen input conditions for 1987.



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Most estuaries with high eutrophic conditions also have high levels of human influence due to a combination of moderate to high nutrient inputs and natural susceptibility.

tics appeared to suppress the expression of symptoms. It should be noted, however, that 10 of the estuaries with low eutrophic conditions exhibited high susceptibility.

It is important to note that although these generalizations can be made, the relationships between nutrient inputs and the expression of symptoms, or between susceptibility and the expression of symptoms (Figure 10), are not entirely predictable. For instance, not all of the 44 estuaries with high eutrophic conditions had high nutrient inputs *and* high susceptibility, though most did follow this general rule. There were exceptions, including six estuaries assessed with high levels of eutrophic conditions and low human influence. Five of these are located in the North Atlantic region, where susceptibility is low due to tidal ranges greater than six feet, and nitrogen inputs are generally low due to low population densities and densely forested watersheds. The overall eutrophic conditions in some of these estuaries were assessed as high because toxic blooms occurred each year; these events were natural, however, originating offshore and then drifting into the estuaries. Once a bloom has reached an estuary, it is possible that land-based nutrients maintain it.

Shellfishing is a typical impaired estuarine use. Photo courtesy of Zoe Rasmussen, Puget Sound Water Quality Action Team.

Impaired Uses Relative to Symptoms. The finding that more than half of the nation's estuaries have moderate to high expressions of at least one secondary symptom of eutrophication is of considerable importance, because these symptoms may negatively impact estuarine resources in a variety of ways (Figure 11). For instance, losses in the nation's fishery resources may be directly caused by fish kills associated with low dissolved oxygen and toxic blooms. Declines in tourism occur when low dissolved oxygen causes noxious smells and floating mats of algae create unfavorable aesthetic conditions. Risks to human health increase when the toxins from algal blooms accumulate in edible fish and shellfish, and when toxins become airborne, causing respiratory problems due to inhalation. This report does not directly address economic losses, however, seasonal economies may suffer when eutrophic symptoms occur during the height of the tourist and/or fishing seasons. The cost of implementing strategies to reduce nitrogen inputs may also be considerable. For example, the U.S. Environmental Protection Agency's Long Island Sound Study reported in 1998 that the potential cost of reducing nitrogen levels from point sources alone (70 treatment plants) in the Long Island Sound watershed would be about $2.5 billion.

Figure 11. *Number of estuaries with resources impaired for human use*

Region	Number of Estuaries With Impaired Uses	Commercial /Recreational Fishing	Fish Consumption	Shellfish	Swimming	Boating	Aesthetics	Tourism
North Atlantic	12	0	0	11	0	1	0	0
Middle Atlantic	16	12	0	9	6	2	8	2
South Atlantic	9	8	3	3	1	1	0	2
Gulf of Mexico	19	11	5	12	4	1	4	10
Pacific	13	12	0	11	4	0	5	0
National	**69**	**43**	**8**	**46**	**15**	**5**	**17**	**14**

The magnitude of estuarine impacts cannot currently be quanti-

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fied; however, eutrophication experts at the National Assessment Workshop identified estuarine uses that they knew or suspected to be impaired because of eutrophic symptoms (Figure 11). Although this information is qualitative, it is still useful in understanding the nature of impaired uses on a national basis. In all, some type of use impairment was identified in 69 estuaries. The most frequently reported impairments were to commercial fishing and shellfish harvesting. Considered regionally, fishing and/or shellfishing impairments were reported for all coasts. Other frequently reported impairments were aesthetics in the Middle Atlantic, and tourism in the Gulf of Mexico region. The loss of assimilative capacity—the ability of an estuary to receive nutrients without exhibiting symptoms—also appears to be important, particularly in the South Atlantic.

Recommended Management Actions. The general workshop recommendation is for authorities to manage from a watershed perspective, focusing on controllable sources of nutrients and on strategies tailored to individual watershed characteristics in order to maximize potential improvements. This is especially important, given that nutrient-control strategies may not be universally applicable across geographic regions. The individually tailored management plans should also take into account overall eutrophic conditions and the factors influencing the level of expression in each estuary, so that efforts can focus on estuaries that will benefit the most from nutrient controls. For instance, the 23 estuaries with high expression of eutrophic conditions and high susceptibility (which represent about 10% of the national estuarine surface area studied) will likely require greater management efforts and a longer response time for results, than those estuaries with low susceptibility. In contrast, the 10 estuaries with low eutrophic conditions and high susceptibility (about 3% of national estuarine area) should be priorities for preventive management.

> ***Experts at the National Assessment Workshop predicted that more than half of the nation's estuaries are likely to develop worsening eutrophic conditions during the next 20 years.***

On a national basis, the most frequently recommended management targets were agriculture, wastewater treatment, urban runoff, and atmospheric deposition (Figure 12). Although previous management efforts have targeted point sources, they were still one of the top three targets recommended. In all regions except the North Atlantic, however, nonpoint sources are the primary focus, representing 60 percent of the recommended targets. Agriculture was the most frequently recommended target for the Pacific, Gulf of Mexico, and South Atlantic regions; wastewater treatment plants were important in the North Atlantic; and agriculture and atmospheric sources were most frequently recommended in the Middle Atlantic. Notable among the point sources were combined sewer overflows, specifically in the North Atlantic, and wastewater treatment plants in all regions. Of the nonpoint sources, atmospheric deposition was among the most frequently recommended targets, but was noted almost exclusively for the Gulf of Mexico and Middle Atlantic regions. Another important nonpoint source identified as needing management action in the South Atlantic and Gulf of Mexico were large animal production facilities.

Figure 12. *Sources that experts at the National Assessment Workshop identified as most important targets to manage nutrient inputs*

Region	Waste Water Treatment Plants	Combined Sewer Overflow	Onsite Disposal	Industry	Animal Operations	Urban	Agriculture	Forestry	Range	Atmospheric
North Atlantic	11	7	0	0	0	2	1	0	0	1
Middle Atlantic	8	1	3	0	1	5	12	0	0	12
South Atlantic	8	0	2	3	4	12	13	5	0	0
Gulf of Mexico	11	0	2	9	5	11	15	1	5	11
Pacific	11	0	5	1	0	7	14	3	0	0
National	**49**	**8**	**12**	**13**	**10**	**37**	**55**	**9**	**5**	**24**

Future Outlook to 2020. At the National Assessment Workshop, projections were made to predict what might happen to U.S. estuaries in the future. The future outlook was based on predictions of population growth and expert knowledge of specific management and development activities that are planned for the watersheds. Past trends were also considered, to varying degrees, for this determination (for the most part, this information was not explicitly dealt with at the Workshop; see sidebar, page 18). The future outlook assessment (Figure 13) indicates that overall eutrophic conditions will worsen in 86 estuaries, stay the same in 44, and improve in only eight estu-

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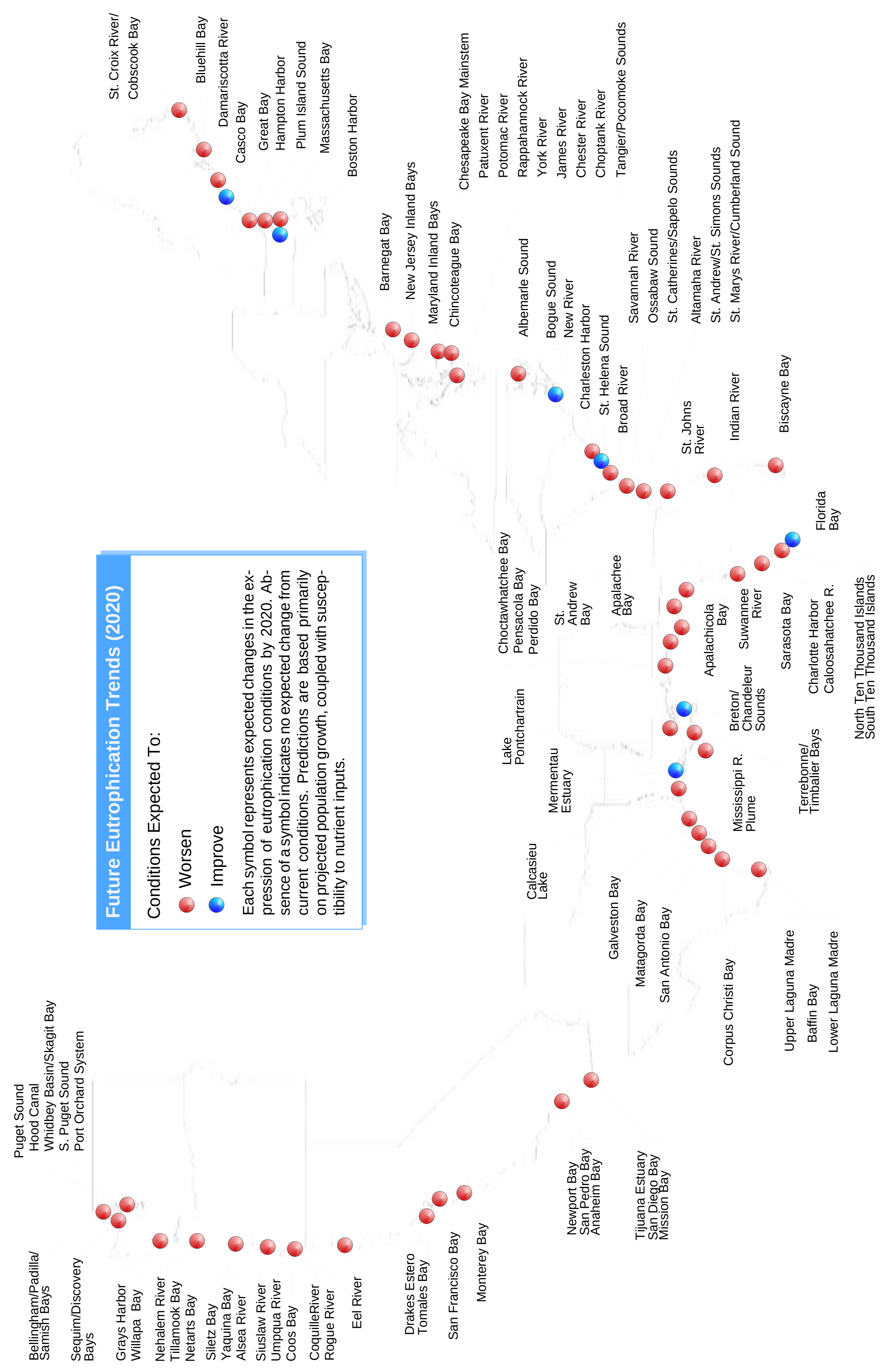
Figure 13. *Expected trends in eutrophication through 2020*

Experts at the National Assessment Workshop determined that conditions are expected to worsen in more than half of the nation's estuaries, and along all of the coasts, by 2020. However, the experts cautioned that uncertainty is inherent in these predictions and that they may be unduly pessimistic. A number of factors that affect eutrophic conditions may change over time, making it difficult to predict with substantial certainty the ultimate effect of population growth on nutrient loadings and the subsequent expression of eutrophic conditions in estuaries.



Future Eutrophication Trends (2020)

Conditions Expected To:

🔴 Worsen

🔵 Improve

Each symbol represents expected changes in the expression of eutrophication conditions by 2020. Absence of a symbol indicates no expected change from current conditions. Predictions are based primarily on projected population growth, coupled with susceptibility to nutrient inputs.

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Past Trends in Eutrophication

The assessment of symptom trends (ca. 1970 to 1995) was based on data from NOAA's Estuarine Eutrophication Survey. These data are less certain, and the assessments were less rigorously reviewed at the National Assessment Workshop. For 51 estuaries, data was insufficient to assess trends.

A greater number of estuaries were reported to have worsening conditions for chlorophyll *a*, epiphytes, macroalgae, nuisance blooms, toxic blooms, and submerged aquatic vegetation loss, than the number of estuaries for which conditions improved. For dissolved oxygen, conditions improved in more estuaries than those that worsened. Overall, eutrophic conditions worsened in 48 estuaries and improved in 14. In 26 systems, there was no trend in overall eutrophic conditions since 1970. Most of the estuaries that showed overall improvement were located in the Gulf of Mexico. The greatest number of estuaries in which conditions worsened were in the Gulf of Mexico and Middle Atlantic regions.

Worsening trends have been attributed to a general increase in population density in estuarine watersheds. Some of these estuaries are historically rural, with farming and urban development intensifying concurrently. Notably, recent toxic blooms in the Middle Atlantic and South Atlantic regions are thought to be linked to the increase in confined animal operations and the release of untreated animal wastes into local water bodies. Successes have also been reported, with improvements in water quality over time. These trends are attributed to the implementation of strategies that primarily reduce point sources, as mandated by the Clean Water Act. In addition, some of the National Estuary Program estuaries, such as Tampa and Sarasota Bays, are good examples of successful nutrient-reduction strategies that have reversed eutrophic conditions.

aries during the next 20 years. At present, overall eutrophic conditions are moderate to low in 43 of the estuaries that are predicted to worsen; conditions are unknown in 12 additional estuaries predicted to worsen. The 10 estuaries that currently exhibit low eutrophic conditions, and are highly susceptible, are at particular risk of developing worsening conditions if nutrient inputs increase. Most of the estuaries with negative outlooks are located in the Pacific and Gulf of Mexico regions. These predictions tend to mirror historic trends; over time, more estuaries have experienced worsening conditions.

Data Gaps and Research Needs

The greatest need is for data that better characterize the levels of eutrophic symptoms in estuaries. For 17 estuaries, there is insufficient information to assess conditions, and for many more (31), the assessment reliability is low due to limited or uncertain data. These estuaries represent 25% of the nation's estuarine area. Physical processes and levels of nutrient inputs also need to be better characterized, so that causal linkages can be made and used to develop appropriate management plans.

Process-oriented research is needed to improve understanding of the mechanisms involved in the progressive development of eutrophication. For example, little is known about "thresholds," such as the level of nutrient inputs above which toxic blooms will flourish. Research must be done to improve the understanding of historically higher levels of biological grazing as a controlling mechanism, and of the ways in which the decline of this mechanism affects the rate of development of eutrophic symptoms. The influence of phosphorus and other nutrients as contributors to eutrophication, relative to nitrogen, also needs further clarification. Climate change, specifically global warming, will affect water levels, circulation, temperature and salinity, all of which will have an effect on the susceptibility of estuaries, and, thus, the potential development of symptoms. Finally, the combined effects of nutrient inputs and other pollutant stressors on the health of estuaries should be investigated. All of this information should be used to develop predictive models that will enhance and ensure effective management actions.

In 17 estuaries, there was insufficient data to assess overall eutrophic conditions:

Merrimack River
Albemarle Sound
Pamlico Sound
St. Helena Sound
Lake Borgne
Santa Monica Bay
Drakes Estero
Rogue River
Coquille River
Coos Bay
Umpqua River
Siuslaw River
Alsea River
Siletz Bay
Netarts Bay
Tillamook Bay
Nehalem River

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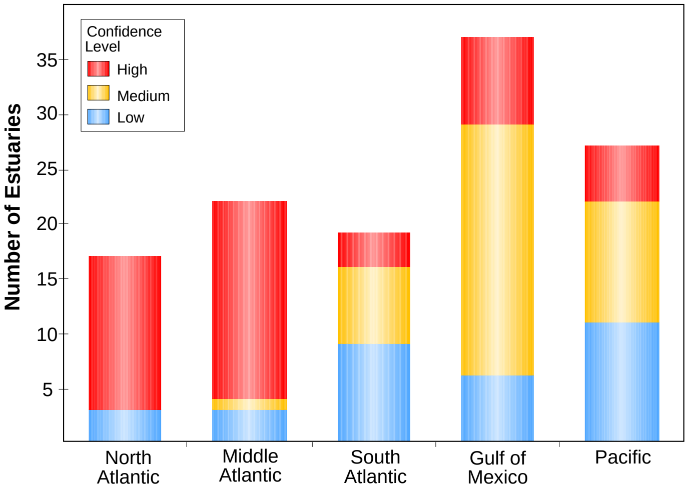
Regional Summaries

This section focuses on five major regions of the coterminous U.S. It highlights regional differences in overall eutrophic conditions; the factors influencing the development of these conditions; the associated impairments to human uses of estuarine resources; the future outlook; and the priorities for management, data and research. Differences between regions occur due to variations in estuarine susceptibility in combination with the level of nutrient inputs reaching estuarine waters. In some regions, the climate, shoreline structure, coastal topography, and circulation and flushing patterns are similar across the entire region, and its estuaries respond similarly, for the most part, to nutrient inputs. In other regions, these characteristics vary greatly among estuaries, and identifiable subregional differences occur in response to inputs. Therefore, in addition to regional summaries, detailed results are provided for each of the 138 estuaries and the Mississippi River Plume. To facilitate comparison among the regions, brief descriptions are provided of physical settings, general land-use characteristics and the locations of major population centers. Also provided are confidence levels for the assessments.

Eutrophic Conditions and Expression of Symptoms. The overall eutrophic condition is a reflection of the combined levels of expression of six individual symptoms: three primary symptoms (chlorophyll *a*, epiphyte abundance, and macroalgal abundance) and three secondary symptoms (dissolved oxygen conditions, loss of submerged aquatic vegetation, and the occurrence of nuisance / toxic algal blooms). Each estuary received an overall rating, as well as ratings for the level of impact of each individual symptom. The overall eutrophic condition, and the level of impact for each individual symptom, are characterized as high, medium, or low. In addition, improving symptoms, *as indicated by the most recent trend direction*, are noted with an upward-pointing arrow. A summary table is provided to facilitate comparison of the individual symptom levels with the overall level of eutrophic condition (Figures 16, 19, 22, 25, 28).

Data Quality. The level of confidence in the assessment of eutrophic conditions was determined for each estuary characterized in this report and was based on the temporal and spatial representativeness of the data. Figure 14 illustrates the varying confidence levels among the five regions. There are 17 estuaries for which an assessment of overall eutrophic condition was not possible due to insufficient information (see box, page 18). Whenever possible, information on individual symptoms was provided for these estuaries.

Figure 14. *Eutrophication Assessment Confidence Levels*



Factors Influencing Eutrophic Conditions. Participants at the National Assessment Workshop combined nitrogen input estimates with susceptibility values for each estuary to determine the overall influence of human activities on the development of eutrophic conditions. The overall human influence is characterized as high, moderate or low. A summary table facilitates the comparison of individual and overall influencing factors with the severity of eutrophic conditions (Figures 17, 20, 23, 26, 29).

Impaired Uses in Estuaries. Experts at the National Assessment Workshop identified general impairments due to eutrophic conditions within estuaries. The regional assessments highlight this information.

Future Outlook on Eutrophic Conditions. When considering the outlook for 20 years hence, the experts reviewed present conditions and inputs, historic conditions and inputs, and projections of future inputs based primarily on projected population growth. Each regional map shows the estuaries in which conditions are expected to worsen or develop, and those in which conditions are expected to improve. In other estuaries, conditions are expected to remain the same, or there is insufficient information with which to make a prediction.

Management Concerns, Data and Research Needs. Workshop participants identified management targets, data gaps, and research needs for each estuary.

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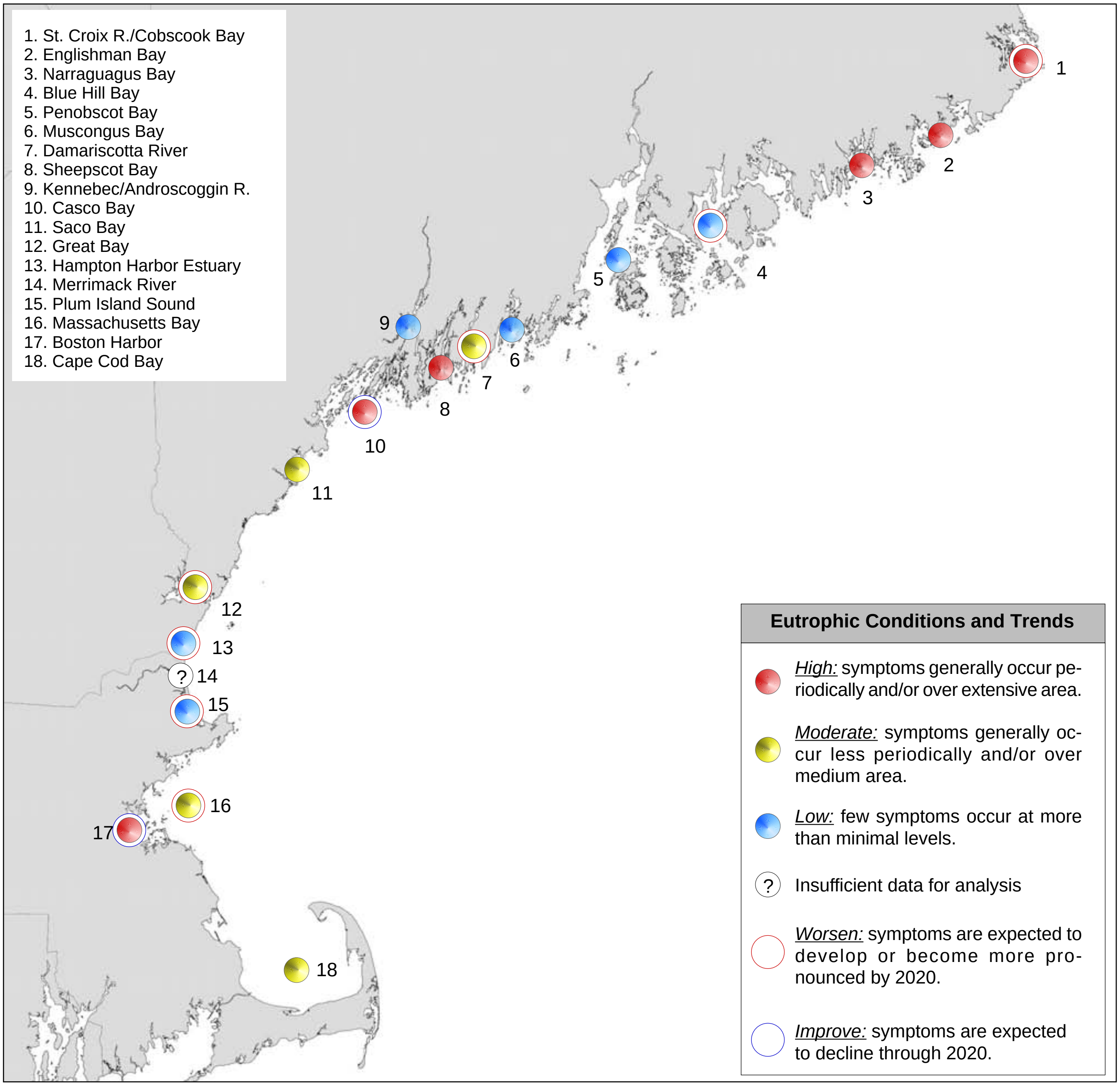
North Atlantic

More than half of the North Atlantic estuaries have moderate to high eutrophic conditions, as assessed by workshop participants. Only a few, however, have a substantial level of human influence. The major nutrient source for most North Atlantic estuarine and coastal systems is from offshore coastal waters; consequently, many of the eutrophic symptoms expressed in the region are thought to be primarily natural conditions, especially for chlorophyll a concentrations and toxic algae. Additionally, the high degree of tidal flushing and low freshwater inputs characteristic of many of the systems tend to minimize impacts due to human-related nutrient inputs. Future increases in nutrient inputs are likely to exacerbate some of these naturally occurring conditions.

Figure 15. *Level of expression of eutrophic conditions and future trends*



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The North Atlantic region includes 18 estuarine systems, encompassing roughly 2,000 square miles of water surface area. In the northern part of the region, the coastal shoreline consists mainly of drowned river valleys characterized by numerous small embayments, rocky shoreline, wave-cut cliffs, and large, rocky islands. The southern part of the region contains more cobble, gravel, and sand beaches, and tidal marshes are more extensive. A high degree of tidal flushing and low freshwater input are characteristic of many of these systems. Major population centers, including Portland and Boston, are located in this southern portion.

Eutrophic Conditions

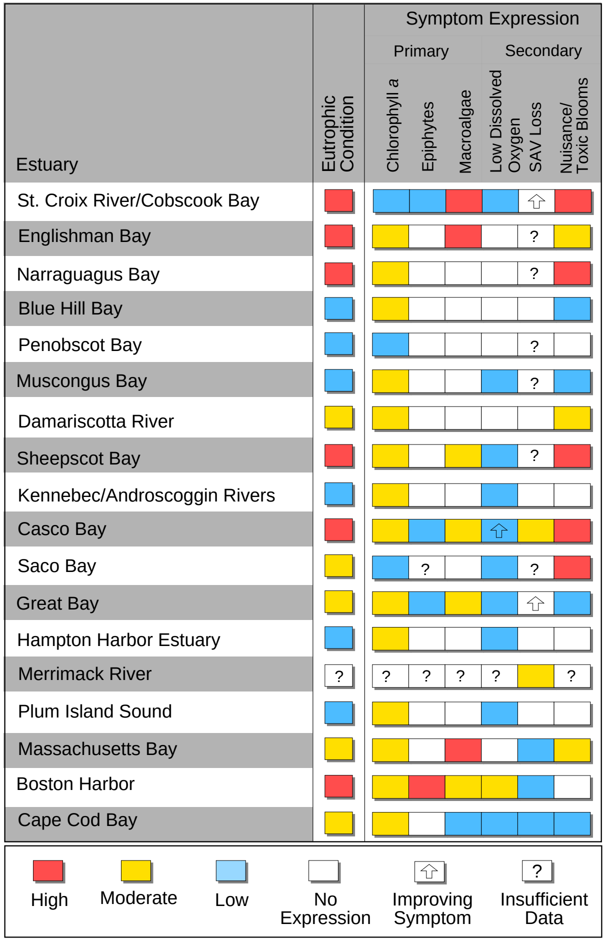
Overall Conditions. Moderate or higher levels of eutrophic conditions occurred in more than half of the estuarine systems, with six being in the high category. Estuaries with these conditions were located along the length of the coast, with estuaries exhibiting low eutrophic conditions interspersed between them.

Expression of Symptoms. Close to half of the estuaries exhibited at least one of the six symptoms at high levels. For the primary symptoms, chlorophyll *a* was expressed at moderate levels for a majority of estuaries; macroalgal abundance problems occurred in almost half of the systems; and epiphyte problems were minimal. For the secondary symptoms, moderate to high levels of nuisance/toxic blooms occurred in more than half of the systems; depleted dissolved oxygen occurred at low levels in more than half, and losses of submerged aquatic vegetation were minimal.

In general, for those systems with high eutrophic conditions, nuisance/toxic algal blooms and overabundance of macroalgae were the principle symptoms contributing to the observed overall condition. Moderate expression of chlorophyll *a* and low expression of depleted dissolved oxygen were also observed in most of the systems with high eutrophic conditions, although these symptoms tended to occur regardless of overall eutrophic condition.

> ***The major nutrient source for many North Atlantic estuarine and coastal systems is from offshore coastal waters. Consequently, many of the eutrophic symptoms expressed in the region, such as toxic algal blooms, are thought to be primarily natural conditions.***

Figure 16. *Eutrophic conditions and symptoms*



Estuary	Eutrophic Condition	Symptom Expression					
		Primary			Secondary		
		Chlorophyll *a*	Epiphytes	Macroalgae	Low Dissolved Oxygen	SAV Loss	Nuisance/ Toxic Blooms
St. Croix River/Cobscook 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	🟨	🟨	🟦	🟨	🟦	⇧	🟦
Hampton Harbor Estuary	🟦	🟨	⬜	⬜	🟦	⬜	⬜
Merrimack River	?	?	?	?	?	🟨	?
Plum Island Sound	🟦	🟨	⬜	⬜	🟦	⬜	⬜
Massachusetts Bay	🟨	🟨	⬜	🟥	⬜	🟦	🟨
Boston Harbor	🟥	🟨	🟥	🟨	🟨	🟦	⬜
Cape Cod Bay	🟨	🟨	⬜	🟦	🟦	🟦	🟦

🟥 High
🟨 Moderate
🟦 Low
⬜ No Expression
⇧ Improving Symptom
? Insufficient Data

Submerged aquatic vegetation improved in a few estuaries, largely due to replanting efforts as well as recovery from wasting disease. In Casco Bay, improvements in levels of dissolved oxygen appeared to be related to point-source controls and declining Atlantic Menhaden runs.

The confidence levels for the assessment of eutrophic conditions were low for four estuaries. Information was sparsest on trends in submerged aquatic vegetation. There are less data for the Merrimack River estuary than for any other system in the region.

