DETERMINING EUTROPHIC CONDITION

How is the eutrophic condition evaluated?

Eutrophic condition ratings are determined by evaluating the occurrence, spatial coverage, and frequency (of problem levels) of each symptom in each salinity zone of an estuary. These individual symptom ratings are then synthesized in a matrix that assigns an overall rating for the system.

Symptom expressions and values

In order to evaluate symptom expressions and values, a rating system was developed to integrate information for the primary and secondary symptoms. The four steps of the process are described in Figure 2.3: (1) determining symptom expression values, (2) calculating system values, (3) assigning categories for primary and secondary symptoms, and (4) determining the overall eutrophic condition.

Determining symptom expression

The first step in determining the eutrophic condition is to calculate an expression value for each eutrophic symptom. The symptom expression value is a combination of the concentration, frequency of occurrence, and spatial coverage of problem levels of each indicator (see box at right and figure 2.4). Symptom expressions are high, moderate, low, or no problem. However, throughout the report, low and no problem are combined into a single rating of low for discussion and tabulation.

Calculating estuary system value

After the symptom expression is determined for all five symptoms and for each salinity zone, the estuary-wide values for each symptom are calculated by taking the symptom (e.g., chlorophyll *a*) values in each salinity zone and creating a combined estuary-wide value for that symptom.

Assigning categories for primary and secondary symptoms

The rating system used in the NEEA averages the primary symptoms (chlorophyll *a* and macroalgae), giving them equal weight. The resulting values are highest for estuaries with multiple primary symptoms that occur with great frequency, over large spatial areas of the estuary, and for extended periods of time. In contrast, low scores indicate estuaries that exhibit few, if any, of the primary symptoms.

Symptom expression index values

Each symptom expression index value combines the following three measurements:

The extreme concentration or problem occurrence of the symptom. For example, for chlorophyll *a*, the 90th percentile of annual chlorophyll *a* data would be used in the calculation. If, however, the symptom present is low dissolved oxygen, the 10th percentile of annual data would be used.

The frequency with which the problem occurs. For example, if the symptom occurs episodically, annually, or persistently.

The area of the system over which the symptom was observed. The calculation uses the percent of area of the estuary over which the problem levels of a symptom are observed.

Using a precautionary approach to evaluate secondary symptoms, the highest of the secondary symptom expression values is selected as representative of more serious impacts within the estuary. An average of the symptom expression values is not used because normal measurements for dissolved oxygen might, for instance, obscure high losses of SAV. In addition, the higher weight given to the secondary symptoms recognizes that these symptoms are indicative of more advanced nutrient-related impacts.

National Oceanic and Atmospheric Administration

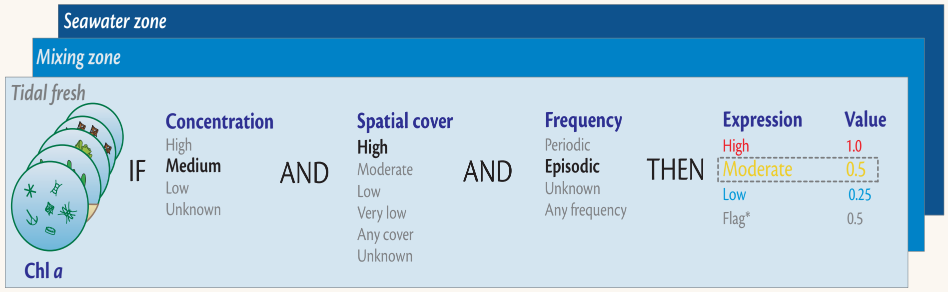
Determining the overall eutrophic condition of an estuary allows researchers to track the water quality changes in a system such as Otter Island, South Carolina, shown here.

EXHIBIT 10 (AR L.3)

Figure 2.3. Determination of overall eutrophic condition.