Influencing Factors

Nutrient inputs from human sources are thought to be high in only three North Atlantic estuarine systems, primarily because freshwater inflow in the region is generally low and drains from watersheds with sparse populations. Susceptibility to nutrient inputs is low in most systems because of the dominance of tidal flushing. As a result of the low nutrient inputs and low susceptibility, human influence is generally very low in the region.

Of the six estuaries exhibiting high eutrophic con-

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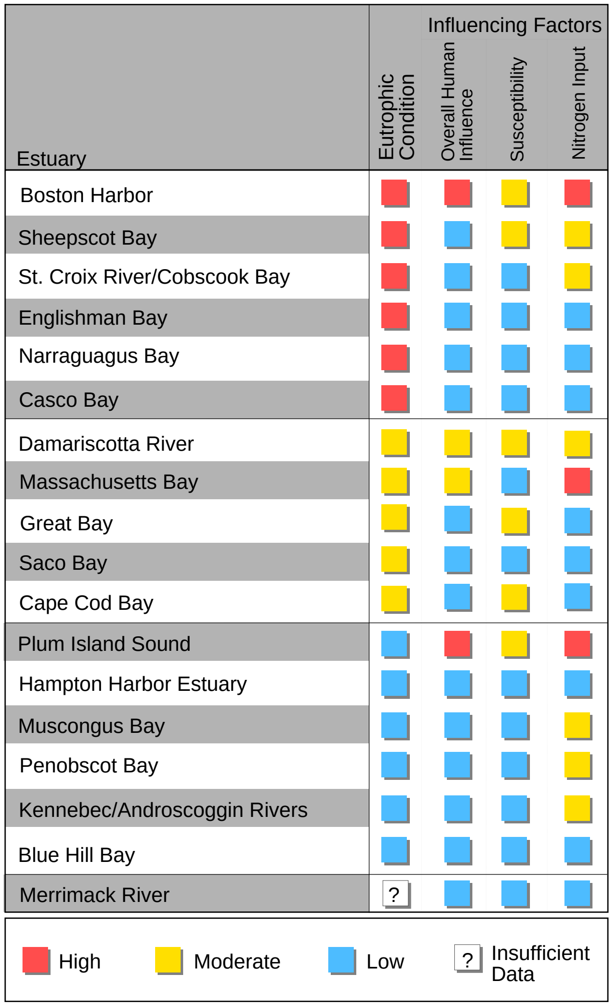
Figure 17. *Eutrophic conditions and influencing factors*



Estuary	Eutrophic Condition	Influencing Factors		
		Overall Human Influence	Susceptibility	Nitrogen Input
Boston Harbor	🟥	🟥	🟨	🟥
Sheepscot Bay	🟥	🟦	🟨	🟨
St. Croix River/Cobscook Bay	🟥	🟦	🟦	🟨
Englishman Bay	🟥	🟦	🟦	🟦
Narraguagus Bay	🟥	🟦	🟦	🟦
Casco Bay	🟥	🟦	🟦	🟦
Damariscotta River	🟨	🟨	🟨	🟨
Massachusetts Bay	🟨	🟨	🟦	🟥
Great Bay	🟨	🟦	🟨	🟦
Saco Bay	🟨	🟦	🟦	🟦
Cape Cod Bay	🟨	🟦	🟨	🟦
Plum Island Sound	🟦	🟥	🟨	🟥
Hampton Harbor Estuary	🟦	🟦	🟦	🟦
Muscongus Bay	🟦	🟦	🟦	🟨
Penobscot Bay	🟦	🟦	🟦	🟨
Kennebec/Androscoggin Rivers	🟦	🟦	🟦	🟨
Blue Hill Bay	🟦	🟦	🟦	🟦
Merrimack River	?	🟦	🟦	🟦

🟥 High 🟨 Moderate 🟦 Low ? Insufficient Data

ditions, only one, Boston Harbor, had high human influences. Furthermore, according to expert consensus at the National and Regional Assessment Workshops, offshore coastal waters are the major nutrient source for most estuarine systems in this region. Consequently, certain eutrophic symptoms, such as toxic algal blooms, are thought to be primarily natural conditions. Human-related nutrient inputs, however, may exacerbate these natural conditions.

The confidence level of the assessment of anthropogenic influence was low for three estuaries.

Impaired Uses

Very few uses of estuarine resources were identified as being impaired by eutrophication in this region. The impaired use of shellfish resources was the most extensive problem identified; however, shellfish-area closures were attributed mainly to natural toxic algal blooms, which can lead to paralytic shellfish poisoning in people. Minor problems were also noted for boating.

Potential Management Concerns

The most frequently noted nutrient sources to target for management efforts were wastewater treatment plants and combined sewer overflows. Urban runoff, agriculture, aquaculture, and atmospheric inputs were also identified as sources of concern, but in relatively few estuaries.

Future Outlook to 2020

By the year 2020, eutrophication symptoms are expected to worsen in about one-third of the systems, primarily due to increased nutrient inputs from population increases and the growth of the aquaculture industry. Of these estuaries, St. Croix River/ Cobscook Bay, Great Bay, and Plum Island Sound are expected to worsen the most. Conversely, Casco Bay and Boston Harbor are expected to improve, to a limited extent.

The confidence levels for the assessment of the future outlook was low for two estuaries.

Data Gaps and Research Needs

Several estuaries were identified as requiring better baseline symptom data, although only four systems were noted to have low confidence levels for assessment.

Important data and research needs generally include improved assessments of nutrient inputs from rivers, groundwater, and aquaculture; better understanding of circulation dynamics; and improved estimates of population growth and land use. For systems with seasonal population changes, research is needed to assess the effects of winter-summer population changes on eutrophic conditions.

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A high degree of tidal flushing and low freshwater input, characteristic of many North Atlantic estuaries, tend to minimize impacts due to human-related nutrient inputs. Photo courtesy of Miranda Harris, NOAA.

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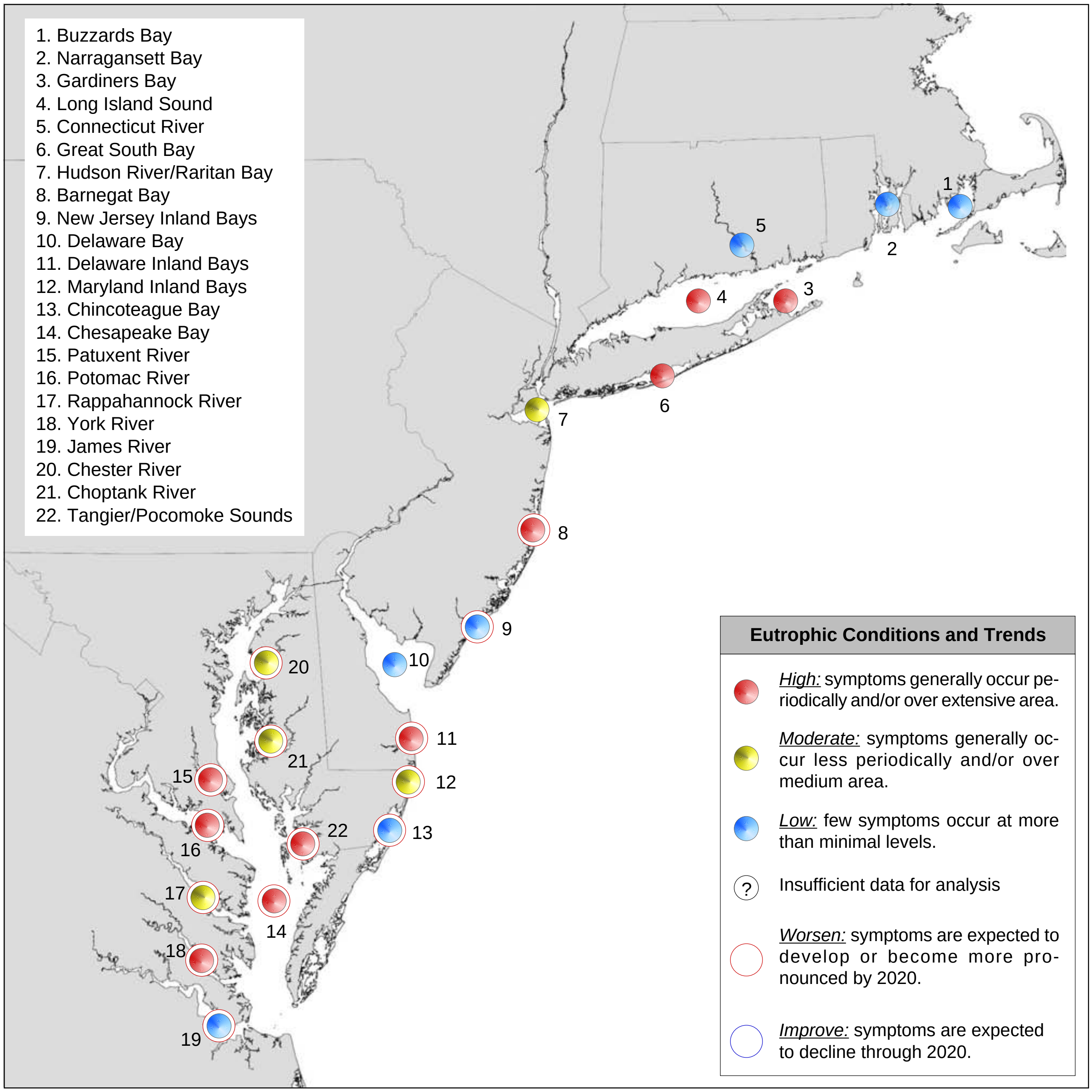
Middle Atlantic

In this region, the expression of high eutrophic conditions is extensive and the level of human influence is high. Eutrophic symptoms are widespread and likely have substantial impacts on many estuarine natural resources. The expression of pronounced eutrophic symptoms tends to be more pervasive in enclosed or river-dominated estuaries, while ocean-influenced systems exhibit fewer impacts. There are numerous ongoing efforts to control nutrient inputs; however, the ecological response to nutrient reductions is often slow in many of these systems, and consequently, the positive effects of these efforts may have yet to materialize. The widespread influence of atmospheric nutrient sources, together with rapid rates of development, pose a great challenge to the control of nutrient inputs and eutrophication.

Figure 18. *Level of expression of eutrophic conditions and future trends*



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The Middle Atlantic region includes 22 estuarine systems, encompassing more than 7,790 square miles of water surface area. Coastal areas are characterized by irregular shorelines, wide, sandy beaches, numerous barrier island formations, and extensive salt marshes. Tides range from one to six feet but generally fall within the lower part of the range. Tidal flushing is most dominant in the northern part of the region, while freshwater inflow is more important in the Chesapeake Bay systems. Land use is characterized by large urban tracts and extensive agricultural areas. Major population centers include Providence, Hartford, New York City, Philadelphia, Baltimore, Washington, D.C., and Richmond.

Eutrophic Conditions

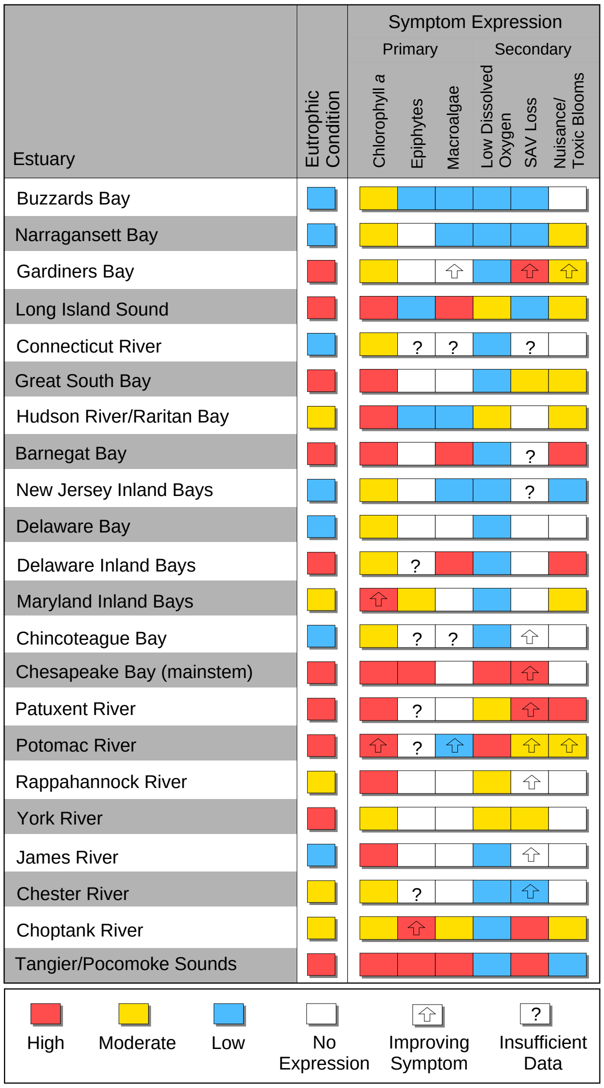
Overall Conditions. Estuaries with moderate to high eutrophic conditions were widespread and evenly spaced throughout the region, with close to half of the estuarine systems exhibiting high levels of eutrophic conditions, and an additional five showing moderate conditions.

> ***The expression of severe eutrophic conditions tends to be more pervasive in enclosed or river-dominated estuaries, while the more ocean-influenced systems experience fewer impacts.***

Expression of Symptoms. Well over half of the estuaries exhibited at least one of the six symptoms at high levels. Of the primary symptoms, chlorophyll *a* had the most pronounced expression, with high levels in half of the estuaries and moderate levels in the rest. Macroalgal abundance problems occurred in 10 estuaries, and in five of these at moderate to high levels. Epiphyte abundance problems occurred in more than one-quarter of the estuaries. Extensive expressions of secondary symptoms were also noted in the region. Depleted dissolved oxygen occurred in every estuary, although it tended to be expressed at low levels. Both submerged aquatic vegetation loss and nuisance/toxic algal blooms were problems in more than half of the estuaries, primarily occurring at moderate to high levels.

There did not appear to be a single symptom dominating the overall expression of high eutrophic conditions. Rather, there was a wide and varied array of symptoms contributing to the overall conditions observed. The 10 estuaries exhibiting high eutrophic conditions had varying combinations of low dissolved oxygen, submerged aquatic vegetation loss, and nuisance/toxic algal blooms. In most of these estuaries, these secondary symptoms coincided with high expressions of primary symptoms. The five estuaries exhibiting moderate eutrophic conditions displayed similar symptoms, except that the secondary symptoms were somewhat less severe.

Figure 19. *Eutrophic conditions and symptoms*



Estuary	Eutrophic Condition	Symptom Expression					
		Primary			Secondary		
		Chlorophyll *a*	Epiphytes	Macroalgae	Low Dissolved Oxygen	SAV Loss	Nuisance/ Toxic Blooms
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 (mainstem)	🟥	🟥	🟥	⬜	🟥	🟥⇧	⬜
Patuxent River	🟥	🟥	?	⬜	🟨	🟥⇧	🟥
Potomac River	🟥	🟥⇧	?	🟦⇧	🟥	🟨⇧	🟨⇧
Rappahannock River	🟨	🟥	⬜	⬜	🟨	⇧	⬜
York River	🟥	🟨	⬜	⬜	🟨	🟨	⬜
James River	🟦	🟥	⬜	⬜	🟦	⇧	⬜
Chester River	🟨	🟨	?	⬜	🟦	🟦⇧	⬜
Choptank River	🟨	🟨	🟥⇧	🟨	🟦	🟥	🟨
Tangier/Pocomoke Sounds	🟥	🟥	🟥	🟥	🟦	🟥	🟦

🟥	🟨	🟦	⬜	⇧	?
High	Moderate	Low	No Expression	Improving Symptom	Insufficient Data

An improvement in at least one symptom is noted as the most recent trend in close to half of the estuaries. Unfortunately, most of these improvements are modest, and follow long periods of declining conditions. Improving trends are a positive sign that management efforts are working; however, where conditions are moderate to high, there is still much room for improvement, and efforts at nutrient control should be maintained and fortified. In the Chesapeake Bay and its tributaries, for example, submerged aquatic vegetation suffered severe declines in the 1960s and 1970s, primarily as the result of nutrient enrichment, and only recently have nutrient management and other factors contributed to the slight improvement.

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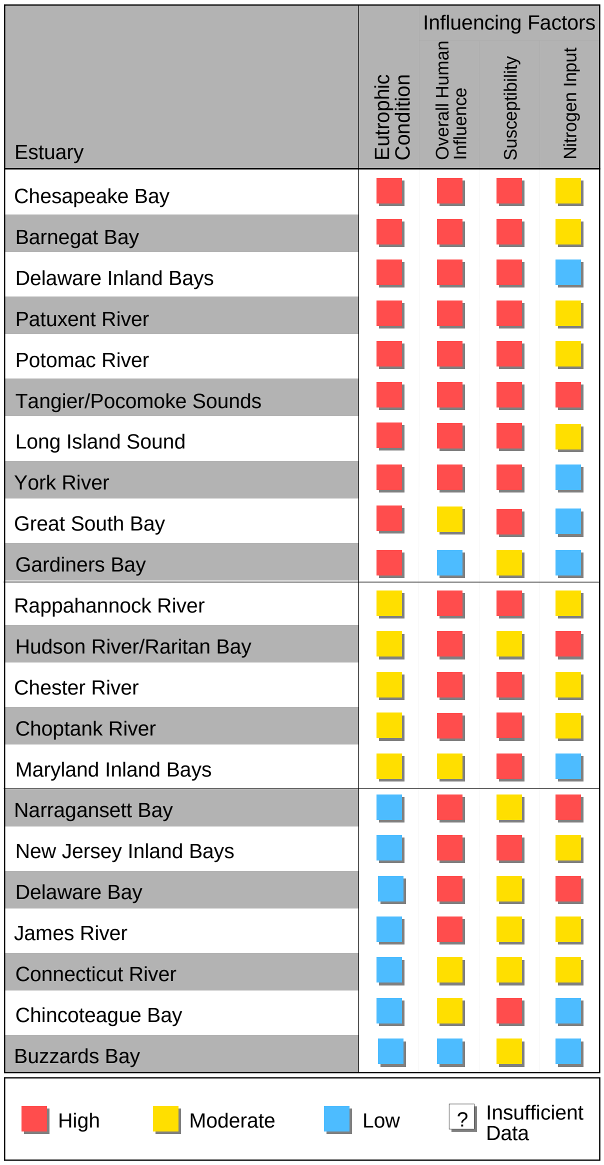
Figure 20. *Eutrophic conditions and influencing factors*



Estuary	Eutrophic Condition	Influencing Factors		
		Overall Human Influence	Susceptibility	Nitrogen Input
Chesapeake Bay	🟥	🟥	🟥	🟨
Barnegat Bay	🟥	🟥	🟥	🟨
Delaware Inland Bays	🟥	🟥	🟥	🟦
Patuxent River	🟥	🟥	🟥	🟨
Potomac River	🟥	🟥	🟥	🟨
Tangier/Pocomoke Sounds	🟥	🟥	🟥	🟥
Long Island Sound	🟥	🟥	🟥	🟨
York River	🟥	🟥	🟥	🟦
Great South Bay	🟥	🟨	🟥	🟦
Gardiners Bay	🟥	🟦	🟨	🟦
Rappahannock River	🟨	🟥	🟥	🟨
Hudson River/Raritan Bay	🟨	🟥	🟨	🟥
Chester River	🟨	🟥	🟥	🟨
Choptank River	🟨	🟥	🟥	🟨
Maryland Inland Bays	🟨	🟨	🟥	🟦
Narragansett Bay	🟦	🟥	🟨	🟥
New Jersey Inland Bays	🟦	🟥	🟥	🟨
Delaware Bay	🟦	🟥	🟨	🟥
James River	🟦	🟥	🟨	🟨
Connecticut River	🟦	🟨	🟨	🟨
Chincoteague Bay	🟦	🟨	🟥	🟦
Buzzards Bay	🟦	🟦	🟨	🟦

🟥 High 🟨 Moderate 🟦 Low ? Insufficient Data

The confidence levels for the assessment of eutrophic conditions were generally high, although three estuaries were rated as low. The Connecticut River had the least data and the lowest confidence. Information was sparsest for trends in epiphyte abundance.

Influencing Factors

The expression of severe eutrophic conditions tended to be more pervasive in enclosed or river-dominated estuaries, such as the Chesapeake Bay and its tributaries and the Delaware Inland Bays, while ocean-influenced systems, such as Buzzards Bay and Delaware Bay, exhibited fewer impacts (although these systems may have had small, more localized areas of high symptoms). Nitrogen inputs were moderate to high in 15 estuaries, and susceptibility was moderate to high in all systems. Accordingly, human influence was considered to be extremely strong in this region. Of the 15 estuaries with moderate to high eutrophic conditions, 12 also exhibited high human influence.

Additionally, several systems displayed minimal eutrophic conditions despite a substantial level of human influence. It is possible that some of these systems are close to developing full-scale eutrophic symptoms. Alternatively, some of the systems may not be as susceptible as the data indicated, or the estimates of nitrogen inputs may have been too high.

The confidence levels for the assessment of overall human influence were generally high; three estuaries were rated as low.

Impaired Uses

The loss of habitat (primarily submerged aquatic vegetation) was the most cited impaired use (15 estuaries), followed closely by degradation of recreational and commercial fishing (12 estuaries). Shellfish resources, swimming, and aesthetic values were impaired in a moderate number of estuaries, while tourism and boating were affected to a small extent. Almost all impaired uses occurred in systems in which eutrophic symptoms were moderate or high.

Potential Management Concerns

The most important sources to target to manage nutrient inputs in the region were identified as atmospheric inputs, agricultural runoff, and discharges from wastewater treatment plants. Urban runoff, septic systems, combined sewer overflows, and animal operations were also noted as important targets, but in fewer estuarine basins.

Future Outlook to 2020

Eutrophication conditions are expected to worsen slightly in 10 estuaries, and to worsen more severely in three. In eight systems (primarily those from Buzzards Bay south through Delaware Bay), no substantial changes are predicted. Great improvement is not expected in any of the region's estuaries.

The confidences levels for the assessment of the future outlook was low for four estuaries. The reliability of all of this information is, however, inherently vulnerable to unforeseen changes.

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Data Gaps and Research Needs

Better quantification of nutrient sources, especially from the atmosphere and groundwater, is needed to determine a more accurate assessment of nutrient loading pressures. A major research need for this region is a concrete determination of, and a more definitive knowledge of, the relationship between the human factors that influence eutrophication and the quality and quantity of living marine resources in the estuaries. This will entail clarifying and quantifying water-quality pathways; that is, both human-related and naturally occurring nutrient inputs, and the nature of their cascading effects throughout the trophic levels of the various estuarine systems.

This dense bloom of cyanobacteria (blue-green algae) occurred in the Potomac River estuary downstream of Washington, D.C. Photo courtesy of W. Bennett, U.S. Geological Survey.

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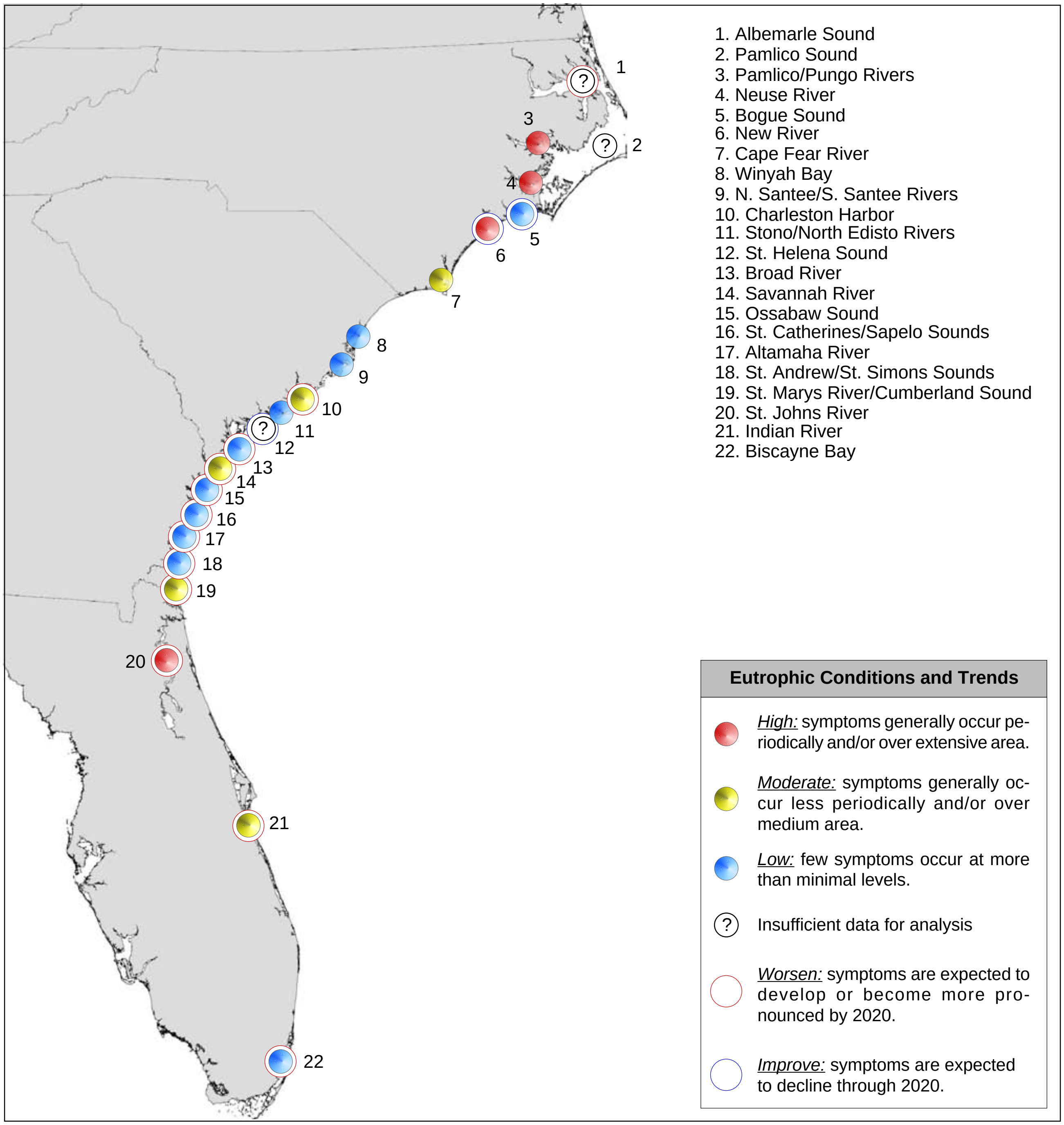
South Atlantic

High eutrophic conditions occur mostly in the northern and southern parts of this region. These conditions are indicated mainly by high expressions of chlorophyll a, harmful algal blooms, and low dissolved oxygen levels. More than half of the estuaries exhibiting minimal eutrophic conditions are likely to develop more pronounced symptoms due to increased nutrient loading. In the affected estuaries, fishing, fish consumption, and shellfish resources are identified as impaired uses. Important sources identified as management concerns are wastewater treatment plants, large animal operations, and other agricultural activities. Urban and forestry sources will become more important as efforts are made to minimize future degradation, especially in systems that currently exhibit few impacts.

Figure 21. *Level of expression of eutrophic conditions and future trends*



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The South Atlantic region includes 22 estuaries, encompassing more than 4,440 square miles of water surface area. The region is comprised of extensive barrier and sea islands that parallel the shoreline. The coastal environment consists of shallow lagoonal estuaries, extensive tidal marshes and drowned river valleys. Estuarine circulation patterns are dominated mainly by wind and seasonal freshwater inflow in North Carolina, and mainly by freshwater inflow and tides in South Carolina and Georgia. Estuarine circulation along the Florida coast is dominated by wind forcing and human engineering. Tidal range throughout the region is moderately low to high (1.5-7.0 feet) and influences mixing in the water column, primarily near the inlets. The dominant land uses are agriculture and industry, and, to a lesser extent, forestry. Major population centers include Miami, Jacksonville, and Savannah.

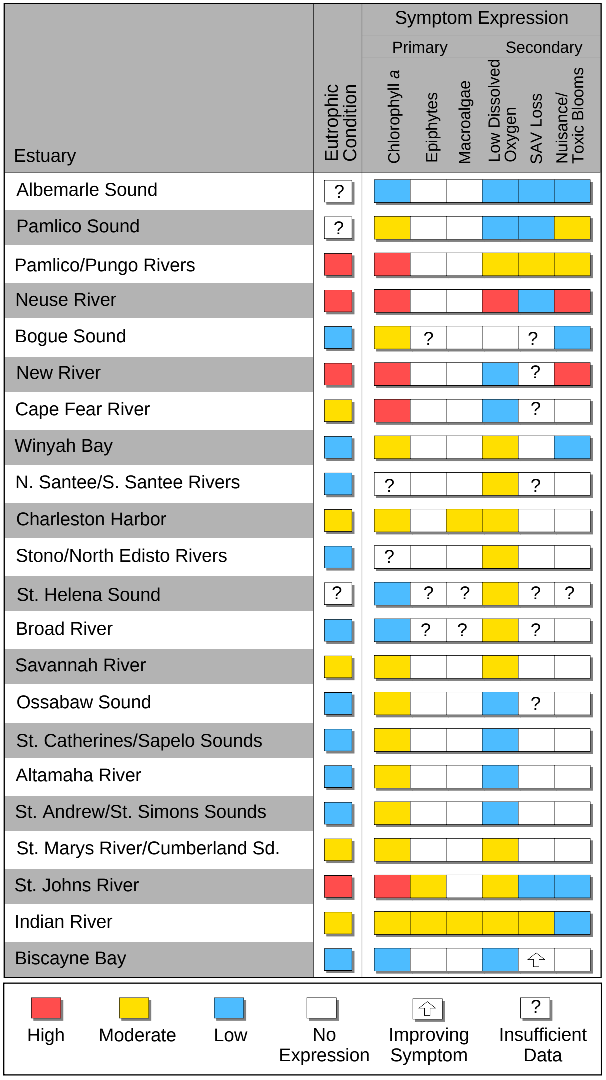
Eutrophic Conditions

Overall Conditions. The South Atlantic region contains only four estuarine systems characterized as having high levels of eutrophic conditions: the Neuse River, Pamlico/Pungo Rivers, New River, and the St. John's River. Most of the other systems were relatively unaffected. Nevertheless, almost half of the region's estuaries exhibited eutrophic conditions at low to moderate levels. Most of these estuaries are in South Carolina and Georgia.

Expression of Symptoms. In five estuaries, at least one of the six individual symptoms was expressed at high levels. Of the primary symptoms, chlorophyll *a* had the most pronounced expression in five estuaries located in North Carolina and Florida. Of the secondary symptoms, depleted dissolved oxygen was considered high only in the Neuse River; however, low to moderate conditions occurred in almost every other estuary in the region. Nuisance/toxic algal blooms occurred at high levels in both the New and Neuse Rivers and at moderate levels in the Pamlico/Pungo Rivers of North Carolina. The loss of submerged aquatic vegetation was a problem in almost half of the estuaries, but mainly at low to moderate levels.

While few estuaries in the South Atlantic exhibit high eutrophic conditions, many estuaries have moderate to high susceptibility. Furthermore, conditions are expected to worsen in 10 estuaries that currently exhibit low to moderate eutrophic conditions.

Figure 22. *Eutrophic conditions and symptoms*



		Symptom Expression					
		Primary			Secondary		
Estuary	Eutrophic Condition	Chlorophyll *a*	Epiphytes	Macroalgae	Low Dissolved Oxygen	SAV Loss	Nuisance/ Toxic Blooms
Albemarle Sound	?	🟦	⬜	⬜	🟦	🟦	🟦
Pamlico Sound	?	🟨	⬜	⬜	🟦	🟦	🟨
Pamlico/Pungo Rivers	🟥	🟥	⬜	⬜	🟨	🟨	🟨
Neuse River	🟥	🟥	⬜	⬜	🟥	🟦	🟥
Bogue Sound	🟦	🟨	?	⬜	⬜	?	🟦
New River	🟥	🟥	⬜	⬜	🟦	?	🟥
Cape Fear River	🟨	🟥	⬜	⬜	🟦	?	⬜
Winyah Bay	🟦	🟨	⬜	⬜	🟨	⬜	🟦
N. Santee/S. Santee Rivers	🟦	?	⬜	⬜	🟨	?	⬜
Charleston Harbor	🟨	🟨	⬜	🟨	🟨	⬜	⬜
Stono/North Edisto Rivers	🟦	?	⬜	⬜	🟨	⬜	⬜
St. Helena Sound	?	🟦	?	?	🟨	?	?
Broad River	🟦	🟦	?	?	🟨	?	⬜
Savannah River	🟨	🟨	⬜	⬜	🟨	⬜	⬜
Ossabaw Sound	🟦	🟨	⬜	⬜	🟦	?	⬜
St. Catherines/Sapelo Sounds	🟦	🟨	⬜	⬜	🟦	⬜	⬜
Altamaha River	🟦	🟨	⬜	⬜	🟦	⬜	⬜
St. Andrew/St. Simons Sounds	🟦	🟨	⬜	⬜	🟦	⬜	⬜
St. Marys River/Cumberland Sd.	🟨	🟨	⬜	⬜	🟨	⬜	⬜
St. Johns River	🟥	🟥	🟨	⬜	🟨	🟦	🟦
Indian River	🟨	🟨	🟨	🟨	🟨	🟨	🟦
Biscayne Bay	🟦	🟦	⬜	⬜	🟦	⇧	⬜

🟥	🟨	🟦	⬜	⇧	?
High	Moderate	Low	No Expression	Improving Symptom	Insufficient Data

In general, the symptoms most often associated with high expressions of eutrophic conditions were high chlorophyll *a* and nuisance/toxic algal blooms, although various levels of other symptoms were known to occur.

Some data existed for the Albemarle and Pamlico Sounds, but it was for very limited portions of the systems. St. Helena Sound also had insufficient data for an overall assessment. In 10 other estuaries, the confidence levels for assessments were low. Information was sparsest for trends in submerged aquatic vegetation.

Influencing Factors

The overall level of human influence was low in half of the region's estuaries, especially in South Carolina and Georgia, and moderate in most of the remaining estuaries. Human influence was most pronounced in the Pamlico/Pungo Rivers, the Neuse River and the New River.

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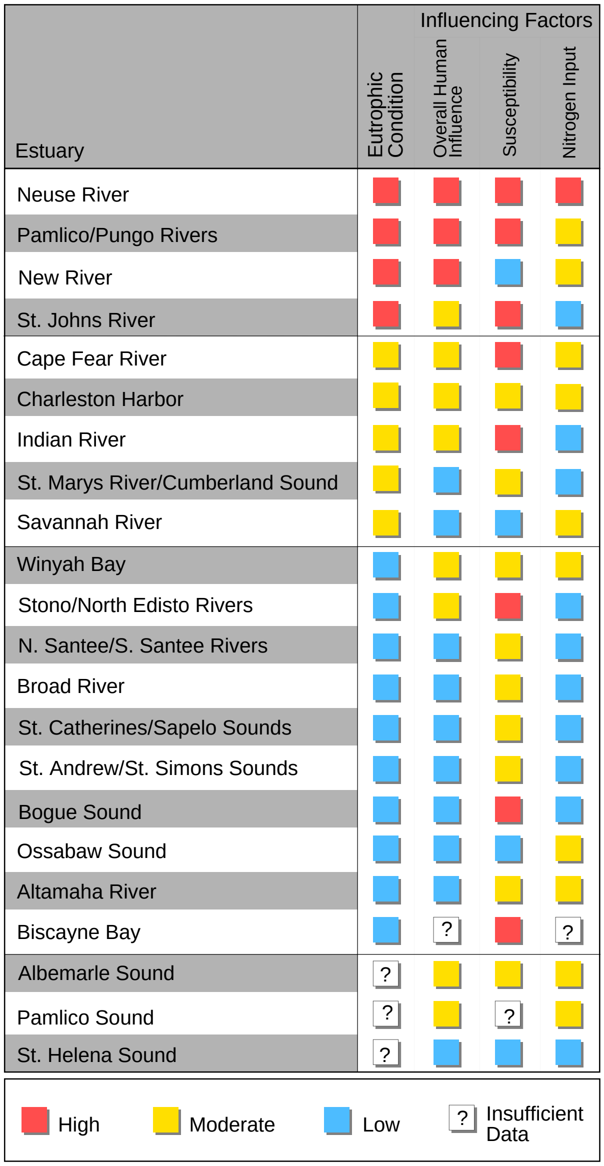
Figure 23. *Eutrophic conditions and influencing factors*



Estuary	Eutrophic Condition	Influencing Factors		
		Overall Human Influence	Susceptibility	Nitrogen Input
Neuse River	🟥	🟥	🟥	🟥
Pamlico/Pungo Rivers	🟥	🟥	🟥	🟨
New River	🟥	🟥	🟦	🟨
St. Johns River	🟥	🟨	🟥	🟦
Cape Fear River	🟨	🟨	🟥	🟨
Charleston Harbor	🟨	🟨	🟨	🟨
Indian River	🟨	🟨	🟥	🟦
St. Marys River/Cumberland Sound	🟨	🟦	🟨	🟦
Savannah River	🟨	🟦	🟦	🟨
Winyah Bay	🟦	🟨	🟨	🟨
Stono/North Edisto Rivers	🟦	🟨	🟥	🟦
N. Santee/S. Santee Rivers	🟦	🟦	🟨	🟦
Broad River	🟦	🟦	🟨	🟦
St. Catherines/Sapelo Sounds	🟦	🟦	🟨	🟦
St. Andrew/St. Simons Sounds	🟦	🟦	🟨	🟦
Bogue Sound	🟦	🟦	🟥	🟦
Ossabaw Sound	🟦	🟦	🟦	🟨
Altamaha River	🟦	🟦	🟨	🟨
Biscayne Bay	🟦	?	🟥	?
Albemarle Sound	?	🟨	🟨	🟨
Pamlico Sound	?	🟨	?	🟨
St. Helena Sound	?	🟦	🟦	🟦

🟥 High 🟨 Moderate 🟦 Low ? Insufficient Data

Many factors influence the expression of eutrophic conditions in South Atlantic estuaries. The limited number of systems in which eutrophic conditions were high generally had restricted circulation, low tidal exchange, and moderate to high nitrogen inputs. In most of the other estuaries, which were relatively unaffected by eutrophication, the influence of tidal marshes (which act as a nutrient filtering mechanism), strong tides, and low nitrogen inputs combined to keep eutrophic conditions at bay.

The confidence levels for the assessment of overall human influence were low in 10 estuaries.

Impaired Uses

Although impaired uses in the South Atlantic were difficult to relate directly to eutrophic conditions, results from the National Assessment Workshop did suggest that the most important impaired uses occurring in the region were commercial and recreational fishing, shellfishing, and fish consumption. Swimming, boating and tourism were also affected, to a lesser extent.

Potential Management Concerns

The areas requiring specific management focus are driven by dominant land-use practices around the estuaries with problematic conditions. For the systems with the most pronounced expressions of eutrophication, the most important nutrient sources to focus on are wastewater treatment plants, large animal operations, and agricultural activities. In estuaries with intermediate to low eutrophic symptoms, management efforts to control nutrients from urban, agricultural, and, to a lesser extent, forestry sources, will minimize further degradation.

Future Outlook to 2020

Based on the experts' knowledge of watershed activities, population trends, and nutrient-loading estimates, 12 estuaries were predicted to develop worsening eutrophication conditions through 2020; at present, more than half of these systems are relatively pristine and as yet unaffected by eutrophication. Coastal Georgia and South Carolina were projected to have the greatest relative population growth of all coastal regions in the nation, and thus, despite moderate to low symptoms at present, the likelihood that these estuaries will develop future problems is inordinately high. In fact, the first red tide blooms ever reported in South Carolina and Georgia occurred in June 1999. Estuaries that currently exhibit moderate to high levels of eutrophication, and that were predicted to develop worsening conditions, are Charleston Harbor, the Savannah River, St. Marys River, St. Johns River, and the Indian River. Bogue Sound, the New River, and St. Helena Sound were noted as potentially showing improvement in the future.

The confidence levels for the assessment of the future outlook were low for three estuaries and moderate for the rest. The reliability of all of this information is, however, inherently vulnerable to unforeseen changes.

Data Gaps and Research Needs

The South Atlantic is generally a poorly studied region. The confidence level of the assessment of overall eutrophic condition was low for 12 systems, and an additional six were specifically identified as requiring improvements in basic monitoring. The need for data in this region is critical, given the projected increases in population and the susceptibility of many

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of the systems. Other identified needs were better data on organic as well as inorganic nutrient loads and concentrations; time-series data sets in both impacted and pristine systems; and more data on the comparative roles of shallow intertidal habitats and water-column processes. Research on the effects of nutrient loading in blackwater systems, and comparative data on nutrient processing in blackwater versus alluvial rivers, were also deemed imperative.

Population growth and the associated development of relatively pristine estuarine watersheds is a major concern for the South Atlantic. Photograph courtesy of Michael A. Mallin, Center for Marine Science Research, University of North Carolina at Wilmington.

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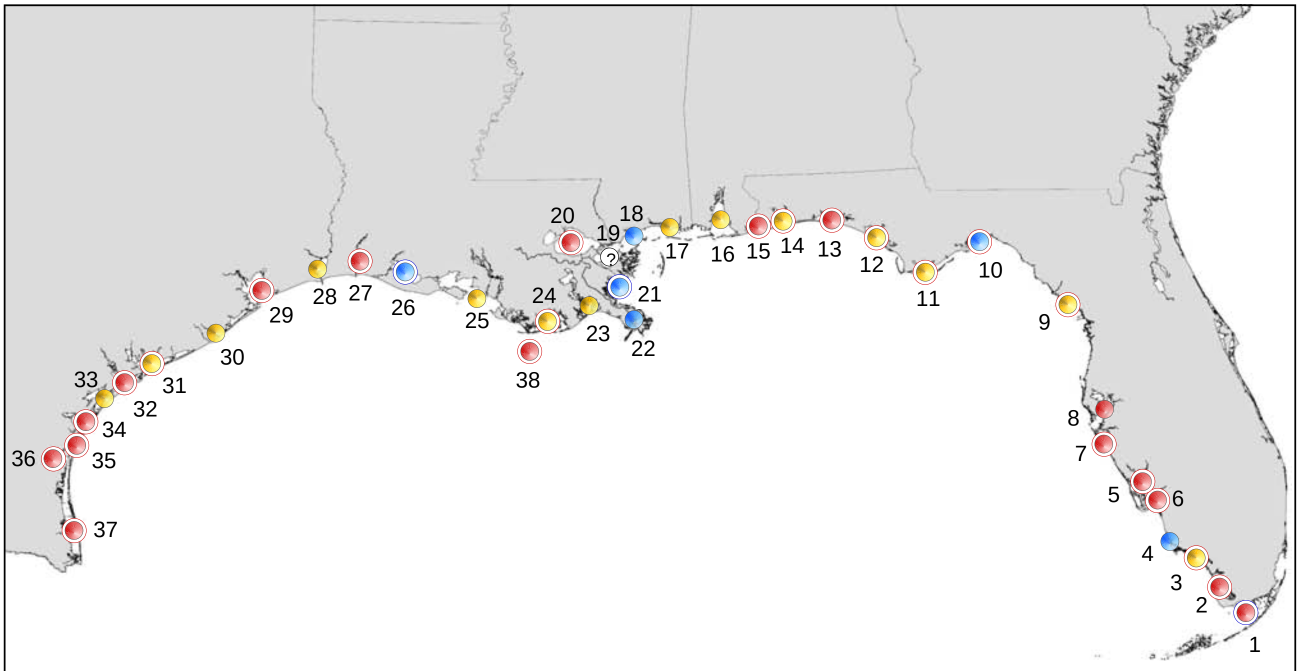
Gulf of Mexico

The expression of high eutrophic conditions is extensive, and human influence is substantial, in the Gulf of Mexico region. Although there is a great diversity of estuary types, common characteristics, such as low tidal flushing, warm water, and long algal growing seasons, create conditions that make many of the region's estuaries susceptible to eutrophic problems. The most significant symptoms in the overall expression of eutrophic conditions are low dissolved oxygen and loss of submerged aquatic vegetation. Impaired resource uses are evident in many, but not all, of the affected systems. Conditions are expected to worsen in more than half of the estuaries by 2020.

Figure 24. *Level of expression of eutrophic conditions and future trends*



Eutrophic Conditions and Trends

🔴 *High:* symptoms generally occur periodically and/or over extensive area.

🟡 *Moderate:* symptoms generally occur less periodically and/or over medium area.

🔵 *Low:* few symptoms occur at more than minimal levels.

? Insufficient data for analysis

○ *Worsen:* symptoms are expected to develop or become more pronounced by 2020.

○ *Improve:* symptoms are expected to decline through 2020.

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

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The Gulf of Mexico region includes 37 estuaries plus the Mississippi River Plume, encompassing more than 24,000 square miles of water surface area. The region is comprised of a gently sloping, lowland area as part of the Gulf Coastal Plain. Estuarine and coastal environments are highly diverse, consisting of unrestricted open bays, semi-enclosed lagoons, tidal marshes and delta complexes. The fresh water that flows naturally into estuaries can fluctuate greatly in the Gulf, and depends on seasonal rainfall patterns. Estuarine circulation patterns are generally wind driven, and coastal waters are usually warmer than in other regions due to the subtropical climate. Estuaries have fairly low tidal energy (0.5-3.5 ft. tide range), and water depths are typically shallow when compared to estuaries in other regions. Land-use activity in the watersheds is typically dominated by agricultural practices. Major population centers include Houston, New Orleans and Tampa.

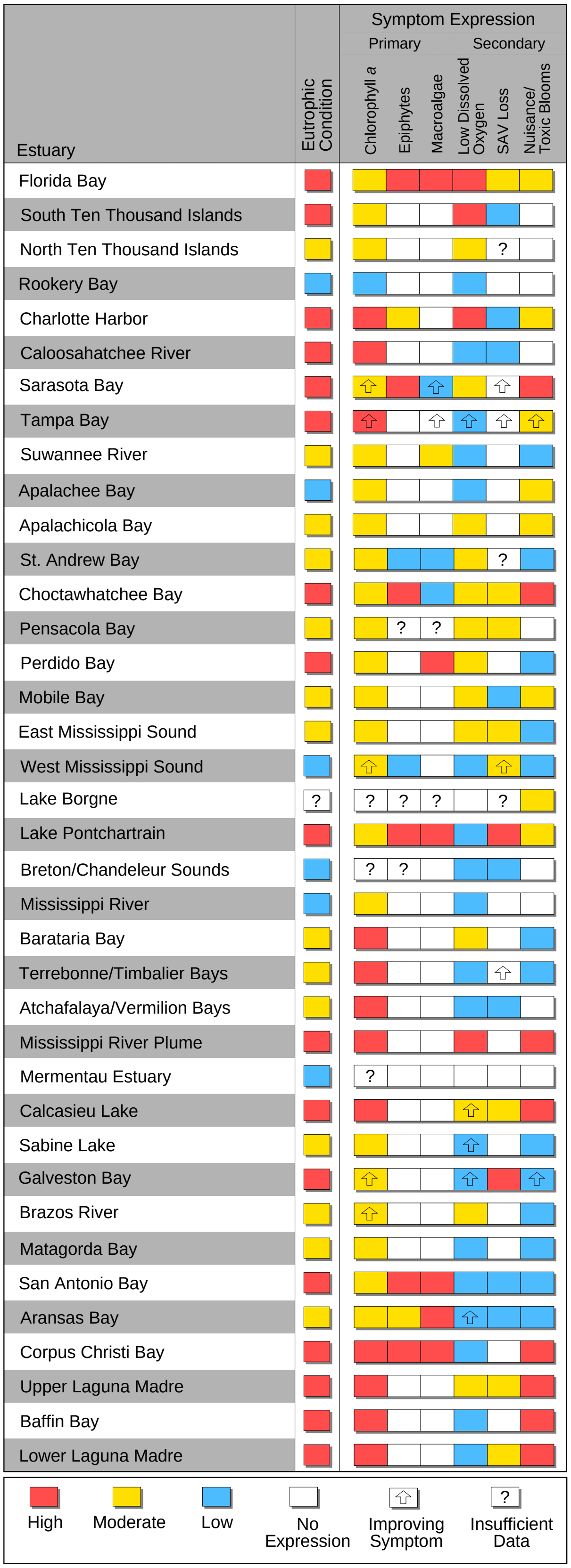
Eutrophic Conditions

Overall Conditions. The Gulf of Mexico was significantly affected by elevated expressions of eutrophication. Almost half of the estuaries were characterized as having high levels of eutrophic conditions. Estuaries noted as having the highest-level conditions were Florida Bay, Lake Pontchartrain, Calcasieu Lake, the Mississippi River Plume, Corpus Christi Bay and the Laguna Madre system. Fourteen estuaries were characterized as having moderate levels of eutrophic conditions, and only six were characterized as having low-level conditions.

Expression of Symptoms. In 20 estuaries, at least one of the six individual symptoms was expressed at high levels. Of the primary symptoms, chlorophyll *a* was expressed at high levels in 12 estuaries that were located mainly on the coasts of western Florida, Louisiana and lower Texas. In eight estuaries, epiphytes were considered moderate to high; in seven estuaries, magroalgal abundance was considered moderate to high. Of the secondary symptoms, low dissolved oxygen occurred at high levels in four estuaries, mainly along the Florida coast and in the Mississippi River Plume. The loss of submerged aquatic vegetation was a problem in almost half of the estuaries, but usually at low to moderate levels. Nuisance / toxic algal blooms also tended to be per-

> ***Of all regions, the Gulf of Mexico has the greatest percentage of estuaries with high eutrophic conditions, despite low to moderate nutrient inputs. In addition to the prevalence of moderate to high susceptibility, the generally long growing season and warm waters result in higher levels of expression of eutrophic conditions.***

Figure 25. *Eutrophic conditions and symptoms*



		Symptom Expression					
		Primary			Secondary		
Estuary	Eutrophic Condition	Chlorophyll *a*	Epiphytes	Macroalgae	Low Dissolved Oxygen	SAV Loss	Nuisance/ Toxic Blooms
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	🟨	🟨	⬜	⬜	🟨	🟦	🟨
East Mississippi Sound	🟨	🟨	⬜	⬜	🟨	🟨	🟦
West Mississippi Sound	🟦	🟨⇧	🟦	⬜	🟦	🟨⇧	🟦
Lake Borgne	?	?	?	?	⬜	?	🟨
Lake Pontchartrain	🟥	🟨	🟥	🟥	🟦	🟥	🟨
Breton/Chandeleur Sounds	🟦	?	?	⬜	🟦	🟦	⬜
Mississippi River	🟦	🟨	⬜	⬜	🟦	⬜	⬜
Barataria Bay	🟨	🟥	⬜	⬜	🟨	⬜	🟦
Terrebonne/Timbalier Bays	🟨	🟥	⬜	⬜	🟦	⇧	🟦
Atchafalaya/Vermilion Bays	🟨	🟥	⬜	⬜	🟦	🟦	⬜
Mississippi River Plume	🟥	🟥	⬜	⬜	🟥	⬜	🟥
Mermentau Estuary	🟦	?	⬜	⬜	⬜	⬜	⬜
Calcasieu Lake	🟥	🟥	⬜	⬜	🟨⇧	🟨	🟥
Sabine Lake	🟨	🟨	⬜	⬜	🟦⇧	⬜	🟦
Galveston Bay	🟥	🟨⇧	⬜	⬜	🟦⇧	🟥	🟦⇧
Brazos River	🟨	🟨⇧	⬜	⬜	🟨	⬜	🟦
Matagorda Bay	🟨	🟨	⬜	⬜	🟦	⬜	🟦
San Antonio Bay	🟥	🟨	🟥	🟥	🟦	🟦	🟦
Aransas Bay	🟨	🟨	🟨	🟥	🟦⇧	🟦	🟦
Corpus Christi Bay	🟥	🟥	🟥	🟥	🟦	⬜	🟥
Upper Laguna Madre	🟥	🟥	⬜	⬜	🟨	🟨	🟥
Baffin Bay	🟥	🟥	⬜	⬜	🟦	⬜	🟥
Lower Laguna Madre	🟥	🟥	⬜	⬜	🟦	🟨	🟥

🟥 High
🟨 Moderate
🟦 Low
⬜ No Expression
⇧ Improving Symptom
? Insufficient Data

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vasive, occurring in 28 estuaries, eight of which showed high levels. All eight of these estuaries were located in the coastal systems of Florida, western Louisiana and the lower Texas coast.

In the systems with high eutrophic conditions, the symptoms that generally contribute the most to the observed overall condition were the loss of submerged aquatic vegetation, increased turbidity associated with high concentrations of chlorophyll *a*, and low levels of dissolved oxygen. Moderate to high levels of nuisance/toxic algal blooms and epiphyte abundance were also major factors in systems with pronounced expressions of eutrophication.

In general, recent improving trends are due primarily to better management of point and nonpoint nutrient sources. Where conditions are moderate to high, however, there is still much room for improvement, and efforts to control nutrient inputs should be maintained and fortified.

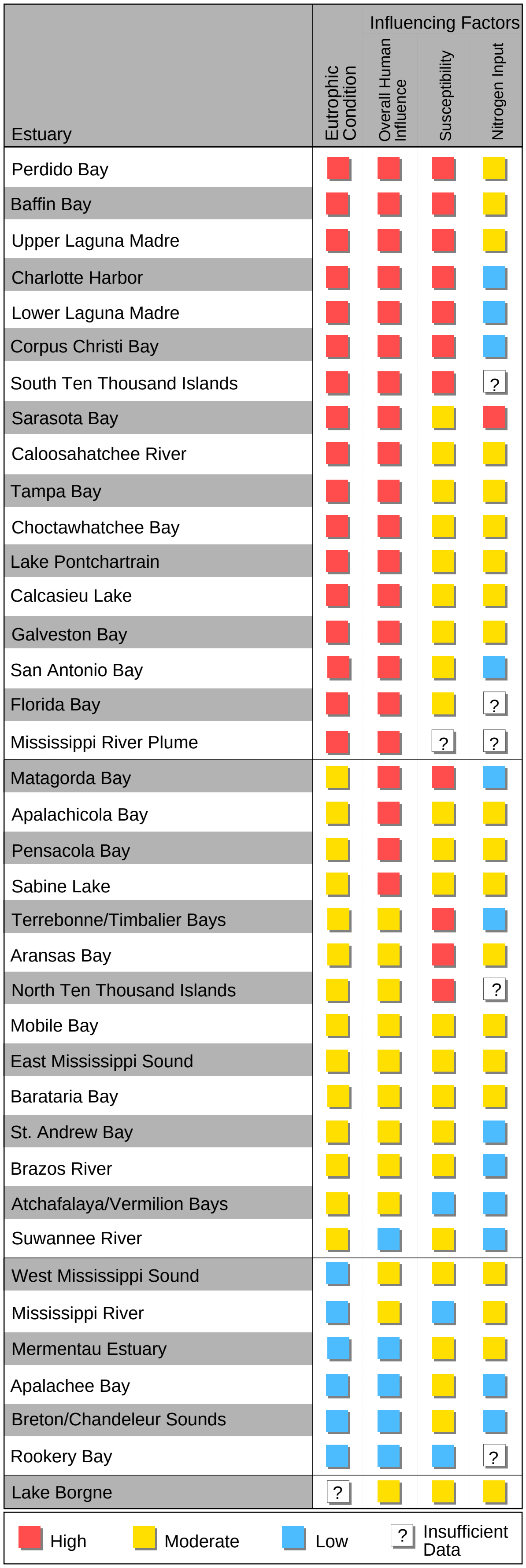
The Gulf of Mexico is generally a well studied region; the confidence levels for the assessment of overall eutrophic conditions were medium to high for 31 systems. The confidence levels for the assessment of overall eutrophic conditions were low for only six systems. Data availability was generally very good; Lake Borgne was the only estuary with insufficient data for an assessment.

Overall Human Influence

The overall level of human influence was high in more than half of all Gulf systems and corresponded well with high levels of eutrophic conditions (Figure 27). Human influence was considered most prominent in the Mississippi River Plume, Lake Pontchartrain, Upper and Lower Laguna Madre, and Baffin Bay. Noted for having relatively low human influence were Rookery Bay, the Suwannee River, Apalachee Bay, and Breton/Chandeleur Sounds.