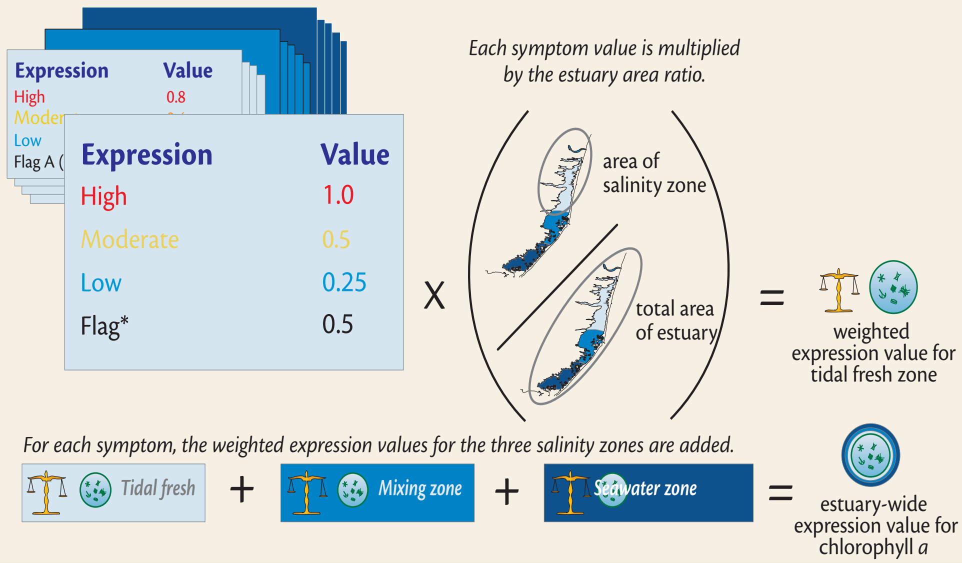
Step 1: Determine expression value for each eutrophic symptom in each salinity zone.

Eutrophic symptom expression values are determined for *each* symptom in *each* salinity zone (seawater, mixing, and tidal fresh), resulting in a total of 15 calculations. The expression is based on a set of IF, AND, THEN, decision rules that incorporate the symptom level (e.g., concentration), spatial coverage, and frequency.



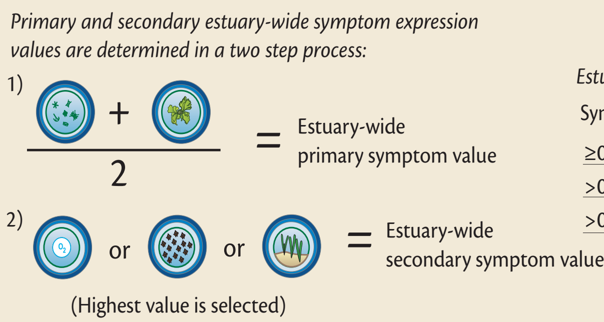
Step 2: Calculate estuary-wide symptom expressions (using chlorophyll *a* as an example).

The expression values are then used to calculate estuary-wide symptom expressions for each symptom. First, each expression value is multiplied by the area of the salinity zone and divided by the entire area of the system to establish the weighted value. Then, the weighted expression values in the tidal fresh, mixing, and seawater zone for each symptom are totaled to calculate the estuary-wide symptom expression value. This process is repeated for all five eutrophic symptoms. Note that "no problem" is the rating assigned if the value is 0, but that "no problem" and low are combined for discussion and tabulation throughout the report.



Step 3: Assign categories for primary and secondary symptoms.

The average of the primary symptoms is calculated to represent the estuary-wide primary symptom value. The highest of the secondary symptom values is chosen to represent the estuary-wide secondary symptom expression value and rating. The highest value is chosen because an average might obscure the severity of a symptom if the other two have very low values (a precautionary approach).

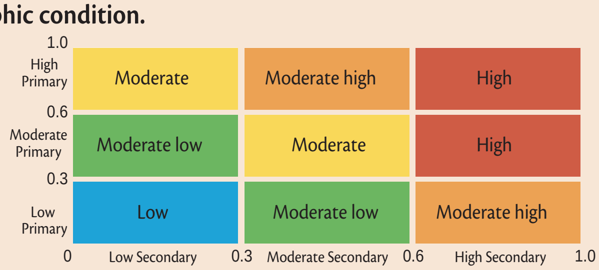


Estuary-wide symptom rating is determined:

Symptom expression value	Symptom rating
≥0 to ≤ 0.3	Low
>0.3 to ≤ 0.6	Medium
>0.6 to ≤ 1	High

Step 4: Determine overall eutrophic condition.