Many factors influenced the expression of eutrophication in Gulf estuaries. The following influencing factors were generally associated with moderate to pronounced levels of expression: low tidal energy, low flushing rates with increased nutrient inputs, and low dissolved oxygen levels generally due to warmer waters and the longer growing season. These factors contributed significantly to the high levels of human influence in many Gulf estuaries with pronounced eutrophic conditions, even though nitrogen inputs were generally moderate (Figure 27). For example, although population density is relatively low in the Baffin Bay and Upper Laguna Madre watersheds, human influence is magnified

Figure 26. *Eutrophic conditions and influencing factors*



Estuary	Eutrophic Condition	Influencing Factors Overall Human Influence	 Susceptibility	 Nitrogen Input
Perdido Bay	🟥	🟥	🟥	🟨
Baffin Bay	🟥	🟥	🟥	🟨
Upper Laguna Madre	🟥	🟥	🟥	🟨
Charlotte Harbor	🟥	🟥	🟥	🟦
Lower Laguna Madre	🟥	🟥	🟥	🟦
Corpus Christi Bay	🟥	🟥	🟥	🟦
South Ten Thousand Islands	🟥	🟥	🟥	?
Sarasota Bay	🟥	🟥	🟨	🟥
Caloosahatchee River	🟥	🟥	🟨	🟨
Tampa Bay	🟥	🟥	🟨	🟨
Choctawhatchee Bay	🟥	🟥	🟨	🟨
Lake Pontchartrain	🟥	🟥	🟨	🟨
Calcasieu Lake	🟥	🟥	🟨	🟨
Galveston Bay	🟥	🟥	🟨	🟨
San Antonio Bay	🟥	🟥	🟨	🟦
Florida Bay	🟥	🟥	🟨	?
Mississippi River Plume	🟥	🟥	?	?
Matagorda Bay	🟨	🟥	🟥	🟦
Apalachicola Bay	🟨	🟥	🟨	🟨
Pensacola Bay	🟨	🟥	🟨	🟨
Sabine Lake	🟨	🟥	🟨	🟨
Terrebonne/Timbalier Bays	🟨	🟨	🟥	🟦
Aransas Bay	🟨	🟨	🟥	🟨
North Ten Thousand Islands	🟨	🟨	🟥	?
Mobile Bay	🟨	🟨	🟨	🟨
East Mississippi Sound	🟨	🟨	🟨	🟨
Barataria Bay	🟨	🟨	🟨	🟨
St. Andrew Bay	🟨	🟨	🟨	🟦
Brazos River	🟨	🟨	🟨	🟦
Atchafalaya/Vermilion Bays	🟨	🟨	🟦	🟦
Suwannee River	🟨	🟦	🟨	🟦
West Mississippi Sound	🟦	🟨	🟨	🟨
Mississippi River	🟦	🟨	🟦	🟨
Mermentau Estuary	🟦	🟦	🟨	🟨
Apalachee Bay	🟦	🟦	🟨	🟦
Breton/Chandeleur Sounds	🟦	🟦	🟨	🟦
Rookery Bay	🟦	🟦	🟦	?
Lake Borgne	?	🟨	🟨	🟨

🟥 High 🟨 Moderate 🟦 Low ? Insufficient Data

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due to these estuaries' high susceptibility.

The confidence level in the assessment of human influence was low for 11 estuaries.

Impaired Uses

Impaired uses were difficult to define as being directly related to eutrophication. Results from the Workshop, however, did suggest that the most impaired uses were recreational and commercial fishing and shellfishing. Habitat-level impacts, such as the loss of submerged aquatic vegetation, were also noted.

Potential Management Concerns

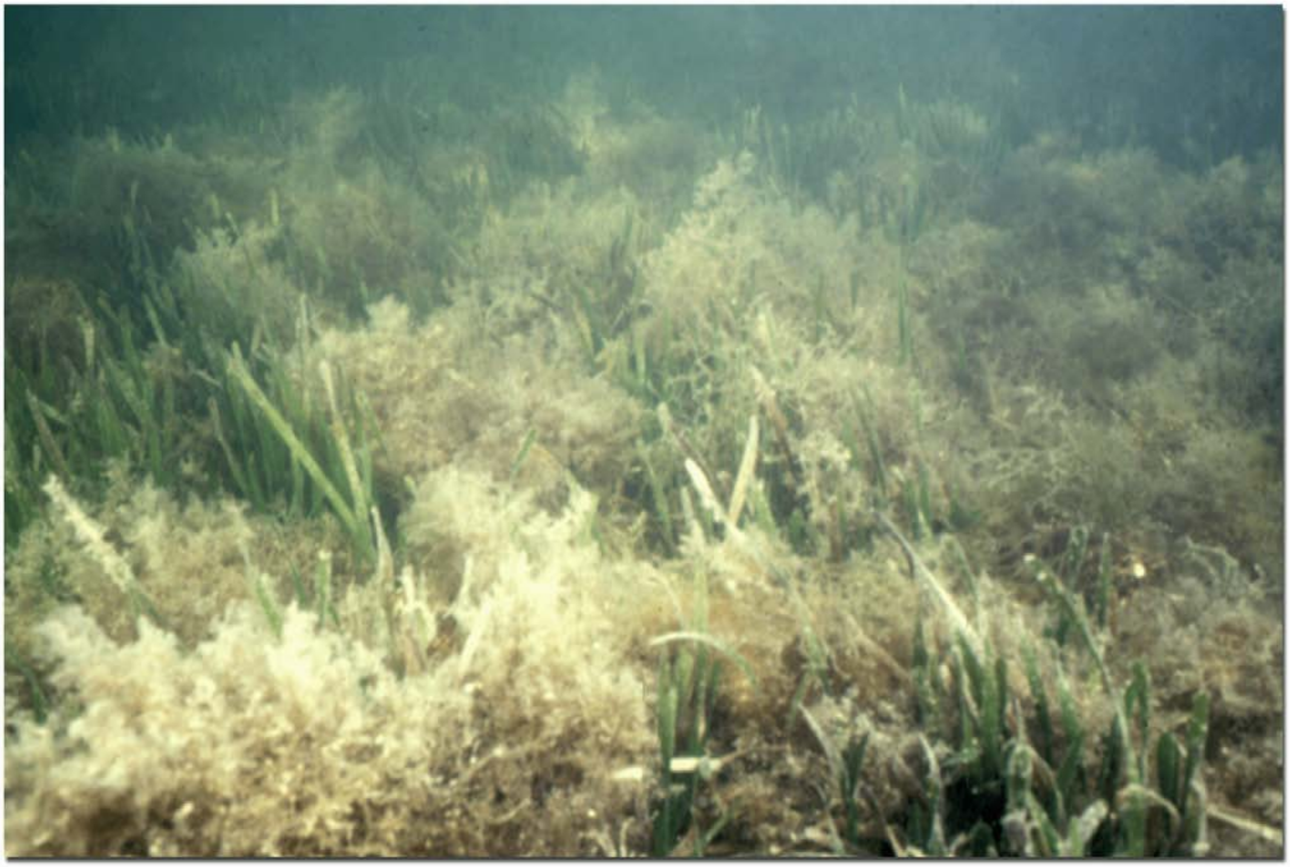
The areas requiring specific management focus are driven by agriculture, which is the dominant land use in the region's watersheds. Management target areas are diverse because of the varied physical makeup and forcing mechanisms that drive conditions in the estuaries. Wastewater treatment plants, industrial discharges, and agricultural practices are common management targets. Atmospheric inputs are important in low-flow systems. Upland inputs should be targeted for large fluvial systems such as the Mississippi, Mobile, and Apalachicola Rivers.

Future Outlook to 2020

Of the 38 Gulf estuaries studied, 23 were predicted to develop worsening conditions over the next 20 years, six of them to a high degree (Mississippi River Plume, Lake Pontchartrain, Corpus Christi Bay, Upper and Lower Laguna Madre, and Baffin Bay). Florida Bay, Breton/Chandeleur Sounds, and Mermentau Estuary were noted as potentially showing signs of future improvement. The level of confidence for the assessment of the future outlook was low for 12 estuaries.

Data Gaps and Research Needs

Research areas, such as biogeochemical cycling and nutrient budget analyses, require an understanding of the processes by which elements are recycled within estuaries. According to the experts, these processes are poorly understood and in need of more attention. Participants at the workshop noted that phosphorus may be an important contributor to eutrophication in some Gulf of Mexico estuaries; however, the relative roles of nitrogen and phosphorus need clarification. The experts also called for better understanding of individual estuaries' assimilative capacity, and more research on inlet circulation and approaches to inlet management.



In Florida Bay, this macroalgae bloom smothered the surrounding submerged aquatic vegetation.
Photograph courtesy of Brian LaPointe, Harbor Branch Oceanographic Institute.

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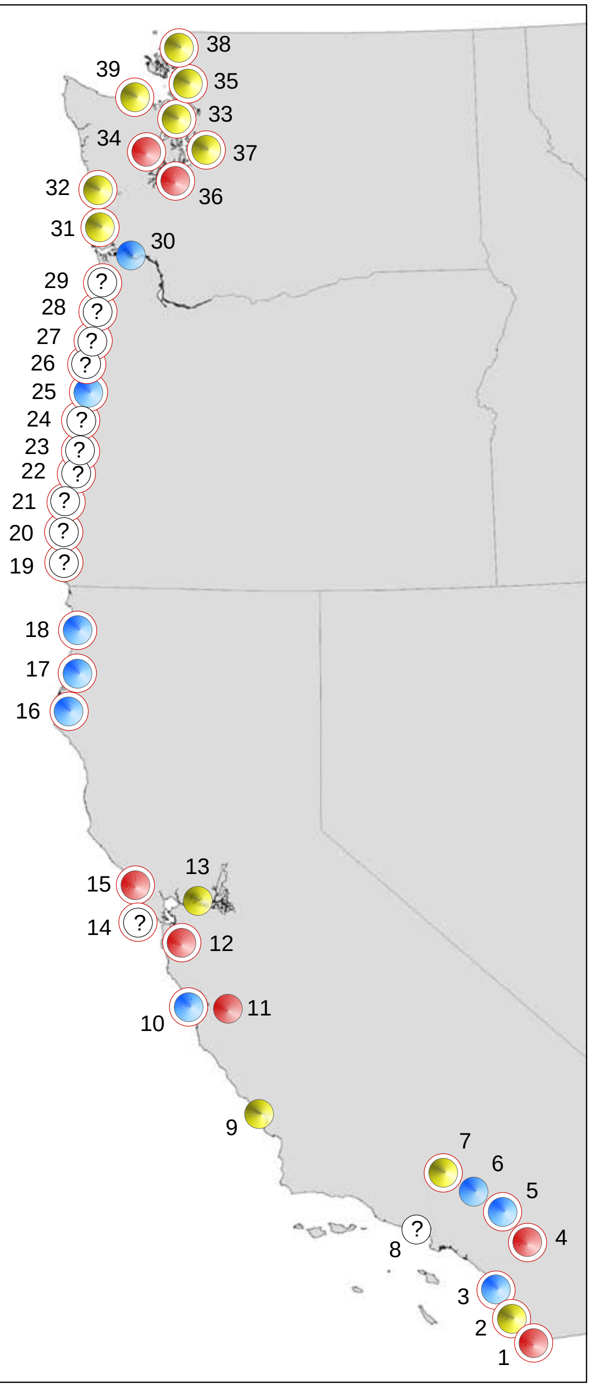
Pacific

High eutrophic conditions occur in the extreme north and south of the region, and on the central California coast. These estuaries tend to have restricted circulation and high nutrient inputs. Symptoms are expected to develop or worsen in the majority of systems, primarily due to projected population increases and development pressures. Estuarine habitats and shellfisheries are the most affected resources. In general, the most important nutrient sources for management concern are agriculture, forestry, wastewater treatment plants, and urban runoff. The assessment confidence is generally low, except in San Francisco Bay and Puget Sound.

Figure 27. *Level of expression of eutrophic conditions and future trends*

1. Tijuana Estuary
2. San Diego Bay
3. Mission Bay
4. Newport Bay
5. San Pedro Bay
6. Alamitos Bay
7. Anaheim Bay
8. Santa Monica Bay
9. Morro Bay
10. Monterey Bay
11. Elkhorn Slough
12. San Francisco Bay
13. Central San Francisco/ San Pablo/Suisun Bays
14. Drakes Estero
15. Tomales Bay
16. Eel River
17. Humboldt Bay
18. Klamath River
19. Rogue River
20. Coquille River
21. Coos Bay
22. Umpqua River
23. Siuslaw River
24. Alsea River
25. Yaquina Bay
26. Siletz Bay
27. Netarts Bay
28. Tillamook Bay
29. Nehalem River
30. Columbia River
31. Willapa Bay
32. Grays Harbor
33. Puget Sound
34. Hood Canal
35. Whidbey Basin/Skagit Bay
36. South Puget Sound
37. Port Orchard System
38. Bellingham/Padilla/Samish Bays
39. Sequim/Discovery Bays



Eutrophic Conditions and Trends

🔴 *High:* symptoms generally occur periodically and/or over extensive area.

🟡 *Moderate:* symptoms generally occur less periodically and/or over medium area.

🔵 *Low:* few symptoms occur at more than minimal levels.

? Insufficient data for analysis

○ *Worsen:* symptoms are expected to develop or become more pronounced by 2020.

○ *Improve:* symptoms are expected to decline through 2020.

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The Pacific region includes 39 estuaries, encompassing more than 2,750 square miles of water surface area. The region consists of a relatively straight and uninterrupted shoreline with rocky shores, sandy beaches and occasional river outlets. Limited areas of flat, lowland environments support estuaries, bays and lagoons. Estuaries are typically small and separated by large distances. Estuarine circulation patterns are dominated mainly by seasonal freshwater inflow in Southern California and by freshwater inflow and tides in the larger estuaries of central California and Washington state. The tidal range is moderately high (5.0-7.5 feet). Forestry, agriculture and industry are the dominant land uses in the region's watersheds. Some of the major population centers include Los Angeles, San Diego, San Francisco and Seattle.

Eutrophic Conditions

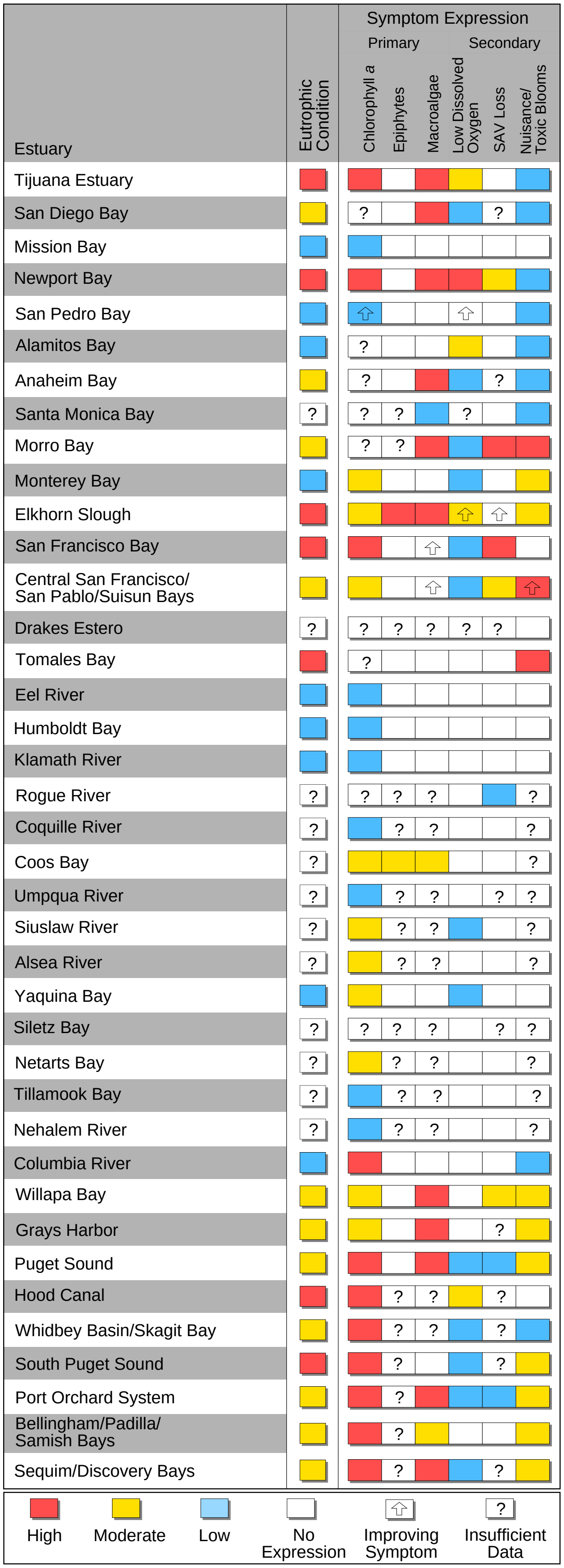
Overall Conditions. Pacific Coast estuaries exhibited a wide range of eutrophic conditions. High-level conditions occurred in seven estuaries, mainly in the northern and southern sections of the region (Figure 29). Among these were Tijuana Estuary, Newport Bay, and San Francisco Bay. Eleven estuaries fell into the moderate range; these were interspersed throughout California and the Pacific Northwest. Nine estuaries were relatively unaffected by eutrophic conditions.

Expression of Symptoms. In 19 estuaries, at least one of the six individual symptoms was expressed at high levels. Of the primary symptoms, chlorophyll *a* was expressed at high levels in 11 systems, most of them in Southern California and northern Washington. Macroalgal abundance was observed at moderate to high levels in 13 estuaries, most of them also found in Southern California and Washington. Epiphyte abundance was minimal. Eight estuaries exhibited losses in submerged aquatic vegetation; two of these at high levels. Nuisance / toxic algal blooms occurred in 21 estuaries, 12 of which were in the moderate to high range.

In general, the symptoms contributing most to high eutrophic conditions were elevated levels of chloro-

> ***The Pacific region, more than any other, is characterized by insufficient data. Although the estuaries with unknown conditions are generally perceived to have few eutrophic problems, many have moderate susceptibility and are predicted to develop eutrophic symptoms by 2020.***

Figure 28. *Eutrophic conditions and symptoms*



Estuary	Eutrophic Condition	Symptom Expression					
		Primary			Secondary		
		Chlorophyll a	Epiphytes	Macroalgae	Low Dissolved Oxygen	SAV Loss	Nuisance/ Toxic Blooms
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	🟥	🟥	⬜	⇧	🟦	🟥	⬜
Central San Francisco/ San Pablo/Suisun Bays	🟨	🟨	⬜	⇧	🟦	🟨	🟥 ⇧
Drakes Estero	?	?	?	?	?	?	⬜
Tomales Bay	🟥	?	⬜	⬜	⬜	⬜	🟥
Eel River	🟦	🟦	⬜	⬜	⬜	⬜	⬜
Humboldt Bay	🟦	🟦	⬜	⬜	⬜	⬜	⬜
Klamath River	🟦	🟦	⬜	⬜	⬜	⬜	⬜
Rogue River	?	?	?	?	⬜	🟦	?
Coquille 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	🟥	🟥	?	?	🟨	?	⬜
Whidbey Basin/Skagit Bay	🟨	🟥	?	?	🟦	?	🟦
South Puget Sound	🟥	🟥	?	⬜	🟦	?	🟨
Port Orchard System	🟨	🟥	?	🟥	🟦	🟦	🟨
Bellingham/Padilla/ Samish Bays	🟨	🟥	?	🟨	⬜	⬜	🟨
Sequim/Discovery Bays	🟨	🟥	?	🟥	🟦	?	🟨

🟥 High
🟨 Moderate
🟦 Low
⬜ No Expression
⇧ Improving Symptom
? Insufficient Data

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phyll *a*, coupled with various combinations of macroalgal abundance, nuisance / toxic algal blooms, and low dissolved oxygen. High chlorophyll *a* concentrations is also a fairly common natural condition in some North Pacific estuaries due to naturally occurring seasonal blooms.

Recent improvements in certain symptoms were primarily attributed to point source controls and hydrologic changes.

The confidence levels for the assessment of eutrophic conditions was generally low in this region. Of the 27 estuaries that were characterized, 11 had low confidence levels. Twelve estuaries, most of them in Oregon, had insufficient data for an assessment of conditions. Part of the reason for the paucity of data, however, is that eutrophication generally is not perceived to be a problem in these systems.

Overall Human Influence

In general, estuaries with high-level eutrophic conditions also had high levels of human influence (Figure 30). Human influence on the expression of eutrophic symptoms was most pronounced in the Tijuana Estuary, Newport Bay, San Pedro Bay, Anaheim Bay and San Francisco Bay. Three of these—Newport, Anaheim and San Pedro—are among the top 10 U.S. estuaries with respect to population density in the watershed. Tijuana Estuary is also notable because three-quarters of the watershed is located in Mexico, making management an international challenge. The Tijuana River is the primary source of freshwater to the estuary; it is also a source of untreated sewage from the city of Tijuana.

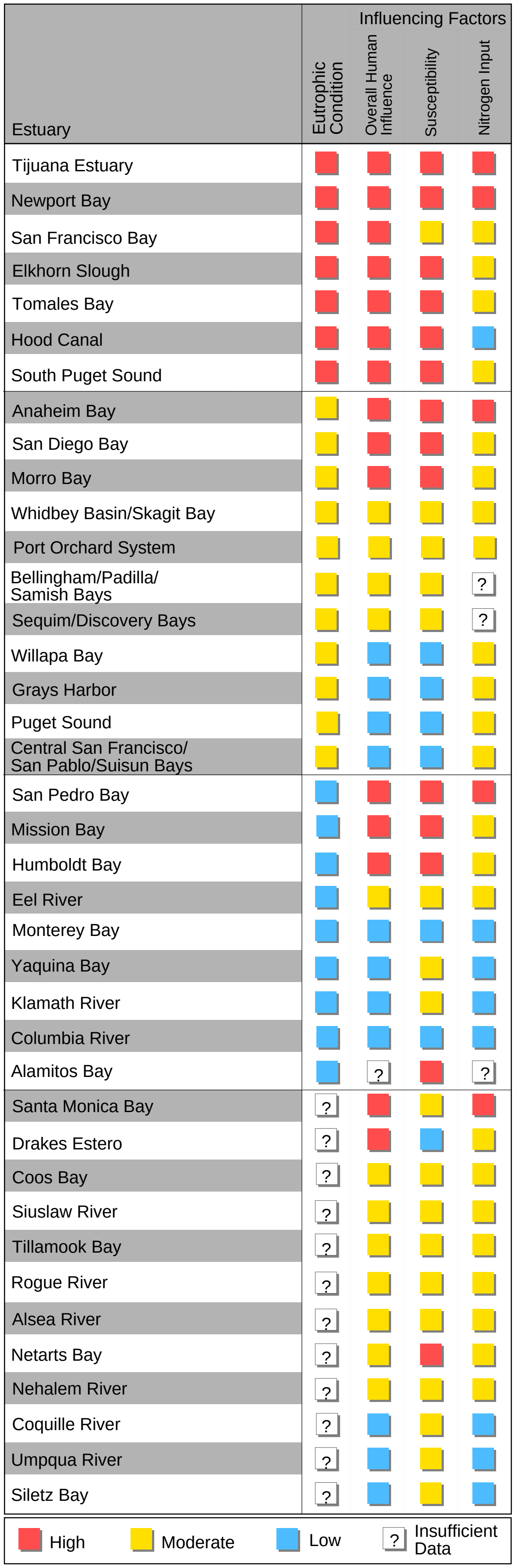
Although 12 estuaries had insufficient data for an assessment of eutrophic conditions, these systems were generally small, with good flushing capabilities, and nutrient loading appeared to be moderate. In general, restricted circulation and moderate to high levels of nutrient inputs were noted as the principle factors contributing to elevated eutrophic symptoms in Pacific Coast systems.

The level of confidence in the assessment of overall human influence was low for 30 estuaries.

Impaired Uses

The uses most often cited as impaired were fishing, shellfishing, swimming and aesthetic value. Most of these responses addressed the estuaries of Southern California and Washington; impaired uses were unknown in Oregon and northern California.

Figure 29. *Eutrophic conditions and influencing factors*



Estuary	Eutrophic Condition	Influencing Factors		
		Overall Human Influence	Susceptibility	Nitrogen Input
Tijuana Estuary	🟥	🟥	🟥	🟥
Newport Bay	🟥	🟥	🟥	🟥
San Francisco Bay	🟥	🟥	🟨	🟨
Elkhorn Slough	🟥	🟥	🟥	🟨
Tomales Bay	🟥	🟥	🟥	🟨
Hood Canal	🟥	🟥	🟥	🟦
South Puget Sound	🟥	🟥	🟥	🟨
Anaheim Bay	🟨	🟥	🟥	🟥
San Diego Bay	🟨	🟥	🟥	🟨
Morro Bay	🟨	🟥	🟥	🟨
Whidbey Basin/Skagit Bay	🟨	🟨	🟨	🟨
Port Orchard System	🟨	🟨	🟨	🟨
Bellingham/Padilla/ Samish Bays	🟨	🟨	🟨	?
Sequim/Discovery Bays	🟨	🟨	🟨	?
Willapa Bay	🟨	🟦	🟦	🟨
Grays Harbor	🟨	🟦	🟦	🟨
Puget Sound	🟨	🟦	🟦	🟨
Central San Francisco/ San Pablo/Suisun Bays	🟨	🟦	🟦	🟨
San Pedro Bay	🟦	🟥	🟥	🟥
Mission Bay	🟦	🟥	🟥	🟨
Humboldt Bay	🟦	🟥	🟥	🟨
Eel River	🟦	🟨	🟨	🟨
Monterey Bay	🟦	🟦	🟦	🟦
Yaquina Bay	🟦	🟦	🟨	🟦
Klamath River	🟦	🟦	🟨	🟦
Columbia River	🟦	🟦	🟦	🟦
Alamitos Bay	🟦	?	🟥	?
Santa Monica Bay	?	🟥	🟨	🟥
Drakes Estero	?	🟥	🟦	🟨
Coos Bay	?	🟨	🟨	🟨
Siuslaw River	?	🟨	🟨	🟨
Tillamook Bay	?	🟨	🟨	🟨
Rogue River	?	🟨	🟨	🟨
Alsea River	?	🟨	🟨	🟨
Netarts Bay	?	🟨	🟥	🟨
Nehalem River	?	🟨	🟨	🟨
Coquille River	?	🟦	🟨	🟦
Umpqua River	?	🟦	🟨	🟦
Siletz Bay	?	🟦	🟨	🟦

🟥 High 🟨 Moderate 🟦 Low ? Insufficient Data

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A bloom of nuisance algae mars an estuary in the state of Washington. Photo courtesy of Puget Sound Water Quality Action Team.

Potential Management Concerns

Potential sources to target to improve conditions in Washington estuaries are wastewater treatment plants, on-site animal operations, agriculture and forestry. In Southern California, wastewater treatment plants, urbanization, agriculture and forestry were cited.

With the exception of three estuaries—San Francisco Bay, Central San Francisco Bay and the Columbia River—experts noted that reductions in nutrient inputs would significantly improve water-quality conditions. Workshop participants also recommended that management efforts focus primarily on the coastal portions of the watersheds.

Future Outlook to 2020

Thirty-one estuaries were predicted to develop worsening conditions during the next 20 years. Five of these—Tijuana Estuary, San Diego Bay, Newport Bay, Hood Canal and South Puget Sound—are expected to get much worse. The reported reason for worsening conditions was increasing population pressures along most of the coast.

The level of confidence in the assessment of the future outlook was low for 24 (nearly two-thirds) of Pacific estuaries.

Data Gaps and Research Needs

The estuaries of the Pacific Coast are predominantly understudied, particularly in Oregon and in some areas of California. Thus, there is a need for baseline monitoring of basic water-quality parameters in these areas. In addition, research is needed to determine the fate of nutrients and their eventual impacts on primary production and human uses of the resources. If water quality is to be managed properly in the presently pristine systems, as well as in those with insufficient data, a much better understanding is needed of the linkages between nutrient inputs, productivity and eutrophic symptoms.

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Conclusions

The National Estuarine Eutrophication Assessment provides a picture of nutrient-enrichment related water quality conditions in the nation's estuaries. These conclusions are based on data and information about water quality conditions, the influence of natural and human-related factors, estuarine use impairments, and management recommendations compiled for 138 estuaries (>90% of U.S. estuarine surface area) and also for the Mississippi River Plume. The results, which were reviewed and synthesized by experts at a National Assessment Workshop, provide a comprehensive assessment of the location, magnitude, and consequences of eutrophication in the nation's estuaries.

Eutrophic Conditions in Estuaries

The overall expression of eutrophic conditions was high in 44 (one-third) of the 138 estuaries studied, and moderate in an additional 40 estuaries. Thus, 84 estuaries—60% of those studied—exhibited moderate to high eutrophic conditions. Although the greatest number of estuaries with pronounced problems were found in the Gulf of Mexico and Middle Atlantic regions, estuaries showing high levels of eutrophic conditions were found along all of the nation's coasts. Furthermore, it is important to note that the estuaries assessed as having a high expression of eutrophic conditions were those that have been the best studied. In the many estuaries that are understudied or for which very little is known, eutrophication may be more serious than the limited data reveal.

Key Findings

- *High expressions of eutrophic conditions are exhibited in 44 estuaries, representing 40% of the total estuarine surface area studied.*
- *High conditions occur in estuaries along all coasts, but are most prevalent along the Gulf of Mexico and Middle Atlantic coasts.*

Symptoms and Related Use Impairments

About 40 percent (58) of the nation's estuaries show high levels of chlorophyll *a*, epiphytes, or macroalgae, signs of the initial stages of eutrophication. In terms of their impacts on estuaries, the most important symptoms indicative of eutrophication are low dissolved oxygen, the loss of submerged aquatic vegetation, and blooms of nuisance and toxic algae. More than half (82) of U.S. estuaries, representing 67% of the estuarine surface area studied, had moderate to high expressions of at least one of these symptoms. This finding is of concern because these symptoms can have serious consequences, including negative impacts on commercial fisheries, the loss of recreational opportunities, and potential risks to human health.

The experts identified more than half of the studied estuaries as having use impairments related to eutrophic conditions. The implications are serious and affect not only the natural resources but also the economy and human health. The resource uses most frequently reported as being impaired were commercial fishing and shellfish harvesting. Recreational fishing, swimming, and boating, all of which contribute to tourism in coastal areas, were also reported as impaired to some degree. The reported risks to human health include the consumption of tainted shellfish, as well as direct skin contact or the inhalation/ingestion of water during an active bloom of toxic algae.

Key Findings

- *82 estuaries, representing 67% of the surface area studied, exhibit moderate to high expressions of either depleted dissolved oxygen, loss of submerged aquatic vegetation, or nuisance/toxic algal blooms.*
- *69 estuaries were identified by workshop participants as having human use impairments related to eutrophication.*
- *Compared to other impaired uses, commercial/recreational fishing and shellfisheries were identified as impaired for human use in the greatest number of estuaries (43 and 46, respectively).*

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Influencing Factors on Eutrophication

Most estuaries that showed high levels of eutrophic conditions were moderately to highly influenced by human-related nutrient inputs (e.g., wastewater treatment, agriculture, urban runoff, atmospheric deposition). Of the 44 estuaries with high expressions of eutrophic conditions, 36 were assessed as being highly influenced by human activities despite relatively moderate nutrient inputs. Most of these estuaries were in the Gulf of Mexico, the Middle Atlantic, and the Pacific regions. Most of the 44 estuaries (86 %) also had moderate to high susceptibility to retaining nutrient inputs; that is, their unique physical characteristics made them vulnerable to developing the symptoms of eutrophication. It follows that susceptibility is an important factor in the expression of high eutrophic conditions, especially when nutrient inputs are not extremely high. Furthermore, of the 38 estuaries with a *low* expression of eutrophic conditions, 10 had high susceptibility, suggesting that they are at risk of future degradation, if human-related nutrient inputs increase.

Key Findings

- *A high level of human influence is associated with 36 of the 44 estuaries (82%) with a high expression of eutrophic conditions.*
- *Only six of the 44 estuaries (14%) with high-level eutrophic conditions have corresponding high-level nitrogen inputs.*
- *Of the 44 estuaries with high-level eutrophic conditions, more than half (25) exhibit a high susceptibility to retaining nutrients.*

Implications for Management

The assessment of eutrophic conditions and influencing factors provides a basis for identifying priority estuaries needing remedial and preventive management action. The level of human influence is a factor in determining to what degree management actions can reduce or reverse eutrophic problems; if the major influence is natural, then it is likely that little can be done, except to plan appropriately. If the major influence is human-related, then impacts may be reduced with appropriate management actions. Therefore, in the 36 estuaries with high expressions of eutrophic conditions and high human influence, conditions can be moderated or reversed with appropriate management action. The success of these efforts depends in part on susceptibility; low susceptibility enhances the effectiveness of nutrient reductions by flushing or diluting nutrients at the same time that inputs are reduced, while highly susceptible estuaries may require greater effort due to their natural tendency to retain nutrients.

Of the non-impacted estuaries, those with moderate to high susceptibility are in need of preventive action because they are most at risk of developing problems if nutrient inputs increase. In contrast, the estuaries that have low overall expressions of eutrophic conditions, low human influence and low susceptibility may not benefit as much from management action. In general, these estuaries are less susceptible to developing problems to begin with. Some estuaries, such as many of those in Maine, exhibit naturally high levels of eutrophic symptoms, mostly due to toxic algal blooms. In these estuaries, however, reductions in nutrient inputs are not likely to greatly affect conditions. While these estuaries should not be ignored, nutrient control is not urgent at the present time.

Key Findings

- *The 23 estuaries with high expressions of eutrophic conditions and high susceptibility will likely require greater management effort and longer response time for results than those estuaries with low susceptibility. These estuaries represent approximately 10% of national estuarine surface area in the study.*
- *There are 10 estuaries, representing 3% of the national estuarine surface area studied, that have low eutrophic conditions and high susceptibility. Of the non-impacted estuaries, these are the most at risk of developing problems.*

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Future Outlook and Management Concerns

Experts at the National Assessment Workshop estimated that the severity and extent of eutrophic conditions would worsen in 86 (nearly two-thirds) of the studied estuaries and in the Mississippi River Plume during the next 20 years, during which time the coastal population is expected to increase by more than 10 percent. The estuaries most at risk are those that presently do not show symptoms but are highly susceptible to retaining nutrients and are located in watersheds in which significant population growth is projected. Most of these estuaries are located in the South Atlantic and Gulf of Mexico regions. Only eight (6%) of 138 estuaries are expected to improve unless more is done to resolve this pervasive environmental problem.

There is reason for optimism that eutrophication effects can be moderated or reversed. The predictions of future outlook may not have taken into account the effectiveness of management efforts presently being pursued but not yet completely effective, and those presently planned but not yet implemented. There have been measurable improvements in estuaries (e.g., Tampa Bay, Sarasota Bay, and parts of Chesapeake Bay) for which there are comprehensive watershed nutrient reduction strategies in place, and from which lessons can be learned. The improvements are mainly a result of point source treatment. However, there is a continued need to further reduce nutrient inputs in order to counteract the effects of expected population growth and other factors that promote the development of eutrophic problems. If further management actions are implemented and better coordinated now, it is possible that the future outlook will be more positive.

Nutrient inputs from agriculture, wastewater treatment, urban runoff, and atmospheric deposition were identified as the most important management targets. Agricultural nutrient sources were mentioned as especially important for management consideration in the Pacific, Gulf of Mexico, and South Atlantic regions. Wastewater treatment plants were identified most often in the North Atlantic. In the Middle Atlantic, agriculture and atmospheric deposition were equally recommended as sources requiring management. The participants also emphasized the importance of managing nutrient inputs from a watershed perspective. Management plans must also take into account human and natural factors, including sources of nutrients as well as watershed alterations that affect the delivery of nutrients (e.g., the loss of wetlands) to maximize the benefit from nutrient reductions.

Key Findings

- *Eutrophic conditions could worsen in 86 estuaries by the year 2020 if projected development patterns are realized.*
- *Of the 86 estuaries projected to worsen, 43 exhibit only low to moderate eutrophic conditions.*
- *Of particular concern, especially if human-related nutrient inputs increase, are the 10 estuaries with low eutrophic conditions and high susceptibility.*
- *All of the typical point and nonpoint pollution sources were identified at the National Assessment Workshop as important to target in order to manage nutrient problems. There are, however, some regional differences in important nutrient sources (e.g., combined sewer overflows in the North Atlantic).*

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Data Gaps and Research Needs

Among the most important data gaps highlighted by this assessment is the lack of information about the levels of eutrophic symptoms and trends. Of 138 estuaries, 39 (nearly 30%) were rated as "low confidence" for the assessment of eutrophic conditions. The factors leading to low confidence include one or more unknown symptoms, poor spatial or temporal resolution of data, and the inclusion of information based on expert judgment and observation rather than data. An additional 17 estuaries (12%) have insufficient data to make any assessment at all. In general, better characterization is needed for existing levels and trends of symptoms and of nutrient inputs, including estimators of inputs such as land use and population. This information is necessary to assess overall eutrophic conditions, to establish baseline conditions, and to track the condition of an estuary. It would be especially useful in evaluating the success of management actions. This information is also needed to determine causal relationships so that appropriate management strategies can be implemented. Among the primary sources of human-related nutrient inputs, more data are particularly needed for atmospheric and groundwater contributions, which are not well known due to the difficulties in obtaining accurate measurements. Additionally, better estimates of population growth are needed for future projections of water quality.

Research is also needed to improve scientists' understanding of the mechanisms involved in, and influences on, the eutrophication process, such as the triggering of toxic algal blooms. Better characterization of basic circulation patterns would increase understanding of how nutrients are processed once they reach an estuary, and thus, the potential outcome in terms of eutrophication. Factors that affect nutrient delivery, such as weather patterns, land use, and dramatic changes in seasonal population density due to tourism, should also be studied. Other research should be directed toward understanding the linkages between the expression of eutrophic symptoms and the resulting impacts to biological resources and risks to human health.

Key Findings

- *Despite all of the monitoring and research done to date, information and knowledge still is inadequate in 48 estuaries (low confidence or inadequate data for assessment). These estuaries represent approximately 25% of the estuarine surface area studied.*
- *All participants in the National Assessment process agreed that research is needed to clarify the linkages between eutrophication and impacts on estuarine resources, including fisheries, recreation and tourism, and risks to human health.*
- *The National Assessment process confirms that much remains to be done to adequately characterize nutrient pressure on estuaries. Better quantification is needed of total nutrient inputs, inputs by source, and estimators of nutrient pressure (e.g., population and land use). Atmospheric and groundwater inputs are least well quantified.*
- *Better characterization of physical factors is needed, including basic circulation patterns, effects of weather patterns, climate change, changing land use, and resultant effects on nutrient delivery, circulation, and eutrophic conditions.*
- *Other research needs include defining the relationship between nutrient inputs and toxic blooms, better characterization of assimilative capacity, and characterization of the effects of seasonal population changes.*

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Toward a National Strategy

At present, there is not a comprehensive national strategy to address the potentially worsening problems of estuarine eutrophication. However, the results from this Assessment can help provide an improved basis for setting national priorities for management, monitoring, and research. In combination with successes in individual estuaries, such as those recently reported for Tampa and Sarasota Bays, these results can provide the information necessary to help guide the development of a comprehensive national strategy to reduce problems where they are presently observed and protect the nation's coastal waters from further degradation.

Why is a National Strategy Needed?

This National Assessment confirms that estuarine eutrophication is indeed a problem of national significance. It indicates that human-related nutrient sources, both nearby and far removed, are substantial contributors to eutrophic conditions within estuaries. Furthermore, many estuarine watersheds cross the boundaries of states, requiring regional, subregional and interagency cooperation. Similarly, there are many important needs with regard to research, monitoring, and assessment that also call for a cogent national strategy. In many instances, for example, eutrophication research has been conducted on a parochial and piecemeal basis, which can impede the rapid advance of scientific understanding of the linkages between eutrophication and marine resources.

A national strategy is needed, especially one that effectively integrates watershed-specific approaches to assessment and management into a comprehensive approach.

How Can These Results Be Used?

National Assessment results can be used to help better focus national attention on existing and emerging priority areas for action; i.e., management, monitoring, and research. The framework shown (Figure 30) can be used to organize assessment results for this purpose. In particular, estuaries that are in serious condition should be priorities for management actions; those in less serious condition, but at risk of deterioration, should be closely monitored, and efforts should be made to identify preventive measures. In addition, estuaries for which there is insufficient information should be targeted for basic monitoring and assessment activities.

The framework incorporates the overall eutrophic condition of an estuary, its natural susceptibility to retain nutrients, and the level of nutrient inputs, to help set priorities for appropriate actions that will allow the most effective results given environmental concerns and resource limitations. This process can be considered environmental triage—necessary due to limited resources—which allows the sorting of estuaries into groups based on their need for, or

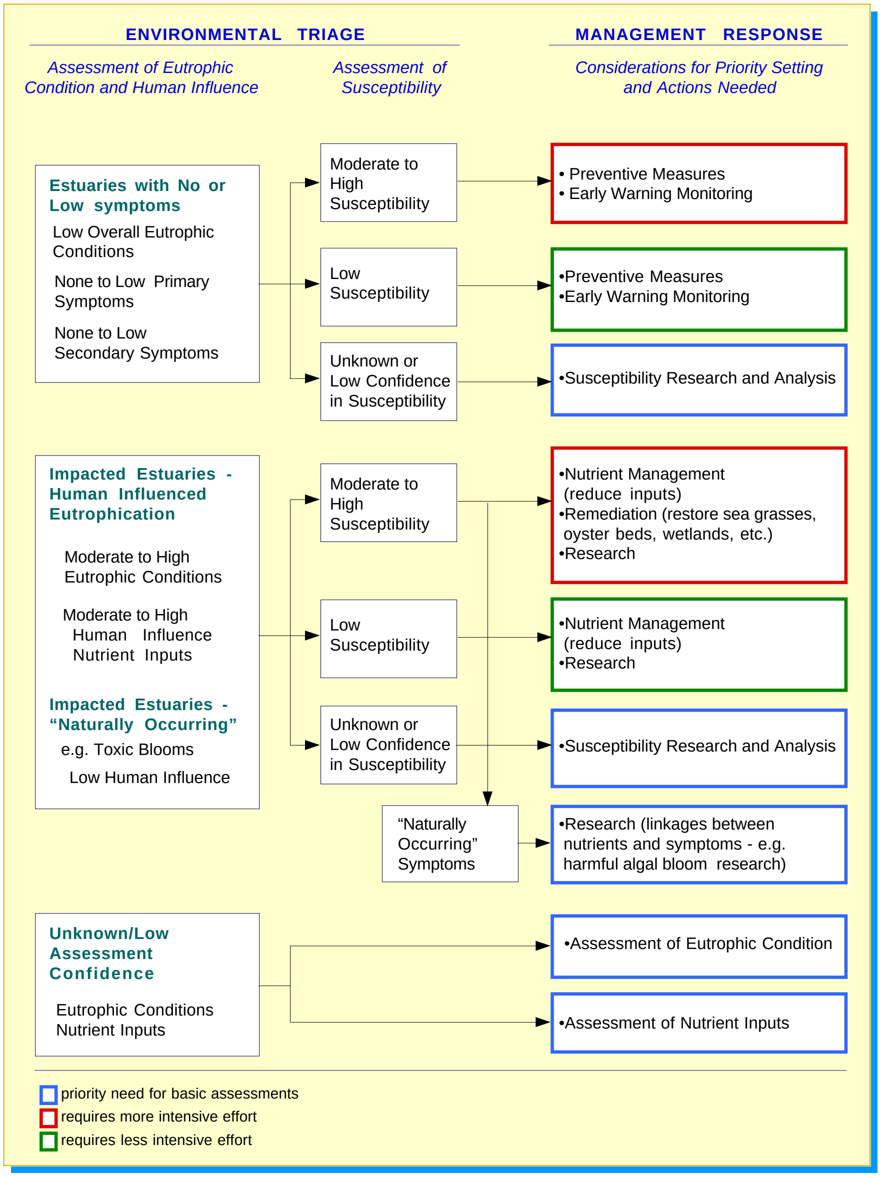

Figure 30. *A framework for developing a national strategy*

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likely benefit from, treatment. By such sorting, a framework is created that allows for logical and effective decisions on how to allocate limited management, monitoring, and research resources among a large number of estuaries. Note that this is not the only way that the National Assessment results might be used; this framework is offered as guidance for how the information might be used in planning a national strategy.

Management

The national assessment indicates that eutrophic symptoms are driven, in large measure, by human-related nutrient sources. However, the response of a system to reductions in nutrient input is dependent upon its natural susceptibility in combination with the level of nutrient input it receives. Thus, in the management of nutrient sources, no one nutrient control strategy is likely to achieve the desired results in all estuaries across the nation.

The proposed assessment framework provides a basis for distinguishing between the remediation of systems that are already impacted, and preventive measures in systems that are at risk due to potential increases in nutrient loading. Both are necessary for improving and protecting the health of the nation's estuaries, and the assessment results should be used to guide appropriate management and remediation plans. For instance, different plans should be implemented for those estuaries that, although in serious condition, might be improved with additional management effort; those in less serious condition but at risk of worsening that should be closely monitored and managed; and those for which a basic assessment is needed because there is presently insufficient information to evaluate conditions. The selection of priority estuaries for management action within these groups should be based on the level of eutrophic conditions, the influence of human activities, and the natural sensitivity to nutrients, to assure the most effective results within the constraints of limited resources. The national assessment provides a heretofore unavailable capability to target the nation's investments to control eutrophication.

Monitoring and Research

Some of the most useful information that has been developed while conducting this assessment is a comprehensive understanding of what is actually known about the phenomenon called "eutrophication," how well it is known, and whether it is understood well or not at all. When taken together, the assessment data base and framework provide a "working model" for designing and evaluating the efficiency and effectiveness of alternative national strategies for monitoring and research.

For example, there is a need to strike the right balance between monitoring designed primarily to describe spatial patterns or extent (e.g., EPA's Environmental Monitoring and Assessment Program) and fixed, continuous monitoring that emphasizes temporal resolution (both short- and long-term) and the tracking of nutrients and eutrophic symptoms. The data base and framework can also be used to determine how monitoring programs can be integrated across scales (local, regional, national) and across media (water, air, land).

The assessment results also reconfirm the need for monitoring programs that are capable of documenting ephemeral or real-time changes in symptoms, such as day-to-night fluctuations in dissolved oxygen, as well as over long time frames. Observational systems, such as the Global Ocean Observing System that is presently being developed, need to be promoted and sustained.

Within the framework of research, the detail that the assessment provides on the perspective of estuaries as mixing zones between rivers and oceans is invaluable for determining where to direct many research efforts. For example, the results of this national assessment should provide useful input to the National Research Council's ongoing study of the causes and management of coastal eutrophication, which will help to further identify key science needs.

Nutrient enrichment and associated eutrophic conditions have been identified as a critical problem in the nation's estuaries for over three decades.

As the 20th century comes to a close, a cogent and comprehensive national strategy still remains elusive.

EXHIBIT 21 (AR L.30)

Data Sources

Data sources referenced during the National Assessment Workshop

Eutrophication	Eutrophic Conditions and Trends	NOAA. 1998. NOAA's estuarine eutrophication survey, vol. 5: Pacific Coast region. Silver Spring, MD: Office of Ocean Resources Conservation and Assessment. 75 pp. NOAA. 1997. NOAA's estuarine eutrophication survey, vol. 4: Gulf of Mexico region. Silver Spring, MD: Office of Ocean Resources Conservation and Assessment. 77 pp. NOAA. 1997. NOAA's estuarine eutrophication survey, volume 3: North Atlantic region. Silver Spring, MD: Office of Ocean Resources Conservation and Assessment. 46 pp. NOAA. 1997. NOAA's estuarine eutrophication survey, vol. 2: Mid-Atlantic region. Silver Spring, MD: Office of Ocean Resources Conservation and Assessment. 51 pp. NOAA. 1996. NOAA's estuarine eutrophication survey, vol. 1: South Atlantic region. Silver Spring, MD: Office of Ocean Resources Conservation and Assessment. 50 pp.
Physical and Hydrologic Characteristics	Estuary Boundaries and Water Surface Areas	NOAA, 1985. National Estuarine Inventory, Volume 1: Physical and Hydrologic Characteristics. National Ocean Service, Silver Spring, MD. ***Note:*** This information is now included as part of NOAA's Coastal Assessment and Data Synthesis System (CA&DS) and can be accessed at http://cads.nos.noaa.gov.
	Watershed Boundaries (EDAs & FDAs) and Land Surface Areas	
	Estuarine Salinity Zones	
	Estuary Average Depth	
	Estuary Volume	
	Vertical Stratification	
	Tide Range	NOAA. 1993. Tide Tables 1993, High and Low Water Predictions. National Ocean Service, Silver Spring, MD
	Freshwater Inflow	USGS, not dated. Water Resources Data. Gaged Streamflow Data. Water Resources Division, Reston, VA.
	Susceptibility: Estuarine Export Potential (EXP)	NOAA. 1998. Coastal Assessment and Data Synthesis System. National Ocean Service, Silver Spring, MD.
	Dilution Potential	
	Flushing Potential	
Nutrient Indicators	Nitrogen Loads (kg/yr) and Yields (kg/sq. mi/yr)	Smith, et al., 1997. Spatially Referenced Regressions on Watershed Attributes (SPARROW). In: Regional Interpretation of Water Quality Monitoring Data. Water Resources Research, Vol 33, No. 12, pp. 2781-98
	Nitrogen Trends from Livestock (1978-92)	USDA, 1987 and 1992. Census of Agriculture. CD-ROMs for 1987 and 1992. Soil Conservation Service, April, 1992, the Agricultural Waste Management Field Handbook, Chapter 4.
	Cropland Area Trends (sq.miles) (1978-92)	USDA, 1987 and 1992. Census of Agriculture. CD-ROMs for 1987 and 1992.
	Nitrogen Trends from Fertilizer Use (1970-91)	USGS, 1990. County Level Estimates of Nitrogen and Phosporus Fertilizer Use in the US 1945-85. In: Alexander and Smith, 1990. USGS Open File Report 90-130. US EPA, 1990 and J. Fletcher 1992 (written comm., U West VA). County Level Estimates of Nitrogen Fertilizer Sales in the Conterminous US 1986-91. In: Alexander and Smith, 1990. USGS Open File Report 90-130.
	Land Use (sq. miles)	USGS, various dates. Land Use and Land Cover (LUDA).
	Population (1970 and 1990)	US Bureau of the Census, undated. 1970 and 1990 population estimates. Population Estimates Program, Population Division. Washington, DC.
	Population (2010)	NPA Data Services, Inc, 1988. Key Indicators of County Growth 1970-2010. Washington, DC.

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Appendix A: Methods

This appendix describes the methodology used in the National Eutrophication Survey and the National Estuarine Eutrophication Assessment. The survey process was used to establish a database of current (ca. 1995) eutrophication conditions and trends (ca. 1970-1995) for all coastal regions of the coterminous United States. The National Assessment is an aggregation and interpretation of the Eutrophication Survey data plus additional assessments of human influence, future outlook, impaired uses, potential management concerns, and data gaps and research needs.

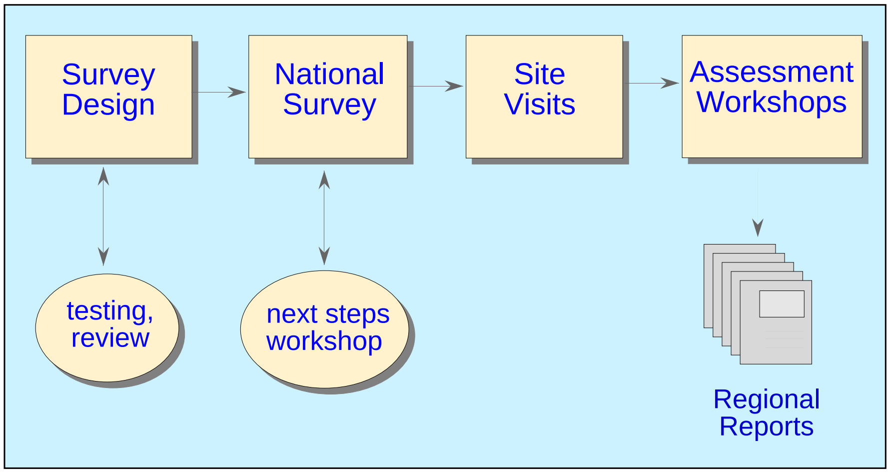
National Survey: Data Collection and Synthesis

NOAA conducted three workshops in 1991-92 with local and regional estuarine scientists and coastal resource managers. Two workshops held in January 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 NOAA's proposed data collection survey. A third workshop, held in April 1992, 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, NOAA 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. Based on the workshops and additional meetings with experts, NOAA identified information requirements for a set of parameters which could be used to characterize estuarine nutrient enrichment and eutrophication conditions. To be included in the survey, a parameter had to be (1) essential for accurate characterization of nutrient enrichment related phenomena; (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).

The next step was to establish response ranges for each parameter to ensure discrete gradients among responses. For example, the survey asked whether total dissolved nitrogen in the water column is high, medium, or low based upon specific thresholds (High ≥ 1 mg/l, Medium $\geq 0.1 < 1$ mg/l, low > 0 <0.1 mg/l, or unknown). The ranges were determined from reviewing nationwide data and from discussions with eutrophication experts. The thresholds used to classify ranges are designed to distinguish conditions among estuaries on a national basis.

Data Collection Framework. For each parameter, information was collected for existing conditions and recent trends (circa 1970-1995). Existing conditions describe maximum parameter values observed over a typical annual cycle (e.g., normal freshwater inflow, average temperatures, etc.). For instance, for nutrients, information was collected characterizing peak concentrations observed during the annual cycle such as those associated with spring runoff and/or turnover. For chlorophyll *a*, information was collected on peak concentrations that are typically reached during a bloom period. Additional information describing the timing and duration of existing conditions was collected.



Eutrophication Survey Process

EXHIBIT 21 (AR L.30)

Eutrophication Survey Parameters

	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

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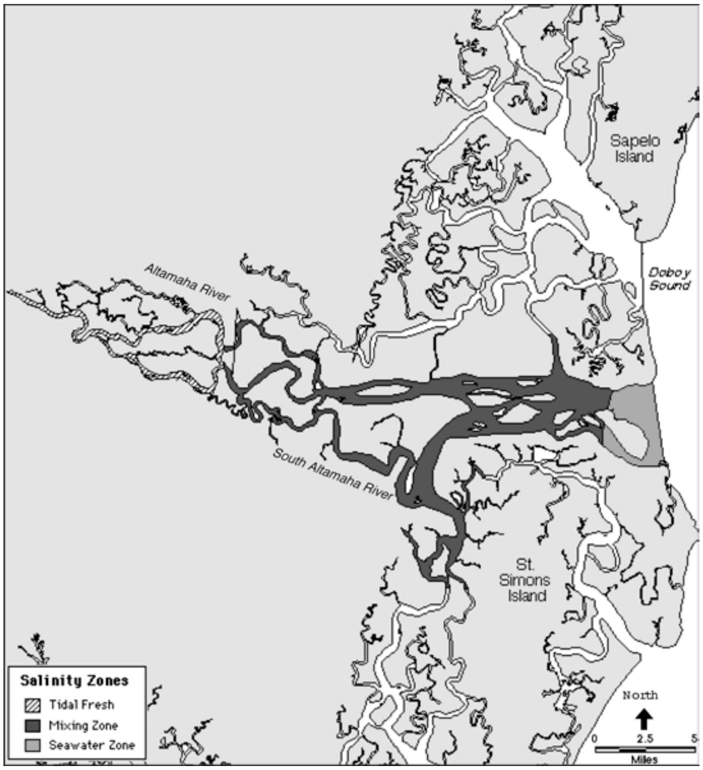
NOAA's National Estuarine Inventory (NEI) was used as a spatial framework to collect and organize information. Each parameter was characterized for three salinity zones as defined in the NEI (tidal fresh 0-0.5 ppt, mixing 0.5-25 ppt, and seawater >25 ppt), providing a consistent basis for comparisons among the estuarine systems.

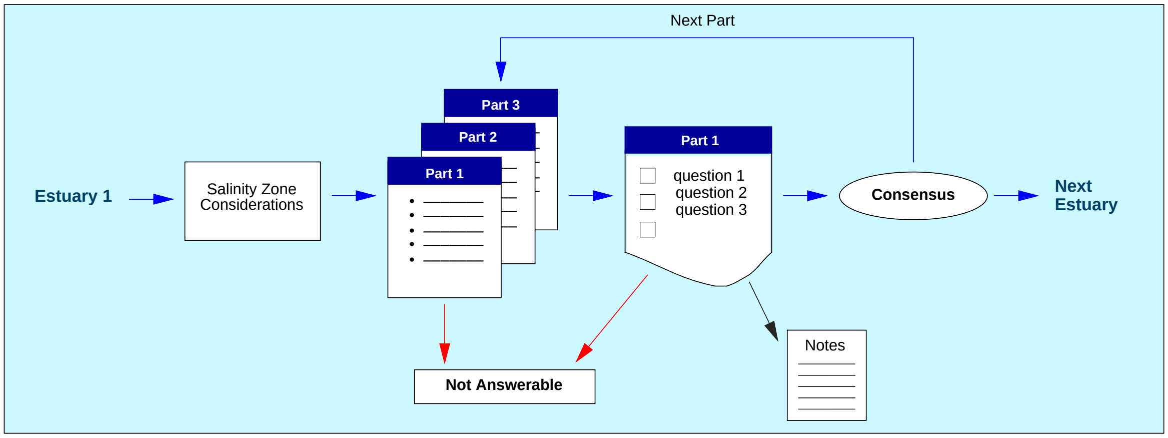


Spatial Framework Example

Data Collection. Survey forms designed to collect information on 16 parameters related to nutrient enrichment and eutrophication were mailed in 1993 to over 400 experts who had agreed to participate in the survey. The response rate was approximately 25 percent with at least one response for 112 of the 129 estuaries being surveyed. The survey methods and initial results were evaluated in May 1994 by a panel of NOAA, state, and academic experts. The panel recommended that NOAA proceed with a regional approach for completing data collection, including site visits with selected experts to fill data gaps, regional assessment workshops to finalize and reach consensus on the responses to each question, and regional reports on the results. Estuaries were targeted for site visits based upon the completeness of the data received from the original mailed survey forms. The new information collected from site visits was incorporated into the project data base and summary materials were then prepared for regional workshops.

Workshop participants included local and regional experts (at least one per estuary representing the group of people with the most extensive knowledge and insight about an estuary). In general, these persons had either filled out a survey form and/or participated in a site visit. Preparations included sending all regional data to participants prior to workshops. Participants were also encouraged to bring to the workshops relevant data and reports. During the workshops, NOAA staff facilitated a careful discussion and review of the survey data and salinity maps for each estuary and recorded the results accordingly.

Participants were also asked to rank the reliability as either highly certain or speculative inference, reflecting the robustness of the data the response is based on. This is especially important given that responses are based upon a range of information sources from statistically tested monitoring data to general observations. Following the workshops, results were summarized for review by workshop participants. The information was then compiled into regional reports that were also reviewed by participants prior to publication.



Regional Workshop Assessment Review Process

EXHIBIT 21 (AR L.30)

Analysis of Data Completeness and Reliability (DCR)

The estuarine eutrophication survey is a compilation of information for 16 water quality parameters that are related to nutrient enrichment. These parameters, in various combinations and at specific levels, are reflections of eutrophic conditions. For each of these parameters, information on characteristics of timing, duration, spatial coverage, and frequency of occurrence was also collected as appropriate. The robustness of this data set is affected by two factors - missing data and data that are judged to be based on speculative inference. Data gaps were created when respondents could not supply information —either information was not available or was of insufficient quality or quantity to give a reasonable answer. Responses were deemed speculative when, in the respondents judgment, they were based on either very limited data or general observations. The extent of data gaps and speculative responses is important because formulations developed to assess the rating of eutrophication status on a national basis use combinations of the parameters and parameter characteristics. The power of these formulations to accurately discriminate among systems is reduced if they contain significant gaps or a high degree of speculative inferences.

Data completeness and reliability was defined as the percent of the total area of the estuary for which there was a known value that was considered highly certain for each parameter. DCR was calculated as follows:

1. A DCR calculation was made for each estuary by using the following combinations of parameter characteristics:

Chlorophyll *a*	Concentration * Spatial Coverage * Frequency * Reliability
Epiphytes	Concentration * Frequency * Reliability
Macroalgae	Concentration * Frequency * Reliability
Dissolved Oxygen**	Concentration * Spatial Coverage * Frequency * Reliability
SAV	Direction of change * Magnitude *Reliability
Nuisance algae	Concentration * Frequency * Duration * Reliability
Toxic algae	Concentration * Frequency * Duration * Reliability

** (mean of Anoxia, Hypoxia, and Biological Stress

2. A rating based on the DCR score was assigned to each parameter and to the entire system as follows:

High = 75 - 100 %
Medium = 50 - 74%
Low = 0 - 49%

The entire estuarine system DCR value was then computed as the mean of the parameter DCRs.

The following is an example of the DCR calculation of chlorophyll *a* for an estuary.

Salinity Zone		Surf. Area (sq. mi.)	Concentration	Reliability	Spatial Coverage	Reliability	Frequency	Reliability	Sum of DCR Area
Tidal Fresh	Survey response	3	Low	Highly certain	Not eval.	Not eval.	Not eval.	Not eval.	--
	DCR value	3	1	1	1	1	1	1	3
Mixing	Survey response	28.8	Medium	Highly certain	High	Spec-ulative	Periodic	Highly certain	--
	DCR value	28.8	1	1	1	0	1	1	0
Seawater	Survey response	18.1	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	--
	DCR value	18.1	0	0	0	0	0	0	0
System Total		**49.9**	**--**	**--**	**--**	**--**	**--**	**--**	**3**

Note that the **speculative** reliability rating for the spatial coverage call in the mixing zone and the **unknown** call for chlorophyll *a* concentration in the seawater zone result in the areas of these zones being zeroed out in the calculation. Note also that spatial coverage and frequency are not evaluated when concentrations are low. Thus, the DCR value for this parameter for this estuary would be:

(3 (tidal fresh) + 0 (mixing) + 0 (seawater))/System Total = 3/49.9 = 0 .061

Thus the DCR in the example above would be rated Low (6.1%).

The DCR scores were used by participants at the National Assessment Workshop to help assign confidence ratings to the overall eutrophic conditions assessment of estuaries (see Appendix B).

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The National Assessment

In all, the eutrophication survey produced a data array containing over 40,000 data values (120-1,200/estuary). While providing the best possible resolution of the problem, the array also represented a challenge to interpret the data. NOAA worked with a “core group” of 15 scientists and managers who participated in the original data survey to develop and apply methods that best integrate the survey data for each estuary. It seemed reasonable that eutrophication symptoms and their time/space characteristics could be combined in a way that provided a single categorical value to represent the status of eutrophic conditions for each estuary. The assessment also included human influence, impaired uses of estuaries, nutrient management targets, future outlook, and data gaps and research needs.

The Eutrophication Model. The core group participated in two work sessions to develop and test several analytical and numerical methods. Ultimately, a single model was developed that made maximum use of the survey data and best described the sequence and severity of eutrophication conditions. The model used six symptoms that were most directly related to nutrient inputs. Three primary symptoms, algal abundance (using chlorophyll *a* as an indicator), epiphyte abundance, and macroalgae represent the first possible stage of water quality degradation associated with eutrophication. Although nitrogen and phosphorus concentrations in the water column are directly related to nutrient inputs, elevated concentrations do not necessarily indicate that eutrophication symptoms are present. Likewise, low water column concentrations do not necessarily translate to no problems present. Thus, these were not included as primary symptoms in the model.

In many estuaries, the primary symptoms lead to secondary symptoms, such as submerged aquatic vegetation loss, nuisance and toxic algal blooms, and low dissolved oxygen (anoxia and hypoxia). In some cases, secondary conditions can exist in the estuary without originating from the primary symptoms. This occurs, for instance, in many North Atlantic estuaries where toxic algal blooms are transported into these systems from the coastal ocean.

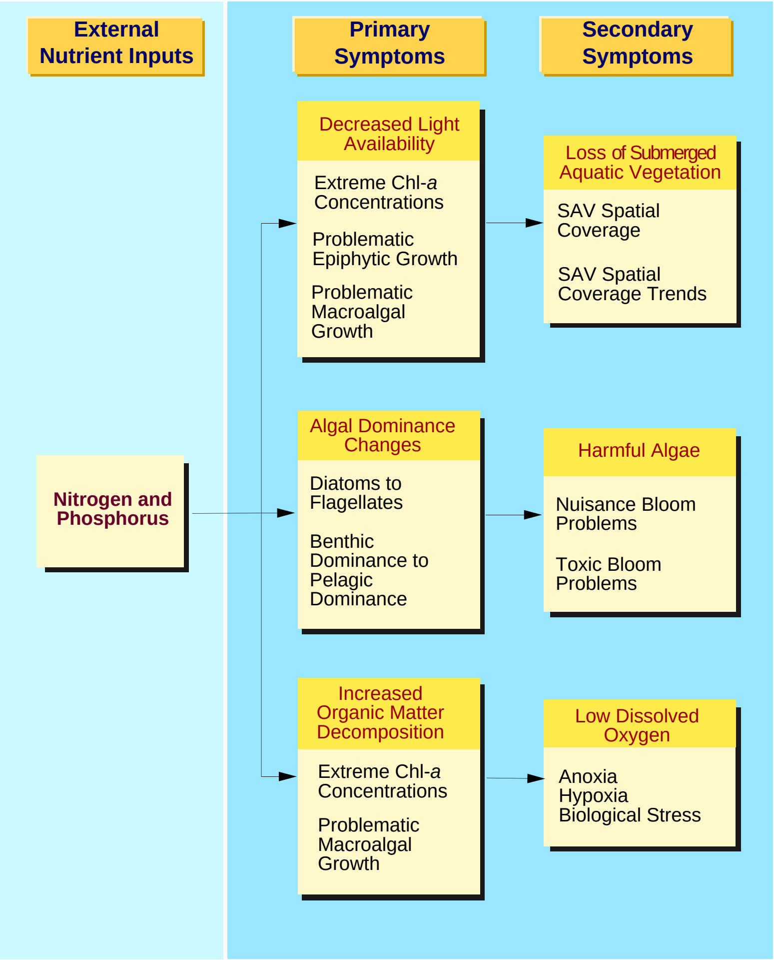
Determining the Overall Eutrophic Condition

A numerical scoring system was developed to integrate information from all six primary and secondary symptoms to determine the overall status of eutrophication symptoms in each estuary. This scoring system was implemented in three phases.

First, a single index value was computed from all primary symptoms. An average of the three symptoms was then made to provide an overall score for the primary symptoms.

Next, a single index value was computed from all secondary symptoms. The highest secondary score of the three symptoms was assigned to the estuary rather than taking an average. This was done because an estuary exhibiting high impacts from only one of the conditions may be just as impacted as an estuary with all three symptoms.

Finally, the range of numeric scores assigned to primary and secondary symptoms were divided into categories of high, moderate, and low. Primary and secondary scores were then compared in a matrix so that overall categories could be assigned to the estuaries. A detailed description of these three phases follows.



Eutrophication model used for National Assessment

EXHIBIT 21 (AR L.30)

Phase 1: Primary Symptoms Method Description. This method assesses the level of expression of chlorophyll *a* concentrations, epiphyte abundance problems, and macroalgal abundance problems. The method uses only the survey information pertinent to each particular symptom to determine the level of expression. For chlorophyll *a*, concentration, spatial coverage and frequency of occurrence are used; for epiphytes and macroalgae, the frequency of occurrence of problem conditions was used.

Classification Criteria. The following is a set of decision rules which were applied to the eutrophication survey data to determine the level of expression of the primary symptoms.

Chlorophyll *a* Level of Expression Determination

Spatial coverage and frequency of occurrence are used to determine the level of expression for each salinity zone and are then aggregated up to the estuary level (See Estuary Aggregation Rules).

IF	***AND***	***AND***	***THEN***	
Concentration	Spatial Coverage	Frequency	Expression	Value
Hypereutrophic *or* High	High	Periodic	High	1
	Moderate	Periodic	High	1
	Low	Periodic	Moderate	0.5
	Very Low	Periodic	Moderate	0.5
	High	Episodic	High	1
	Moderate	Episodic	Moderate	0.5
	Low/Very Low	Episodic	Low	0.25
	Any Spatial Coverage	Unknown	Flag A	0.5
	Unknown	Any Frequency	Flag A	0.5
Concentration	Spatial Coverage	Frequency	Expression	
Medium	High	Periodic	High	1
	Moderate	Periodic	Moderate	0.5
	Low/Very Low	Periodic	Low	0.25
	High	Episodic	Moderate	0.5
	Mod/Low/Very Low	Episodic	Low	0.25
	Any Spatial Coverage	Unknown	Flag A	0.5
	Unknown	Any Frequency	Flag A	0.5
Concentration	Spatial Coverage	Frequency	Expression	
Low	Any Spatial Coverage	Any Frequency	Low	0.25
Concentration	Spatial Coverage	Frequency		
Unknown	Unknown	Unknown	Not included in calculation at zone level	

EXHIBIT 21 (AR L.30)

Phase 1: Primary Symptoms Method, continued.

Epiphyte Problem Level of Expression Determination

The frequency of problematic epiphytic growth is used to determine level of expression at the salinity zone level and is then aggregated up to the estuary level (See Estuary Aggregation Rules).

IF	*AND*	*THEN*	
Epiphyte Problems	Frequency	Expression	Value
Observed	Periodic	High	1
	Episodic	Moderate	0.5
	Unknown	Flag B	0.5
Unknown	Unknown	Not included in calculation at zone level	

Macroalgae Problem Level of Expression Determination

The frequency of problematic macroalgal growth is used to determine level of expression at the salinity zone level and is then aggregated up to the estuary level (See Estuary Aggregation Rules).

IF	*AND*	*THEN*	
Macroalgae Problems	Frequency	Expression	Value
Observed	Periodic	High	1
	Episodic	Moderate	0.5
	Unknown	Flag C	0.5
Unknown	Unknown	Not included in calculation at zone level	

Flags A through C are used to identify components for which not enough data was available. In these cases, assumptions were made based on conservative estimates that unknown spatial coverage is at least 10 percent of a zone, and that unknown frequency is at least episodic.

Estuary Aggregation Rules

1. For each symptom (chlorophyll *a*, epiphytes, and macroalgae), an area weighted expression value for each zone is determined. First the surface area of the salinity zone is multiplied by the symptom expression value for the zone and then divided by the surface area of the entire estuary to obtain an area weighted value for the zone. The area weighted values are then summed to obtain the estuary level of expression value for the symptom.

$$\sum_{i=1}^{n} \left(\frac{A_z}{A_t}\right)\left(\begin{array}{c}\text{Expression}\\ \text{Value}\end{array}\right) = \text{symptom level of expression value for estuary}$$

Symbols:

A_z= surface area of a single zone

A_t= total surface area of estuary

n= total number of zones in estuary

2. The level of expression of the primary symptoms for the estuary is determined by calculating the ***average*** of the three estuary level of expression values (chlorophyll *a*, epiphytes, and macroalgae).

3. The estuary is then assigned a category for Primary Symptoms as follows:

Estuary Expression Value	Level of Expression Category Assigned
≥ 0 to ≤ 0.3	Low
>0.3 to ≤ 0.6	Moderate
>0.6 to ≤ 1	High

EXHIBIT 21 (AR L.30)

Phase 2: Secondary Symptoms Method Description. This method uses the same approach as used for the primary symptoms in order to assess the level of expression of depleted dissolved oxygen (anoxia, hypoxia, biological stress), submerged aquatic vegetation decline, and nuisance/toxic blooms. The method uses the information pertinent to each particular symptom to determine the level of expression. For depleted dissolved oxygen, spatial coverage and frequency of occurrence were used; for submerged aquatic vegetation decline, the magnitude of change of the decline in spatial extent was used; for nuisance/toxic blooms, the duration of bloom events and frequency of occurrence was used.

Classification Criteria. The following is a set of decision rules which were applied to the eutrophication survey data to determine the level of expression for low dissolved oxygen conditions, submerged aquatic vegetation declines, and nuisance/toxic blooms.

Low Dissolved Oxygen Level of Expression Determination

Spatial coverage and frequency of occurrence are used to determine level of expression at the zone level and are then aggregated up to the estuary level (See Estuary Aggregation Rules).

IF	*AND*	*AND*	*THEN*	
Anoxia	Spatial Coverage	Frequency	Expression	Value
Observed	High	Periodic	High	1
	Moderate	Periodic	High	1
	Low	Periodic	Moderate	0.5
	Very Low	Periodic	Low	0.25
	High	Episodic	Moderate	0.5
	Moderate/Low/Very Low	Episodic	Low	0.25
	Unknown	Any frequency	Flag A	0.25
Hypoxia	Spatial Coverage	Frequency	Expression	Value
Observed	High	Periodic	High	1
	Mod	Periodic	Moderate	0.5
	Low/Very Low	Periodic	Low	0.25
	High	Episodic	Moderate	0.5
	Moderate/Low/Very Low	Episodic	Low	0.25
	Unknown	Any frequency	Flag B	0.25
Biological Stress	Spatial Coverage	Frequency	Expression	Value
Observed	High	Periodic	Moderate	0.5
	Moderate/Low /Very Low	Periodic	Low	0.25
	Any Spatial Coverage	Episodic	Low	0.25
	Unknown	Any frequency	Flag C	0.25

EXHIBIT 21 (AR L.30)

Phase 2: Secondary Symptoms Method Description, continued.

Submerged Aquatic Vegetation (SAV) Loss Level of Expression Determination

The magnitude of loss of the decline is used to determine the level of expression at the zone level and is then aggregated up to the estuary level (See Estuary Aggregation Rules).

IF	***AND***	***THEN***	
SAV Loss	Magnitude of Loss	Expression	Value
Observed	High	High	1
	Moderate	Moderate	0.5
	Low	Low	0.25
	Unknown	Flag D	0.25

Nuisance and Toxic Blooms Level of Expression Determination

The duration of bloom events and frequency of occurrence is used to determine impact severity at the salinity zone level, and are then aggregated up to the estuary level (See Estuary Aggregation Rules).

IF	***AND***	***AND***	***THEN***	
Nuisance Blooms	Duration	Frequency	Expression	Value
Problem	M, WM, WS, S, PR	Periodic	High	1
	DW, V, W	Periodic	Moderate	0.5
	D	Periodic	Low	0.25
	M, WM, WS, S, PR	Episodic	Moderate	0.5
	DW, V, W	Episodic	Low	0.25
	D	Episodic	Low	0.25
	Unknown	Any Frequency	Flag E	0.25
Toxic Blooms	Duration	Frequency	Expression	Value
Problem	M, WM, WS, S, PR	Periodic	High	1
	DW, W, V	Periodic	Moderate	0.5
	D	Periodic	Low	0.25
	M, WM, WS, S, PR	Episodic	Moderate	0.5
	DW, W, V	Episodic	Low	0.25
	D	Episodic	Low	0.25
	Unknown	Any frequency	Flag F	0.25

S = seasonal, M = months, V = variable, W = weeks, D = days, WS = weeks to seasonal, WM = weeks to months, DW = days to weeks

Flags A through F are used to identify impacts for which not enough data was available for the components. In these cases, assumptions were made based on conservative estimates that unknown spatial coverage is at least 10 percent of the zone, unknown duration is at least days, and unknown frequency is at least episodic.

EXHIBIT 21 (AR L.30)

Phase 2: Secondary Symptoms Method Description, Continued.

Interpretation and Review. At the National Assessment Workshop, experts reviewed each primary and secondary symptom assessment for all 138 estuaries in the survey. In some cases changes were made to these assessments based on the experts knowledge of the estuary. For instance, borderline estuaries with values around 0.3 and 0.6 were sometimes moved up or down a category level based on the experts knowledge of recent conditions not reflected by the original survey data.

Estuary Aggregation Rules

1. For each symptom (anoxia, hypoxia, biological stress, submerged aquatic vegetation loss, nuisance blooms, toxic blooms), an area weighted expression value for each zone is determined. First the surface area of the salinity zone is multiplied by the symptom expression value for the zone and then divided by the surface area of the entire estuary to obtain an area weighted value for the zone. The area weighted values are then summed to obtain the estuary level of expression value for the symptom.

$$\sum_{i=1}^{n} \left(\frac{A_z}{A_t}\right)\left(\begin{array}{c}\text{Expression}\\\text{Value}\end{array}\right) = \begin{array}{l}\text{symptom level}\\\text{of expression}\\\text{value for estuary}\end{array}$$

Symbols:

A_z= surface area of a single zone

A_t= total surface area of estuary

n= total number of zones in estuary

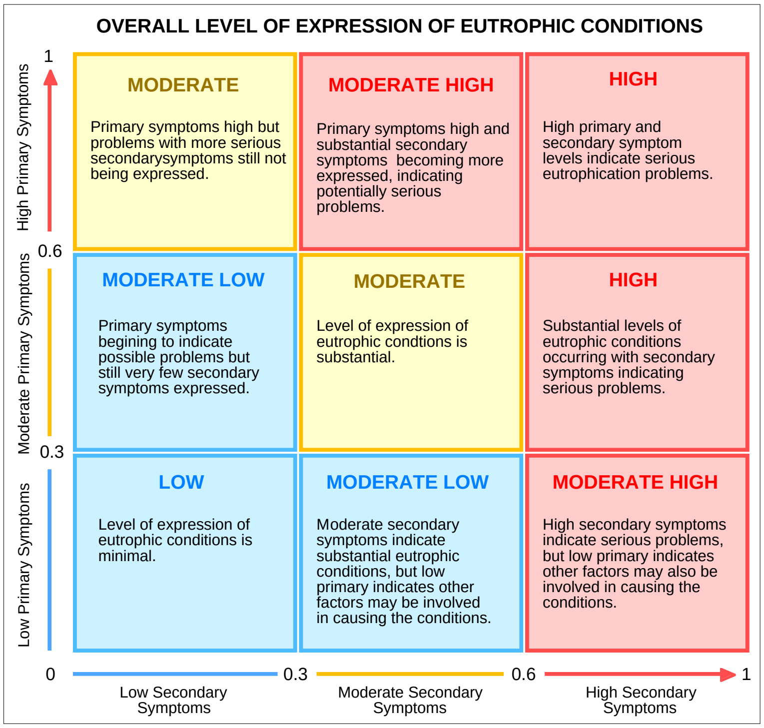
2. The level of expression of the secondary symptoms for the estuary is determined by choosing the highest of the three estuary level symptom expression values (depleted dissolved oxygen, submerged aquatic vegetation loss, and nuisance/toxic blooms). For dissolved oxygen the highest value is chosen from the anoxia, hypoxia, or biological stress values. For blooms the highest value is chosen from the nuisance or toxic bloom values.

3. The estuary is then assigned a category for Secondary Symptoms as follows:

Expression Value	Level of Expression Category Assigned
≥ 0 to ≤ 0.3	Low
>0.3 to ≤ 0.6	Moderate
>0.6 to ≤ 1	High

Phase 3: Determination of the Overall Level of Expression of Eutrophic Conditions. The primary and secondary symptoms were next compared in a matrix to determine an overall ranking of eutrophic conditions for the estuary. The overall assessments were reviewed by experts at the National Assessment Workshop. In some cases changes were made to these assessments based on the experts knowledge of the estuary. For instance, if an estuary was near the borderline of moderate and moderately high, expert judgement may have been used to move the category up or down based on comparison with the condition of other similar estuaries in the area.

In this report low and moderate low are grouped together as low; moderate high and high are grouped together as high.



OVERALL LEVEL OF EXPRESSION OF EUTROPHIC CONDITIONS

	Low Secondary Symptoms	Moderate Secondary Symptoms	High Secondary Symptoms
High Primary Symptoms	MODERATE Primary symptoms high but problems with more serious secondarysymptoms still not being expressed.	MODERATE HIGH Primary symptoms high and substantial secondary symptoms becoming more expressed, indicating potentially serious problems.	HIGH High primary and secondary symptom levels indicate serious eutrophication problems.
Moderate Primary Symptoms	MODERATE LOW Primary symptoms begining to indicate possible problems but still very few secondary symptoms expressed.	MODERATE Level of expression of eutrophic condtions is substantial.	HIGH Substantial levels of eutrophic conditions occurring with secondary symptoms indicating serious problems.
Low Primary Symptoms	LOW Level of expression of eutrophic conditions is minimal.	MODERATE LOW Moderate secondary symptoms indicate substantial eutrophic conditions, but low primary indicates other factors may be involved in causing the conditions.	MODERATE HIGH High secondary symptoms indicate serious problems, but low primary indicates other factors may also be involved in causing the conditions.

EXHIBIT 21 (AR L.30)

Determining Overall Human Influence

This analysis was performed as an attempt to determine the extent to which human activities have contributed to the observed eutrophic symptoms and conditions. The underlying assumption is that any particular level of nutrient input will have varying effects in different estuaries due to varying levels of susceptibility to the nutrient inputs. Therefore, separate analyses of both susceptibility and nutrient inputs were made and then the results of each were combined to determine the overall level of human influence.

Susceptibility: Determining the Estuarine Export Potential (EXP)

Estuarine susceptibility to nutrients is dependent in large part on the amount of time that nutrients entering a system stay in the system before exiting the system. The estuarine export potential is a method, developed as part of NOAA's Coastal Assessment and Data Synthesis system, to estimate relative determinations of this amount of time by defining the relative capacity of estuaries to dilute and flush dissolved nutrient loads. The analysis uses physical and hydrologic data to define separately 1) a dilution rating and 2) a flushing rating. In both cases, the higher the rating, the greater the capacity to dilute or flush nutrient loads (conversely, lower ratings suggest a greater tendency to retain nutrient loads).

1. Decision Rules for DILUTION Potential. This analysis assumes that a larger portion of the water column is potentially available to dilute nutrient loads in a vertically homogenous estuary than in a vertically stratified system. The assumption is that for stratified systems, nutrients are most often retained in the upper portion (freshwater fraction) of the water column. In contrast, downward transport (more complete mixing) is likely in vertically homogenous systems. Type B estuaries are generally vertically homogenous, although stratification is observed (confined) in narrow navigation channels or the extreme upper reaches of an estuary. In this case, nutrients are assumed to be diluted throughout the entire water column.

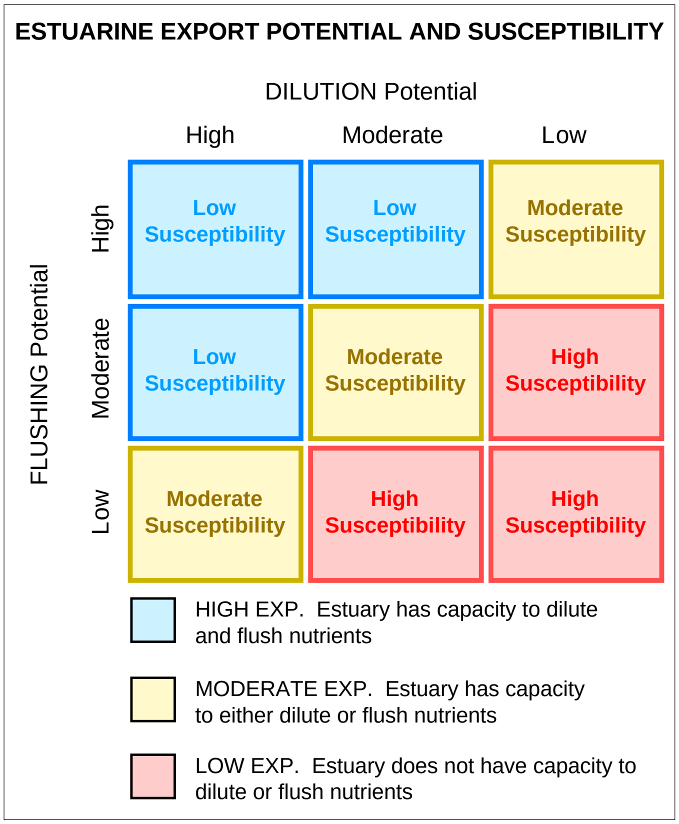
Type	IF: Vertical Stratification	THEN: Dilution Volume	IF: Dilution Value	**Dilution Potential**	Number of Estuaries
A	Vertically Homogenous •all year •throughout estuary	$1 / VOL_{estuary}$	10^{-13} 10^{-12}	**HIGH**	30
B	Minor Vertical Stratification •navigation channels •upper estuary	$1 / VOL_{estuary}$	10^{-11}	**MODERATE**	63
C	Vertically Stratified •most of year •most of estuary	$1 / VOL_{fwf}$ (fwf = freshwater fraction)	10^{-10} 10^{-09}	**LOW**	45

2. Decision Rules for FLUSHING Potential. This analysis assumes that a greater capacity to flush nutrient loads exists for estuaries that have large tide and freshwater influences.

Type	Tide Range (ft)		Freshwater Inflow / Estuary Volume	**Flushing Potential**	Number of Estuaries
1	macro (>6)	and	large or moderate (10^{00} to 10^{-02})	**HIGH**	12
2	macro (>6)	and	small (10^{-03}, 10^{-04})	**MODERATE**	21
3	meso (>2.5)	and	large (10^{00}, 10^{-01})	**HIGH**	15
4	meso (>2.5)	and	moderate (10^{-02})	**MODERATE**	16
5	meso (>2.5)	and	small (10^{-03}, 10^{-04})	**LOW**	26
6	micro (<2.5)	and	large (10^{00}, 10^{-01})	**HIGH**	4
7	micro (<2.5)	and	moderate (10^{-02})	**MODERATE**	13
8	micro (<2.5)	and	small (10^{-03}, 10^{-04})	**LOW**	31

EXHIBIT 21 (AR L.30)

Combining Dilution Potential and Flushing Potential. By combining dilution and flushing components, an EXP is determined. Estuaries in the upper left portion of the matrix generally have a high EXP that suggests an ability to dilute and flush nutrient loads. Estuaries in the lower right portion suggest estuaries that lack the ability to dilute or flush nutrients, making them more susceptible to nutrient pollution.



ESTUARINE EXPORT POTENTIAL AND SUSCEPTIBILITY

FLUSHING Potential	DILUTION Potential: High	Moderate	Low
High	Low Susceptibility	Low Susceptibility	Moderate Susceptibility
Moderate	Low Susceptibility	Moderate Susceptibility	High Susceptibility
Low	Moderate Susceptibility	High Susceptibility	High Susceptibility

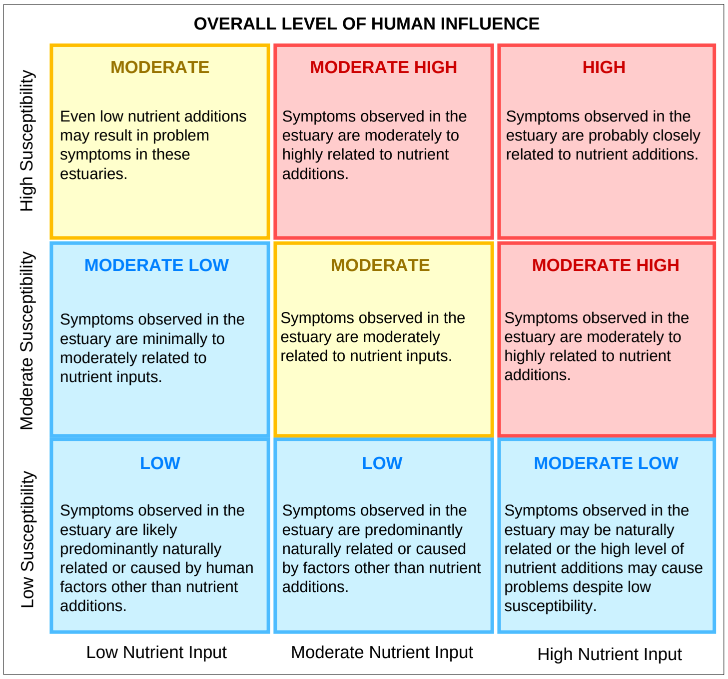
🟦 HIGH EXP. Estuary has capacity to dilute and flush nutrients

🟨 MODERATE EXP. Estuary has capacity to either dilute or flush nutrients

🟥 LOW EXP. Estuary does not have capacity to dilute or flush nutrients

Nutrient Inputs. In order to develop an understanding of the amount of nutrient inputs being delivered to the estuarine systems from human activities, nationally comparable data sets had to be developed. Estimates of nitrogen and phosphorus loads from point, nonpoint, and atmospheric sources were developed for each estuarine watershed. The USGS' SPARROW (spatially referenced regressions of contaminant transport on watershed attributes) model was used as the primary indicator of nitrogen pressure. In addition, a host of other data sets were used as surrogate nutrient pressure indicators to help substantiate load estimates. These included EPA's county level estimates of fertilizer sales, USGS' county level estimates of fertilizer use, USGS' Land Use/Land Cover, U.S. Census Bureau Population Census, and U.S. Department of Agriculture Census of Agriculture (see Data Sources Table).

A brief description of the SPARROW model is provided here, as this was the principal data set used to evaluate the extent of nitrogen pressure with respect to the observed eutrophic symptoms. Estimates of total nitrogen loads are provided for five major nutrient source types: point sources, fertilizer, livestock, atmospheric deposition, and nonpoint/nonagricultural. Data are available for all USGS 8-digit hydrologic catalog units and are based on measurements from a national network of stream gaging stations (NASQAN) that operated during 1970-1988. For the purposes of the national workshop, NOAA aggregated data for the 8-digit units to the watershed scale, though this may have overestimated actual loads to some estuaries. The modeled estimates provide a snapshot of conditions during the early-1980s and do not offer time series data.



OVERALL LEVEL OF HUMAN INFLUENCE

	Low Nutrient Input	Moderate Nutrient Input	High Nutrient Input
High Susceptibility	MODERATE Even low nutrient additions may result in problem symptoms in these estuaries.	MODERATE HIGH Symptoms observed in the estuary are moderately to highly related to nutrient additions.	HIGH Symptoms observed in the estuary are probably closely related to nutrient additions.
Moderate Susceptibility	MODERATE LOW Symptoms observed in the estuary are minimally to moderately related to nutrient inputs.	MODERATE Symptoms observed in the estuary are moderately related to nutrient inputs.	MODERATE HIGH Symptoms observed in the estuary are moderately to highly related to nutrient additions.
Low Susceptibility	LOW Symptoms observed in the estuary are likely predominantly naturally related or caused by human factors other than nutrient additions.	LOW Symptoms observed in the estuary are predominantly naturally related or caused by factors other than nutrient additions.	MODERATE LOW Symptoms observed in the estuary may be naturally related or the high level of nutrient additions may cause problems despite low susceptibility.

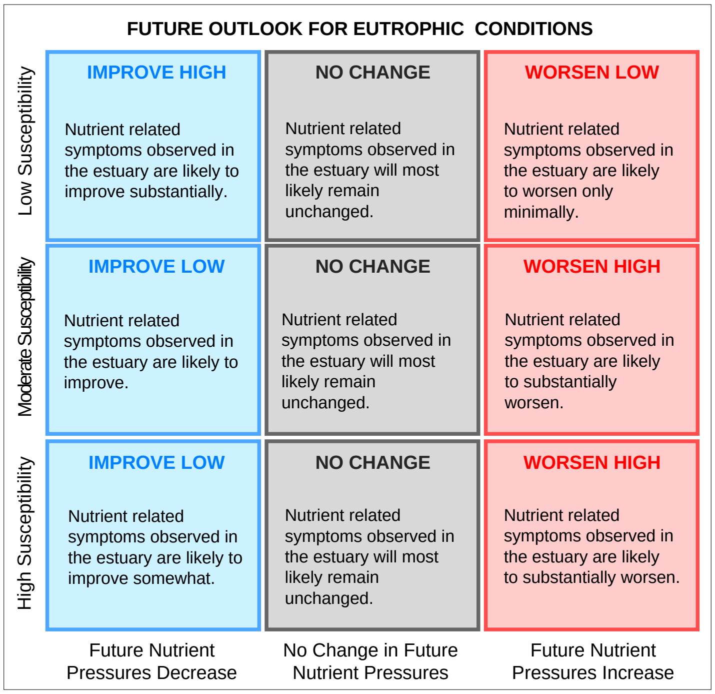
Determination of the Overall Level of Human Influence. The susceptibility to retain nutrients and the level of nitrogen inputs were compared in a matrix to determine an overall ranking of the overall level of expression of human influence on eutrophic conditions in the estuary.

Experts at the National Assessment Workshop reviewed and, when appropriate, modified the susceptibility or nutrient pressure assessments. Modifications were made based on higher quality data available for some estuaries and expert knowledge and judgement.

EXHIBIT 21 (AR L.30)

Determining Future Outlook

This analysis was performed as an attempt to determine the likelihood of whether conditions in an estuary will worsen, improve, or stay the same over the next twenty years. In the analysis, nutrient input changes are predicted to determine which direction conditions will move. The estuarine susceptibility to nutrients is then used to determine the magnitude. Population projections are used as a primary indicator of the level of future nutrient input changes. However, population projections are subject to unpredictable changes. Therefore, experts at the National Assessment Workshop were asked to make modifications to the determinations of future nutrient changes, based on their knowledge of planned or likely changes that will take place in the estuarine basins that will affect the level of nutrients entering the system.



FUTURE OUTLOOK FOR EUTROPHIC CONDITIONS

	Future Nutrient Pressures Decrease	No Change in Future Nutrient Pressures	Future Nutrient Pressures Increase
Low Susceptibility	IMPROVE HIGH Nutrient related symptoms observed in the estuary are likely to improve substantially.	NO CHANGE Nutrient related symptoms observed in the estuary will most likely remain unchanged.	WORSEN LOW Nutrient related symptoms observed in the estuary are likely to worsen only minimally.
Moderate Susceptibility	IMPROVE LOW Nutrient related symptoms observed in the estuary are likely to improve.	NO CHANGE Nutrient related symptoms observed in the estuary will most likely remain unchanged.	WORSEN HIGH Nutrient related symptoms observed in the estuary are likely to substantially worsen.
High Susceptibility	IMPROVE LOW Nutrient related symptoms observed in the estuary are likely to improve somewhat.	NO CHANGE Nutrient related symptoms observed in the estuary will most likely remain unchanged.	WORSEN HIGH Nutrient related symptoms observed in the estuary are likely to substantially worsen.

Identifying Impaired Uses and Potential Management Concerns

Experts at the National Assessment Workshop identified impaired uses which they judged to be related to the expression of eutrophic conditions in the water body. These impaired uses included recreational and commercial fishing, fish consumption, shellfish, swimming, boating, aesthetics, tourism, SAV and habitat loss, and loss of assimilative capacity. Although this information is not supported by a comprehensive data set, it does provide a rough picture of the extent of problems stemming from eutrophic conditions. The experts also identified the point and nonpoint sources which they judged as most important to target for managing nutrients. These sources included wastewater treatment, combined sewer overflow, on-site waste disposal such as septic systems, industrial discharge, large animal operations, urban runoff, agriculture, forestry practices, rangeland use, atmospheric inputs, and aquaculture. Also evaluated were potential effectiveness of nutrient reductions and watershed focus areas. Although these assessments were not based on a national data set, the expert evaluations are useful for gaining a first order understanding at the national level of what types and level of actions will be required to address eutrophication.

Identifying Data Gaps and Research Needs

Experts at the National Assessment Workshop identified data gaps and research needs for improving the assessment of the severity, human influence, impacts, and appropriate response to eutrophication in estuaries. The experts used their experience and knowledge, in combination with data completeness and reliability analysis of the eutrophication survey results, to produce these findings.

EXHIBIT 21 (AR L.30)

Data sources referenced during the National Assessment Workshop.

Eutrophication	Eutrophic Conditions and Trends	NOAA. 1998. NOAA's estuarine eutrophication survey, vol. 5: Pacific Coast region. Silver Spring, MD: Office of Ocean Resources Conservation and Assessment. 75 pp. NOAA. 1997. NOAA's estuarine eutrophication survey, vol. 4: Gulf of Mexico region. Silver Spring, MD: Office of Ocean Resources Conservation and Assessment. 77 pp. NOAA. 1997. NOAA's estuarine eutrophication survey, volume 3: North Atlantic region. Silver Spring, MD: Office of Ocean Resources Conservation and Assessment. 46 pp. NOAA. 1997. NOAA's estuarine eutrophication survey, vol. 2: Mid-Atlantic region. Silver Spring, MD: Office of Ocean Resources Conservation and Assessment. 51 pp. NOAA. 1996. NOAA's estuarine eutrophication survey, vol. 1: South Atlantic region. Silver Spring, MD: Office of Ocean Resources Conservation and Assessment. 50 pp.
Physical and Hydrologic Characteristics	Estuary Boundaries and Water Surface Areas Watershed Boundaries (EDAs & FDAs) and Land Surface Areas Estuarine Salinity Zones Estuary Average Depth Estuary Volume Vertical Stratification	NOAA, 1985. National Estuarine Inventory, Volume 1: Physical and Hydrologic Characteristics. National Ocean Service, Silver Spring, MD. ***Note:*** This information is now included as part of NOAA's Coastal Assessment and Data Synthesis System (CA&DS) and can be accessed at http://cads.nos.noaa.gov.
	Tide Range	NOAA. 1993. Tide Tables 1993, High and Low Water Predictions. National Ocean Service, Silver Spring, MD
	Freshwater Inflow	USGS, not dated. Water Resources Data. Gaged Streamflow Data. Water Resources Division, Reston, VA.
	Susceptibility: Estuarine Export Potential (EXP) Dilution Potential Flushing Potential	NOAA. 1998. Coastal Assessment and Data Synthesis System. National Ocean Service, Silver Spring, MD.
Nutrient Indicators	Nitrogen Loads (kg/yr) and Yields (kg/sq. mi/yr)	Smith, et al., 1997. Spatially Referenced Regressions on Watershed Attributes (SPARROW). In: Regional Interpretation of Water Quality Monitoring Data. Water Resources Research, Vol 33, No. 12, pp. 2781-98
	Nitrogen Trends from Livestock (1978-92)	USDA, 1987 and 1992. Census of Agriculture. CD-ROMs for 1987 and 1992. Soil Conservation Service, April, 1992, the Agricultural Waste Management Field Handbook, Chapter 4.
	Cropland Area Trends (sq.miles) (1978-92)	USDA, 1987 and 1992. Census of Agriculture. CD-ROMs for 1987 and 1992.
	Nitrogen Trends from Fertilizer Use (1970-91)	USGS, 1990. County Level Estimates of Nitrogen and Phosporus Fertilizer Use in the US 1945-85. In: Alexander and Smith, 1990. USGS Open File Report 90-130. US EPA, 1990 and J. Fletcher 1992 (written comm., U West VA). County Level Estimates of Nitrogen Fertilizer Sales in the Conterminous US 1986-91. In: Alexander and Smith, 1990. USGS Open File Report 90-130.
	Land Use (sq. miles)	USGS, various dates. Land Use and Land Cover (LUDA).
	Population (1970 and 1990)	US Bureau of the Census, undated. 1970 and 1990 population estimates. Population Estimates Program, Population Division. Washington, DC.
	Population (2010)	NPA Data Services, Inc, 1988. Key Indicators of County Growth 1970-2010. Washington, DC.

EXHIBIT 21 (AR L.30)

Appendix B: Table of Results

This appendix contains results of the National Estuarine Eutrophication Assessment, including some information that is not provided elsewhere in the report, i.e., overall primary and secondary assessments, nutrient reduction effectiveness, and the type of watershed focus. The data is also presented as determined at the Assessment Workshop, i.e., "moderate low" was not combined with "low," nor was "moderate high" combined with "high." Impaired uses are indicated by their assessment basis: highly certain, moderately certain, or reasonable inference.

			Primary				Secondary				Influencing				Future		Impaired Uses									Potential Management Concerns													
	Eutrophic Condition		Chlorophyll *a*	Epiphyte Abundance	Macroalgal Abundance	Overall Primary Level	Low Dissolved Oxygen	SAV Loss	Nuisance/Toxic Blooms	Overall Secondary Level	Overall Human Influence	Confidence	Susceptibility	Nitrogen Yield	Expected Change (2020)	Confidence	Rec./Comm. Fishing	Fish Consumption	Shellfish	Swimming	Boating	Aesthetics	Tourism	SAV/Habitat Loss	Assimilative Capacity	Would Nutrient Reductions Improve Conditions?	Watershed Focus	Wastewater Treatment	Combined Sewer Overflow	On-site (septics, etc.)	Industry	Animal Operations	Urban Runoff	Agriculture	Forestry Activities	Rangeland Use	Atmosphere	Aquaculture	Other
North Atlantic																																							
St. Croix River/Cobscook Bay	MH	MH	L	L	H	L	L	N	H	H	L	H	L	M	WH	M			HC							NO	WC							√					
Englishman Bay	MH	MH	M	N	H	H	N	U	M	M	L	MH	L	L	NC	MH			HC							NO	WC											√	
Narraguagus Bay	MH	MH	M	N	N	M	N	U	H	H	L	MH	L	L	NC	MH			HC							NO	WC											√	
Blue Hill Bay	ML	ML	M	N	N	M	N	N	L	L	L	H	L	L	WL	M			HC							NO	U												
Penobscot Bay	L	MH	L	N	N	L	N	U	N	L	ML	MH	L	M	NC	MH										NO	EDA	√	√										
Muscongus Bay	ML	L	M	N	N	M	L	U	L	L	L	L	L	M	NC	M			HC							NO	EDA	√											
Damariscotta River	M	H	M	N	N	M	N	N	M	M	M	H	M	M	WL	M					MC					NO	WC												√
Sheepscot Bay	MH	MH	M	N	M	M	L	U	H	H	ML	H	M	M	NC	MH			HC							NO	EDA												
Kennebec/Androscoggin Rivers	ML	H	M	N	N	M	L	N	N	L	L	H	L	M	NC	MH										NO	U	√											
Casco Bay	MH	H	M	L	M	L	L	M	H	H	ML	MH	L	L	IL	MH			HC							U	ENTR	√	√				√						
Saco Bay	M	MH	L	U	N	L	L	U	H	H	L	MH	L	L	NC	M			RI							NO	ENTR	√	√										
Great Bay	M	MH	M	L	M	M	L	N	L	M	ML	MH	M	L	WH	MH			MC							U	FDA	√	√										
Hampton Harbor Estuary	ML	L	M	N	N	M	L	N	N	L	L	ML	L	L	WL	M			MC							NO	U	√											
Merrimack River	U	U	U	U	U	L	U	M	U	M	L	ML	L	L	NC	ML										U	U												
Plum Island Sound	ML	MH	M	N	N	M	L	N	N	L	MH	M	M	H	WH	L										U	FDA	√											
Massachusetts Bay	M	MH	M	N	H	H	N	L	M	M	M	MH	L	H	WL	MH			HC							YES	EDA	√	√								√		
Boston Harbor	MH	H	M	H	M	H	M	L	N	L	MH	H	M	H	IL	MH										YES	EDA	√	√				√						
Cape Cod Bay	M	MH	M	N	L	M	L	L	L	M	ML	H	M	L	NC	H										NO	ENTR	√	√										
Middle Atlantic																																							
Buzzards Bay	ML	H	M	L	L	L	L	L	N	L	ML	H	M	L	NC	H										U	U												
Narragansett Bay	ML	H	M	N	L	L	L	L	M	M	MH	H	M	H	NC	H										U	U												
Gardiners Bay	MH	H	M	N	N	M	L	H	M	H	ML	M	M	L	NC	M	HC		HC	HC		HC	HC	HC		YES	ENTR			√				√			√		
Long Island Sound	MH	H	H	L	H	H	M	L	M	M	MH	H	H	M	NC	H	HC		HC					HC		YES	ENTR	√					√				√		
Connecticut River	ML	L	M	U	U	M	L	U	N	L	M	L	M	M	NC	L										U	U												
Great South Bay	MH	H	H	N	N	H	L	M	M	M	M	H	H	L	NC	H	HC		HC	HC		HC				YES	ENTR			√			√						
Hudson River/Raritan Bay	M	H	H	L	L	M	M	N	M	M	MH	H	M	H	NC	H				HC		HC		MC		YES	ENTR	√	√				√						
Barnegat Bay	H	H	H	N	H	H	L	U	H	H	MH	H	H	M	WL	H								MC		YES	ENTR						√						
New Jersey Inland Bays	ML	L	M	N	L	M	L	U	L	L	MH	L	H	M	WH	L										U	U												
Delaware Bay	ML	H	M	N	N	M	L	N	N	L	MH	H	M	H	NC	H										U	ENTR	√									√		
Delaware Inland Bays	H	H	M	U	H	H	L	N	H	H	MH	MH	H	L	NC	M			HC	MC	MC	HC		RI		YES	ENTR					√		√			√		
Maryland Inland Bays	M	M	H	M	N	M	L	N	M	M	M	H	H	L	WL	L				RI		RI	RI	RI		YES	EDA							√			√		
Chincoteague Bay	ML	L	M	U	U	M	L	N	N	L	M	L	H	L	WL	L										U	U												
Chesapeake Bay	H	H	H	H	N	H	H	H	N	H	H	H	H	M	WL	H	RI		HC			HC		RI		YES	ENTR	√						√			√		
Patuxent River	H	H	H	U	N	H	M	H	H	H	MH	H	H	M	WL	H	RI		HC			RI		MC		YES	ENTR	√					√	√					
Potomac River	H	H	H	U	L	M	H	M	M	H	MH	H	H	M	WL	H	RI		HC					MC		YES	ENTR	√						√			√		
Rappahannock River	M	H	H	N	N	M	M	N	N	M	H	H	H	M	WL	H	RI		HC					MC		YES	ENTR	√						√			√		
York River	MH	H	M	N	N	M	M	M	N	M	MH	H	H	L	WH	H	RI		HC			RI		MC		YES	ENTR			√				√			√		
James River	ML	H	H	N	N	M	L	N	N	L	MH	H	M	M	WL	H	RI							RI		YES	ENTR	√						√			√		
Chester River	M	H	M	U	N	M	L	L	N	L	MH	H	H	M	WL	H	RI							MC		YES	ENTR							√			√		
Choptank River	M	H	M	H	M	H	L	H	M	H	MH	H	H	M	WL	H	RI							MC		YES	ENTR							√			√		
Tangier/Pocomoke Sounds	MH	H	H	H	H	H	L	H	L	M	H	H	H	H	WH	H	HC			HC	HC			RI		U	ENTR							√					

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EXHIBIT 21 (AR L.30)

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	Eutrophic Condition	Confidence	Chlorophyll *a*	Epiphyte Abundance	Macroalgal Abundance	Overall Primary Level	Low Dissolved Oxygen	SAV Loss	Nuisance/Toxic Blooms	Overall Secondary Level	Overall Human Influence	Confidence	Susceptibility	Nitrogen Yield	Expected Change (2020)	Confidence	Rec./Comm. Fishing	Fish Consumption	Shellfish	Swimming	Boating	Aesthetics	Tourism	SAV/Habitat Loss	Assimilative Capacity	Would Nutrient Reductions Improve Conditions?	Watershed Focus	Wastewater Treatment	Combined Sewer Overflow	On-site (septics, etc.)	Industry	Animal Operations	Urban Runoff	Agriculture	Forestry Activities	Rangeland Use	Atmosphere	Aquaculture	Other
South Atlantic																																							
Albemarle Sound	U	U	L	N	N	L	L	L	L	L	M	L	M	M	WL	M										NO	EDA	√		√			√						
Pamlico Sound	U	U	M	N	N	M	L	L	M	H	M	L	M	M	NC	M	MC									YES	ENTR	√				√							
Pamlico/Pungo Rivers	MH	H	H	N	N	H	M	M	M	M	MH	H	H	M	NC	M	HC	MC	RI							YES	ENTR	√			√			√					
Neuse River	H	H	H	N	N	H	H	L	H	H	H	H	H	H	NC	M	HC	MC	MC	HC	MC		MC			YES	ENTR	√				√		√					
Bogue Sound	ML	M	M	U	N	M	N	U	L	L	L	L	H	L	IL	M										U	EDA	√		√			√						
New River	MH	M	H	N	N	H	L	U	H	H	MH	M	L	M	IL	M	MC	RI	RI				MC			YES	ENTR	√				√		√					
Cape Fear River	M	M	H	N	N	H	L	U	N	L	M	L	H	M	NC	M	MC							RI		U	ENTR					√	√	√					
Winyah Bay	ML	L	M	N	N	M	M	N	N	M	M	M	M	M	NC	M	RI									NO	EDA				√			√					
N. Santee/S. Santee Rivers	ML	L	U	N	N	L	M	U	N	M	ML	M	M	L	NC	M										NO	U												
Charleston Harbor	M	H	M	N	M	M	M	N	N	M	M	M	M	M	WH	M	HC								HC	YES	ENTR	√			√		√						
Stono/North Edisto Rivers	ML	M	U	N	N	L	M	N	N	M	M	M	H	L	NC	M										NO	EDA						√	√					
St. Helena Sound	U	U	L	U	U	L	M	U	U	M	L	M	L	L	IL	M										NO	EDA						√	√					
Broad River	ML	M	L	U	U	L	M	U	N	M	ML	M	M	L	WH	M										NO	ENTR	√					√						√
Savannah River	M	M	M	N	N	M	M	N	N	L	L	M	L	M	WL	M	HC								HC	NO	ENTR						√	√	√				
Ossabaw Sound	ML	L	M	N	N	M	L	U	N	L	L	ML	L	M	WL	M										NO	ENTR						√	√	√				
St. Catherines/Sapelo Sounds	ML	L	M	N	N	M	L	N	N	L	ML	L	M	L	WH	M										NO	EDA						√	√					
Altamaha River	ML	M	M	N	N	M	L	N	N	L	L	M	M	M	WL	M										NO	ENTR						√	√	√				
St. Andrew/St. Simons Sounds	ML	L	M	N	N	M	L	N	N	L	ML	L	M	L	WH	M										NO	EDA							√	√				
St. Marys R./Cumberland Snd.	M	L	M	N	N	M	M	N	N	L	ML	L	M	L	WH	M									RI	NO	EDA						√	√	√				√
St. Johns River	MH	L	H	M	N	H	M	L	L	M	M	L	H	L	WH	L										U	U												
Indian River	M	L	M	M	M	M	M	M	L	M	M	L	H	L	WH	L										U	U												
Biscayne Bay	L	L	L	N	N	L	L	N	N	L	U	U	H	U	WH	L										U	U												
Gulf of Mexico																																							
Florida Bay	H	MH	M	H	H	H	H	M	M	H	MH	L	M	U	IL	M	HC		HC	RI	RI	HC	HC			YES	ENTR	√		√				√					
South Ten Thousand Islands	MH	L	M	N	N	M	H	L	N	H	MH	L	H	U	WL	M										U	U												
North Ten Thousand Islands	M	M	M	N	N	M	M	U	N	M	M	L	H	U	WL	L										U	U												
Rookery Bay	ML	M	L	N	N	L	L	N	N	L	ML	L	H	U	NC	L										U	U												
Charlotte Harbor	MH	M	H	M	N	M	H	L	M	H	MH	M	H	L	WL	M										U	ENTR				√		√	√					
Caloosahatchee River	MH	M	H	N	N	H	L	L	N	L	MH	M	M	M	WL	M						RI	RI	MC		YES	FDA							√					
Sarasota Bay	MH	H	M	H	L	M	M	N	H	M	MH	H	M	H	WL	M								RI		YES	ENTR	√		√			√						
Tampa Bay	MH	H	H	N	N	H	L	N	M	M	MH	H	M	M	NC	M								MC	MC	YES	ENTR	√					√				√		
Suwannee River	M	M	M	N	M	L	L	N	L	L	ML	M	M	L	WL	M										NO	FDA					√		√	√				
Apalachee Bay	ML	L	M	N	N	M	L	N	M	M	ML	L	M	L	WL	L										U	U												
Apalachicola Bay	M	H	M	N	N	M	M	N	M	M	MH	H	M	M	WL	M										U	U												
St. Andrew Bay	M	M	M	L	L	L	M	U	L	M	M	L	M	L	WL	L										YES	EDA												
Choctawhatchee Bay	MH	M	M	H	L	M	M	M	H	H	MH	M	M	M	WL	L						RI	RI			YES	EDA												
Pensacola Bay	M	M	M	U	U	M	M	M	N	M	MH	M	M	M	WL	L			RI							YES	EDA				√		√						
Perdido Bay	MH	M	M	N	H	H	M	N	L	M	MH	M	H	M	WL	L		RI				MC				YES	EDA				√		√						
Mobile Bay	M	M	M	N	N	M	M	L	M	M	M	M	M	M	NC	M			HC							U	ENTR				√			√					
East Mississippi Sound	M	L	M	N	N	M	M	M	L	M	M	L	M	M	NC	L			MC							U	U												
West Mississippi Sound	ML	M	M	L	N	L	L	M	L	M	M	M	M	M	NC	L										U	U												

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Gulf of Mexico (continued)																																							
Lake Borgne	U	U	U	U	U	L	N	U	M	M	M	L	M	M	NC	L										U	U												
Lake Pontchartrain	H	M	M	H	H	H	L	H	M	H	H	M	M	M	WH	M										YES	U												
Breton/Chandeleur Sounds	ML	L	U	U	N	L	L	L	N	L	ML	L	M	L	IL	L										U	U												
Mississippi River	ML	M	M	N	N	M	L	N	N	L	M	H	L	M	NC	M										U	U												
Barataria Bay	M	M	H	N	N	H	M	N	L	M	M	M	M	M	NC	M										U	U												
Terrebonne/Timbalier Bays	M	M	H	N	N	H	L	U	L	L	M	M	H	L	WL	M										U	U												
Atchafalaya/Vermilion Bays	M	M	H	N	N	H	L	L	N	L	M	M	L	L	NC	M										U	U												
Mississippi River Plume	H	H	H	N	N	H	H	N	H	H	H	H	U	U	WH	M										U	U												
Mermentau Estuary	L	L	U	N	N	L	N	N	N	L	L	L	M	M	IL	L										U	U												
Calcasieu Lake	H	M	H	N	N	H	M	M	H	H	MH	M	M	M	WL	M										YES	U												
Sabine Lake	M	M	M	N	N	M	L	N	L	L	MH	M	M	M	NC	M	RI									YES	EDA	√			√		√	√			√		
Galveston Bay	MH	H	M	N	N	M	L	H	L	H	MH	M	M	M	WL	M	HC	HC	HC	HC			HC			YES	EDA	√			√		√	√			√		
Brazos River	M	M	M	N	N	L	M	N	L	M	M	M	M	L	NC	M	RI	MC		RI			RI			YES	EDA				√			√			√		
Matagorda Bay	M	M	M	N	N	M	L	N	L	L	MH	M	H	L	WL	M	MC		RI							YES	EDA	√			√	√		√		√	√	√	
San Antonio Bay	MH	M	M	H	H	H	L	L	L	L	MH	M	M	L	WL	M	RI		RI							YES	ENTR	√			√			√		√	√		
Aransas Bay	M	M	M	M	H	M	L	L	L	L	M	M	H	M	NC	L	RI		RI	RI			RI			YES	ENTR	√					√	√			√		
Corpus Christi Bay	H	M	H	H	H	H	L	N	H	H	MH	M	H	L	WH	H	MC		RI				RI			YES	EDA	√					√	√			√		
Upper Laguna Madre	H	H	H	N	N	H	M	M	H	H	H	M	H	M	WH	M	MC		MC				MC			YES	EDA					√		√		√	√		
Baffin Bay	H	L	H	N	N	H	L	N	H	H	H	L	H	M	WH	L	MC	MC	MC				MC			YES	ENTR	√				√	√	√		√	√		
Lower Laguna Madre	H	H	H	N	N	H	L	M	H	H	H	M	H	L	WH	H	MC	MC	MC				MC			YES	ENTR	√				√	√	√		√	√		
Pacific																																							
Tijuana Estuary	H	H	H	N	H	H	M	N	L	M	H	H	H	H	WH	H	RI		RI	HC		HC				YES	EDA						√						
San Diego Bay	M	L	U	N	H	H	L	U	L	L	MH	L	H	M	WH	L										U	U												
Mission Bay	ML	L	L	N	N	L	N	N	N	L	MH	L	H	M	WL	L										U	U												
Newport Bay	H	MH	H	N	H	H	H	M	L	M	H	H	H	H	WH	H	HC		HC	HC		HC				YES	EDA						√	√					
San Pedro Bay	L	L	L	N	N	L	N	N	L	L	H	L	H	H	WL											U	U												
Alamitos Bay	ML	L	U	N	N	L	M	N	L	M	U	U	H	U	U											U	U												
AnaheimBay	M	M	U	N	H	H	L	U	L	L	H	M	H	H	WL	M				MC		MC				YES	ENTR						√	√					
Santa Monica Bay	U	U	U	U	L	L	U	N	L	L	MH	L	M	H	NC											U	U												
Morro Bay	M	L	U	U	H	H	L	H	H	H	MH	L	H	M	NC											U	U												
Monterey Bay	ML	M	M	N	N	L	L	N	M	M	ML	ML	L	L	WL	M										U	ENTR	√						√					
Elkhorn Slough	MH	L	M	H	H	H	M	N	M	M	MH	L	H	M	NC											U	U	√					√						
San Francisco Bay	H	H	H	N	N	H	L	H	N	H	H	H	M	M	WL	M										NO	EDA	√					√						
Cent. SF./San Pablo/Suisun Bays	M	H	M	N	N	M	L	M	H	M	L	H	L	M	NC	MH										NO	ENTR	√					√	√					
Drakes Estero	U	U	U	U	U	L	U	U	N	L	MH	L	L	M	WH											U	U												
Tomales Bay	MH	L	U	N	N	L	N	N	H	H	MH	L	H	M	WH											U	U												
Eel River	L	L	L	N	N	L	N	N	N	L	M	L	M	M	WL											U	U												
Humboldt Bay	L	L	L	N	N	L	N	N	N	L	MH	L	H	M	NC											U	U												
Klamath River	L	L	L	N	N	L	N	N	N	L	ML	L	M	L	NC											U	U												
Rogue River	U	U	U	U	U	L	N	L	U	L	M	L	M	M	WL	L										U	U												
Coquille River	U	U	L	U	U	L	N	N	U	L	ML	L	M	L	WL	L										YES	EDA	√											

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Pacific (continued)																																							
Coos Bay	U	U	M	M	M	M	N	N	U	L	M	L	M	M	WL	L										YES	U												
Umpqua River	U	U	L	U	U	L	N	U	U	L	ML	L	M	L	WL	L										U	U												
Siuslaw River	U	U	M	U	U	L	L	N	U	L	M	L	M	M	WL	L										U	U												
Alsea River	U	U	M	U	U	L	N	N	U	L	M	L	M	M	WL	L										U	U												
Yaquina Bay	ML	H	M	N	N	M	L	N	N	L	ML	L	M	L	WL	L										U	U												
Siletz Bay	U	U	U	U	U	L	N	U	U	L	ML	L	M	L	WL	L										U	U												
Netarts Bay	U	U	M	U	U	M	N	N	U	L	M	L	H	M	WL	L										U	U												
Tillamook Bay	U	U	L	U	U	L	N	N	U	L	M	L	M	M	WL	L										U	U												
Nehalem River	U	U	L	U	U	L	N	N	U	L	M	L	M	M	WL	L										U	U												
Columbia River	ML	M	H	N	N	H	N	N	L	L	L	ML	L	L	NC	ML										NO	FDA							√					
Willapa Bay	M	M	M	N	H	H	N	M	M	M	ML	M	L	M	WL	M	RI		RI							YES	EDA			√				√	√				
Grays Harbor	M	M	M	N	H	H	N	U	M	M	ML	ML	L	M	WL	M	RI		RI							YES	EDA				√			√	√				
Puget Sound	M	M	H	N	H	H	L	L	M	M	ML	M	L	M	WL	M	MC		MC			MC				YES	EDA	√					√	√					
Hood Canal	MH	M	H	U	U	H	M	U	N	M	MH	M	H	L	WH	MH	MC		MC							YES	EDA			√				√	√				
Whidbey Basin/Skagit Bay	M	M	H	U	U	H	L	U	L	L	M	ML	M	M	WL	M	RI		RI							YES	EDA	√		√				√					
South Puget Sound	MH	M	H	U	N	H	L	U	M	M	MH	M	H	M	WH	MH	MC		MC	MC		MC				YES	EDA	√		√				√					
Port Orchard System	MH	M	H	U	H	H	L	L	M	M	M	ML	M	M	WL	M	RI		RI							YES	EDA	√		√				√					
Bellingham/Padilla/Samish Bays	M	M	H	U	M	H	N	N	M	M	M	ML	M	U	WL	M	RI		RI							YES	EDA	√						√					
Sequim/Discovery Bays	M	L	H	U	H	H	L	U	M	M	M	ML	M	U	WL	M	RI		HC							YES	EDA	√						√					

N - none observed; L - low; ML - moderate low; M - moderate; MH - moderate high; H - high; U - unknown; IH - improve high; IL - improve low; NC - no change; WL - worsen low; WH - worsen high
RI - reasonable inference; MC - moderately certain; HC - highly certain; WC - water column; ENTR - entire watershed; EDA - estuarine drainage area; FDA - fluvial drainage area

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Appendix C: Participants

The individuals listed here contributed to the creation of this report. A check mark for a survey form indicates that a participant filled out all or part of an initial data collection form for one or more estuaries. The regional assessment column indicates that the participant was involved in site visits or attendance at regional assessment workshops. Individuals noted for methods development and the National Assessment Workshop columns contributed to the development of data aggregation methods and/or analyzed and reviewed national-level assessments of the resulting data.

		Survey Form	Regional Assessment	Methods Development	National Assessment
North Atlantic					
Arnold Banner	U.S. Fish and Wildlife Service		√		
Seth Barker	Maine Dept. of Marine Resources		√		
Joceline Boucher	Maine Maritime Academy	√	√		
Laurice Churchill	Maine Dept. of Marine Resources	√			
Philip Colarusso	U.S. Environmenal Protection Agency		√		
Canthy Coniaris	University of New Hampshire				
Michael Connor	Massachusetts Water Resources Auth.	√			
Jerome Cura	Menzie-Cura & Associates Inc.	√	√		
Lee Doggett	Maine Dept. of Environmental Protection	√	√		
William Ellis	Maine Maritime Academy		√		
Bernie Gardner	University of Massachusetts	√	√		
Hap Garritt	Woods Hole Oceanographic Institute		√		
Chris Garside	Bigelow Laboratory for Ocean Sciences	√	√		
Diane Gould	Massachusetts Bay Program	√	√		
Chris Heinig	Intertide Corporation	√			
Charles Hopkinson, Jr.	Woods Hole Oceanographic Institute		√		
John Hurst	Maine Dept. of Marine Resources		√		
Kenneth Keay	Massachusetts Water Resources Auth.	√			
Maureen Keller	Bigelow Laboratory for Ocean Sciences	√	√		
Jack Kelly	U.S. Environmenal Protection Agency	√	√		√
Peter Larsen	Bigelow Laboratory for Ocean Sciences	√	√		√
Theodore Loder	University of New Hampshire	√	√	√	√
Caroline Martorano	University of New Hampshire				
Lawrence Mayer	University of Maine		√		
Bernard McAlice	Darling Marine Center	√			
Mike Mickelson	Massachusetts Water Resources Auth.	√	√		
Paul Mitnik	Maine Dept. of Env. Protection	√	√		
Byard Mosher	University of New Hampshire		√		
Carter Newell	Great Eastern Mussel Farm	√			
Judith Pederson	MIT Sea Grant		√		
David Phinney	Bigelow Laboratory for Ocean Sciences		√		
Frederick Short	University of New Hampshire		√		
John Sowles	Maine Dept. of Env. Protection	√	√		
David Taylor	Massachusetts Water Resources Auth.	√	√		
David Townsend	Bigelow Laboratory for Ocean Sciences	√			
Robert Vadas	University of Maine	√			
Middle Atlantic					
Josephine Aller	State University of New York at Stony Brook	√			
Charles App	U.S. Environmenal Protection Agency	√			
Sima Bagheri	New Jersey Institute of Technology	√			
Robert Biggs	Roy F. Weston Inc.	√			
Donald Boesch	University of Maryland - Horn Point	√	√		√
Henry Bokuniewicz	State University of New York at Stony Brook	√			
Walter Boynton	University of Maryland	√		√	√
Denise Breitburg	Academy of Natural Sciences	√			
Thomas Brosnan	National Oceanic and Atmospheric Administration	√	√		√
Claire Buchanon	Interstate Commission on the Potomac River Basin	√	√		
Nick Carter	Maryland Dept. of Natural Resources	√			
James Casey	Maryland Dept. of Natural Resources	√			
Carl Cerco	Army Corps of Engineers	√			
Jonathon Cole	Institute of Ecosystem Studies	√			
Robert Connel	New Jersey Dept. of Env. Protection	√	√		
Sherri Cooper	Duke University		√		
David Correll	Smithsonian Environmental Res. Cent.	√	√		
Elizabeth Cosper	Cosper Environmental Services, Inc.	√	√		√
Joseph Costa	Buzzards Bay Project	√	√		
Christopher D'Elia	State University of New York at Albany	√			√
Christopher DeAcutis	Rhode Island Dept. of Env. Mgmt.	√			
Robert Diaz	Virginia Institute of Marine Science	√	√		
Diana Domotor	Maryland Dept. of the Environment	√			
Bill Eisele	New Jersey Dept. of Env. Protection	√	√		
Deborah Tan Everitt	Maryland Dept. of the Environment	√	√		
Thomas Fisher	University of Maryland - Horn Point	√			
Anne Giblin	Marine Biological Laboratory	√			
Howard Golub	Interstate Sanitation Commission	√			
Sandy Groppenbucher	New Jersey Dept. of Env. Protetion	√	√		

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		Survey Form	Regional Assessment	Methods Development	National Assessment
Middle Atlantic (continued)					
Marilyn Harlin	University of Rhode Island	√			
Donald Heinle	CH2M Hill	√	√		
Frederick Hoffman	Virginia Water Control Board	√	√		
Norbert Jaworski	U.S. Environmental Protection Agency	√			
Tom Jones	Salisbury State University	√			
Stephen Jordan	Maryland Dept. of Natural Resources	√			
Renee Khan	Maryland Dept. of Natural Resources		√		
Grace Klein-MacPhee	University of Rhode Island	√			
Al Korndoerhfer	New Jersey Dept. of Env. Protection	√	√		
Robert Magnien	Maryland Dept. of Natural Resources	√	√		√
Thomas Malone	University of Maryland - Horn Point	√	√	√	√
James Maughan	CH2M HILL	√			
Bruce Michael	Maryland Dept. of the Environment	√	√		
Doreen Monteleone	New York St. Dept. of Economic Development	√			
Jon Morrison	U.S. Geological Survey		√		
James Mummam	New Jersey Dept. of Env. Protection	√	√		
Robert Nuzzi	Suffolk County Dept. of Health Services	√	√		
Jay O' Reilly	NOAA, National Marine Fisheries Service	√			
Paul Olsen	New Jersey Dept. of Env. Protection	√	√		
Christine Olsen	Connecticut Dept. of Env. Protection	√			
Robert Orth	College of William and Mary	√			
Candace Oviatt	University of Rhode Island	√			
John Paul	U.S. Environmental Protection Agency	√	√		
Jonathan Pennock	University of Alabama/Dauphin Island Sea Lab	√	√	√	√
Ernest Pizzuto	Connecticut. Dept. of Environmental Protection	√	√		
Kent Price	University of Delaware	√			
Ananda Ranasinghe	Versar Inc.	√			
Louis Sage	Bigelow Laboratory for Ocean Sciences	√	√		
James Sanders	Benedict Estuarine Research Lab	√			
Sybil Seitzinger	Rutgers University	√			
Valerie Shaffer	Virginia Institute of Marine Science		√		
Frederick Short	University of New Hampshire	√	√		
David Simpson	Connecticut Dept. of Env. Protection	√			
Carl Sindermann	Oxford Laboratory	√			
Theodore Smayda	University of Rhode Island	√			
Paul Stacey	Connecticut Dept. of Env. Protection	√	√		
R. Lawrence Swanson	State University of New York at Stony Brook	√			
Robert Thomann	Manhattan College	√			
James Thomas	NOAA, National Marine Fisheries Service	√			
Elaine Trench	U.S. Geological Survey		√		
Jefferson Turner	University of Massachusetts-Dartmouth	√			
Steve Weisberg	Versar Inc.	√	√		
Richard Wetzel	College of William and Mary	√			√
Robert Whitlatch	University of Connecticut	√			
Gary Wikfors	NOAA, NMFS/N.E. Fisheries Science Center	√			
Charles Yarish	University of Connecticut	√			
South Atlantic					
Merryl Alber	University of Georgia		√		√
Jim Alberts	University of Georgia	√	√		
Clark Alexander	Skidaway Institute of Oceanography		√		
Richard Alleman	South Florida Water Management Dist.	√			
Dennis Allen	University of South Carolina	√			
Richard Barber	Duke University Marine Laboratory	√			
Diane Barile	Marine Res. Council of East Florida	√			
Vincent Bellis	East Carolina University	√			
Jackson Blanton	Skidaway Institute of Oceanography		√		
Elizabeth Blood	J. W. Jones Ecological Research Center	√	√		
Bob Brody	St. Johns River Water Mgmt. Dist.	√	√		
Deborah Bronk	University of Georgia		√		
Ramesh Buch	Dade County Env. Resources Mgmt.		√		
JoAnn Burkholder	North Carolina State University		√		
Larry Cahoon	Univ. of North Carolina at Wilmington	√	√		
David Chestnut	South Carolina Dept. of Health & Env. Control		√	√	√
Daniel Childers	Nat. Marine Fisheries Service/NOAA	√			
Robert Christian	East Carolina University	√			
John Cooper	East Carolina University	√			
Terry Davis	Florida Dept. of Environmental Reg.	√			
Betsy Deuerling	City of Jacksonville	√			
Phillip Dunstan	College of Charleston	√			
Bob Frease	Marine Resources Council of East Fl.	√			
Greg Graves	Florida Dept. of Environmental Reg.	√			
Guy Hadley	Florida Dept. of Environmental Reg.	√			
Jess Hawkins III	North Carolina Div. of Marine Fisheries	√			
Jim Henry	Georgia State University		√		
John Higman	St. Johns Water Management District	√			
Robert Hodson	University of Georgia	√	√		
Fred Holland	South Carolina Dept. of Wildlife and Marine Res.	√	√		√

		Survey Form	Regional Assessment	Methods Development	National Assessment
South Atlantic (continued)					
Jeff Hyland	NOAA, National Ocean Service		√		
William Kirby-Smith	Duke University	√			
David Knott	South Carolina Wildlife & Marine Res.	√			
Alan Lewitus	University of South Carolina, Baruch Institute		√		
Wayne Magley	Florida Dept. of Environmental Reg.	√	√		
Michael Mallin	Univ. of North Carolina - Wilmington	√	√		√
Susan Markley	Dade County Environmental Resources Mgmt.	√			
Hank McKellar	University of South Carolina	√	√		√
Mary Ann Moran	University of Georgia		√		
James Nelson	Skidaway Institute of Oceanography		√		
Jimmie Overton	North Carolina Division of Env. Mgmt.	√			
Hans Paerl	University of North Carolina	√			
James Pinckney	University of North Carolina - Chapel Hill		√		
Lawrence Pomeroy	University of Georgia		√		
Joe Rudek	North Carolina Environmental Defense Fund		√		
Russell Sherer	South Carolina Dept. of Health and Env. Cntrl.	√			
Donald Stanley	East Carolina University	√	√	√	
Stuart Stevens	Georgia Dept. of Natural Resources		√		
Steve Tedder	North Carolina Div. of Environmental Management	√			
Patricia Tester	NOAA, National Marine Fisheries Service		√		
Bob Van Dolah	South Carolina Dept. of Wildlife and Marine Res.	√	√	√	√
Peter Verity	Skidaway Institute of Oceanography	√	√		√
Robert Virnstein	St. Johns River Water Mgmt. Dist.	√			
Randy Walker	Skidaway Institute of Oceanography		√		
Cecelia Weaver	Dade County Env. Resources Mgmt.	√			
A. Quinton White	Jacksonville University	√			
Richard Wiegert	University of Georgia	√			
Herbert Windom	Skidaway Inst. of Oceanography		√		
John Windsor Jr.	Florida Institute of Technology	√	√		
Gulf of Mexico					
Neil Armingeon	Lake Pontchartrain Foundation		√		
Don Axelrad	Florida Dept. of Environmental Protection		√		
Bruce Baird	U.S. Army Corp of Engineers		√		
Ronnie Best	National Biological Survey		√		
Tom Bianchi	Tulane University	√	√		
Jan Boydstun	Louisiana Dept. of Env. Quality	√			
Joe Boyer	Florida International University		√		
Jim Bowman	Texas Natural Resources Cons. Comm.		√		
David Brock	Texas Water Development Board		√	√	
Fred Bryan	Louisiana State University		√		
David Burke	Gulf Coast Research Laboratory		√		
Dave Buzon	Texas Parks and Wildlife Department		√		
Tom Cardinale	Hillsborough County Env. Prot. Comm.	√			
Sneed Collard	University of West Florida		√		
Emelise Cormier	Louisiana Dept. of Env. Quality		√		
Michael Dagg	Louisiana Universities Marine Consortium	√			
John Day	Louisiana State University	√			
Charly Demas	U.S. Geological Survey		√		
Richard DeMay	Barataria/Terrebonne National Estuary Program		√		
Dennis Demcheck	U.S.Geological Survey		√		
Hudson Deyoe	Texas A&M University		√		
Robert Dickey	Gulf Coast Research Laboratory		√		
Juli Dixson	University of Southern Mississippi		√		
Kelly Dixon	Mote Marine Laboratory	√			
Peter Doering	South Florida Water Mgmt. Dist.	√	√		
Quay Dortch	Louisiana Universities Marine Consortium	√	√		
Tom Doyle	National Biological Survey		√		
Ken Dunton	University of Texas		√		
H. Lee Edmiston	Apalachicola Natl. Est. Research Reserve	√	√		
Ernest Estevez	Mote Marine Laboratory	√	√		√
Janice Fellers	Suwannee River Water Mgmt. District	√			
Nichole Fisher	Texas A&M University		√		
David Flemer	U.S. Environmental Protection Agency	√	√	√	√
James Fourqurean	Florida International University	√			
Gary Gaston	University of Mississippi	√	√		
Cynthia Gorham-Test	U.S. Environmental Protection Agency		√		
Holly Greening	Tampa Bay Estuary Program	√		√	√
George Guillen	Texas Water Commission	√			
Joe Hand	Florida Dept. of Environmental Protection		√		
Albert Hindrichs	Louisiana Dept. of Env. Quality		√		
Dan Haurnet	South Florida Water Mgmt. Dist.		√		
Richard Iverson	Florida State University	√	√		

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		Survey Form	Regional Assessment	Methods Development	National Assessment
Gulf of Mexico (continued)					
J. O. Roger Johansson	City of Tampa Bay Study Group	√			
Lori Johnson	National Biological Survey		√		
Clifford Kenwood	Lake Pontchartrain Foundation		√		
Larry Land	U.S. Geological Survey	√			
Brian LaPointe	Harbor Branch Oceanographgic Inst.	√	√		
Graham Lewis	North West Florida Water Mgmt. District		√		
Skip Livingston	Florida State University		√		
Steven Lohrenz	University of Southern Mississippi	√			
Rodney Mach	U.S. Army Corp of Engineers		√		
Robert Mattson	Suwannee River Water Mgmt. Dist.	√	√		
Jerry McLelland	Gulf Coast Research Laboratory		√		
Ben McPherson	U.S. Geological Survey	√			
Russell Miget	Texas A&M University		√		
Cynthia Moncrieff	Gulf Coast Research Laboratory		√		
Paul Montagna	University of Texas at Austin	√	√		
Ralph Montgomery	Environmental Quality Lab	√			
Gerold Morrison	S.W. Florida Water Mgmt. District	√	√		
Harriet Perry	Gulf Coast Research Laboratory		√		
Michael Perry	Southwest Florida Water Mgmt. District	√			
Michael Poirrier	University of New Orleans	√	√		
Gary Powell	Texas Water Development Board	√			√
Warren Pulich	Texas Parks and Wildlife Department		√		
Nancy Rabalais	Louisiana Universities Marine Cons.	√	√		
Chet Rakocinski	Gulf Coast Research Laboratory		√		
Donald Ray	Florida Dept. of Environmental Reg.	√			
Donald Redalje	University of Southern Mississippi	√	√		
Bill Rizzo	National Biological Survey		√		
Patrick Roques	Texas Natural Resources Cons. Comm.		√		
Dugan Sabins	Louisiana Dept. of Env. Quality	√	√		
William Schroeder	University of Alabama	√	√		
James Seagle	Florida Dept. of Natural Resources	√	√		
Frank Shipley	Galveston Bay Natl. Estuary Program	√			
Thomas Smith III	Rookery Bay Natl. Est. Research Reserve	√			
Kerry St. Pe'	LA Dept. of Environmental Quality		√		
Dean Stockwell	University of Texas at Austin	√	√		
J. Kevin Summers	U.S. Environmental Protection Agency	√	√	√	
Carmelo Tomas	U.S. Environmental Protection Agency		√		
David Tomasko	S.W. Florida Water Management District	√	√		√
R. Eugene Turner	Louisiana State University	√	√		
Steven Twidwell	TNRCC/Water Plan. & Assmnts. Div.		√		
Robert Twilley	University of Southwestern Louisiana	√	√		√
Gabriel Vargo	University of South Florida	√	√		
Richard Volk	Corpus Christi Bay National Estuary Program		√		
Michael Waldon	University of Southwestern Louisiana		√		
Albert Walton Jr.	Florida Dept. of Environmental Reg.	√			
William Wardle	Texas A&M University at Galveston	√			
Jeff Waters	Lake Ponchartrain Basin Foundation		√		
James Webb Jr.	Texas A&M University at Galveston	√			
Jay Zieman	University of Virginia	√			
Pacific					
Jim Arthur	Bureau of Reclamation	√			
Shirley Birosik	Los Angeles Water Quality Control Bd.	√	√		
Milton Boyd	Humboldt State University	√			
Karleen Boyle	University of California - Los Angeles		√		
Donald Brown	California St. University at Long Beach	√	√		
Randall Brown	California Dept. of Water Resources	√			
Barbara Ann Butler	Oregon Institute of Marine Biology		√		
Jane Caffrey	Elkhorn Slough Nat. Est. Research Reserve		√		
John Chapman	Hatfield Marine Science Center		√		
James Cloern	U.S. Geological Survey	√			
Brian Cole	U.S. Geological Survey		√		√
Eugene Collias	Northwest Consultant Oceanographers Inc.	√			
Barry Collins	California Dept. of Fish and Game	√			
Andrea Copping	Washington Sea Grant	√			
Frank Cox	Washington Dept. of Health		√		
Clayton Creech	Hatfield Marine Science Center		√		
Scott Dawson	Santa Ana Regional Water Quality Control Board		√		
Andrew DeVogelare	Elkhorn Slough Natl. Est. Research Reserve	√			
Robert Emmett	NOAA, National Marine Fisheries Service	√			
Peggy Fong	University of California - Los Angeles		√		√

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		Survey Form	Regional Assessment	Methods Development	National Assessment
Pacific (continued)					
Jon Graves	Columbia R. Estuary Study Task Force	√			
Michael Graybill	South Slough Nat. Est. Research Reserve		√		
John Hannum	North Coast Regional Water Quality Control Board	√	√		
Jan Hodder	Oregon Institute of Marine Biology		√		
James Hollibaugh	San Francisco State University	√			
Carol Janzen	University of Delaware	√			
John Johnson	Oregon Dept. of Fish and Wildlife	√	√		
Deborah Johnston	California Dept. of Fish and Game	√	√		
Michael Josselyn	San Francisco State	√			
Christopher Kinner	Irvine Ranch Water District		√		
Eric Klein	Orange Co. Public Facilities & Resources Dept.		√		
Katie Kropp	Morro Bay National Estuary Program		√		
Gregg Langlois	California Dept. of Health Services		√		
Peggy Lehman	California Dept. of Water Resources		√		
Lisa Levin	Scripps Institution of Oceanography	√			
Michael Martin	California Dept. of Fish and Game	√			
Larry Marxer	Oregon Dept. of Environmental Quality		√		
Gregory McMurray	Oregon Dept. of Environmental Quality		√	√	√
Peter Michael	San Diego Water Quality Control Board	√	V		
Bruce Moore	Orange Co. Public Facilities & Resources Dept.		√		
Chad Nelsen	Oregon Dept. of Land Cons. & Dev.		√		
Avis Newell	Oregon Dept. of Environmental Quality		√		
Jan Newton	Washington State Dept. of Ecology	√	√	√	√
Frederic Nichols	U.S. Geological Survey	√			
James Nybakken	Moss Landing Marine Laboratory	√			
Don Oswalt	Oregon Dept. of Land Cons. & Dev.		√		
Bill Paznokas	California Dept. of Fish and Game	√			
Greig Peters	San Diego Water Quality Control Board	√			
Bill Peterson	Hatfield Marine Science Center		√		
Chris Prescott	Puget Sound Water Quality Authority	√			
Harlan Proctor	California Dept. of Water Resources	√			
Don Reish	California State University		√		
Jack Rensel	University of Washington	√			
Curtis Roegner	Oregon Institute of Marine Biology		√		
Greg Ruiz	Smithsonian Env. Research Center	√			
Steve Rumrill	South Slough Nat. Est. Research Reserve		√		
Mary Beth Saffo	University of California at Santa Cruz	√			
Kathleen Sayce	Shoalwater Botanical	√			
Larry Schemel	U.S. Geological Survey	√			
Lynda Shapiro	Oregon Institute of Marine Biology		√		
Randy Shuman	Metropolitan King County		√		√
Mark Silberstien	Elkhorn Slough Nat. Est. Research Reserve	√			
Lawrence Small	Oregon State University	√			
David Specht	U.S. Environmental Protection Agency	√			
Pete Striplin	Striplin Environmental Assoc.	√			
Barbara Sullivan	Oregon State University		√		
Kathy Taylor	Columbia R. Estuary Study Taskforce		√		
Ronald Thom	Battelle/Marine Sciences Laboratory	√	√		√
Bruce Thompson	San Francisco Estuary Institute	√			
Ken Thompson	Irvine Ranch Water District		√		
Tim Unterwegner	Oregon Dept. of Fish and Wildlife	√			
William Winchester	North Coast Reg. Water Quality Control Board	√			
Karen Worcester	Cent. Coast Reg. Water Quality Control Board	√	√		
Jack Word	Battelle Ocean Sciences	√			
Joy Zedler	University of Wisconsin	√	√		
National					
Richard Alexander	U.S. Geological Survey			√	
Darrell Brown	U.S. Environmental Protection Agency			√	√
Andrew Robertson	National Oceanic and Atmospheric Administration			√	√
Dick Smith	U.S. Geological Survey				√
Richard Valigura	National Oceanic and Atmospheric Administration			√	√
Terry Whitledge	University of Alaska Fairbanks	√	√	√	√

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