A matrix is used to combine the estuary-wide primary and secondary symptom values into an overall eutrophic condition rating according to the categories at right. Thresholds between rating categories were agreed on by the scientific advisory committee and participants from the 1999 assessment (Bricker et al. 1999).



	Low Secondary (0–0.3)	Moderate Secondary (0.3–0.6)	High Secondary (0.6–1.0)
High Primary (0.6–1.0)	Moderate	Moderate high	High
Moderate Primary (0.3–0.6)	Moderate low	Moderate	High
Low Primary (0–0.3)	Low	Moderate low	Moderate high

*Flags are used to identify components for which data were inadequate or unknown. In these cases, assumptions were made based on conservative estimates that unknown spatial coverage is at least 10% of a zone, frequency at least episodic, and duration at least days.

Determining overall eutrophic condition

To help facilitate the determination of overall eutrophic condition, the range of scores assigned to eutrophic symptoms are divided into categories of high, moderate, and low (Figure 2.3). Primary and secondary ratings are then compared in a matrix so that an overall eutrophic condition rating can be assigned to the estuaries.

Estuaries having high scores for both primary and secondary conditions are considered to have an overall high level of eutrophication (Figure 2.3). Likewise, estuaries with low primary and secondary values are assigned an overall low level of eutrophication. Estuaries with other combinations are interpreted and assigned a rating using the matrix as a guide (Figure 2.4). Those with few primary symptoms (and low numeric ratings) are considered to be relatively unaffected by nutrient-related conditions. Most estuaries show varying degrees of both primary and secondary symptoms, so that the meaning of the rating may be more difficult to determine:


South Florida Water Management District

Epiphytes, such as the ones shown here growing on submerged aquatic vegetation in Biscayne Bay, Florida, can also serve as further evidence of eutrophication.

Moderate to high primary symptoms and low secondary symptoms
Estuaries with well-developed problems associated with elevated chlorophyll *a* and/or macroalgal blooms are in the early stages of eutrophication and may be on the edge of developing more serious conditions.

Low primary symptoms and moderate to high secondary symptoms
There are a few possible interpretations for estuaries with advanced secondary symptoms but less developed primary symptoms (*see box below*).

Advanced secondary eutrophic symptoms in the absence of primary symptoms

Researchers have determined several reasons for the occurrence of secondary eutrophic symptoms in the absence of primary symptoms. For some estuaries, secondary symptoms (e.g., nuisance/toxic blooms) can be transported from offshore coastal areas rather than originating within the estuary (many North Atlantic estuaries function in this way). In addition, some blooms have no relation to nutrient conditions. As a result, this assessment provides a lower rating for blooms when it is clear that they originate offshore and are therefore not related to nutrient loads.

Alternatively, it is possible that nutrient-related water quality conditions have recently improved, but that the response time to reduce secondary symptoms is longer than for the 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 the secondary conditions may occur without being necessarily related to nutrient enrichment. Some submerged aquatic vegetation losses in Chincoteague Bay, Maryland, for example, are related to dredging operations rather than to nutrient conditions. Also, in warmer climates, dissolved oxygen concentrations may be lower on average than cooler systems due to decreased oxygen solubility as water temperature rises.


National Oceanic and Atmospheric Administration

Nuisance/toxic blooms, such as the cyanobacterial bloom above, is a secondary symptom of eutrophication.

Figure 2.4. Descriptions of the ratings used in the NEEA update.

Symptom	Parameters	Expression: Low	Expression: Moderate	Expression: High
Chlorophyll *a* (phytoplankton) Typical high concentration (µg L[-1]) in an annual cycle determined as the 90[th] percentile value.	*Spatial coverage:* High >50%; Moderate 25–50%; Low 10–25%; Very low 0–10% *Frequency:* Episodic; Periodic; Persistent *Concentration:* High >20 µg L[-1]; Medium 5–20 µg L[-1]; Low 0–5 µg L[-1]	*Low symptom expression:* *Conc. / Coverage / Frequency* low / any / any medium / mod. - v. low / episodic high / low - v. low / episodic	*Moderate symptom expression:* *Conc. / Coverage / Frequency* medium / high / episodic medium / moderate / periodic high / low - v. low / periodic high / moderate / episodic	*High symptom expression:* *Conc. / Coverage / Frequency* medium / high / periodic high / mod. - high / periodic high / high / episodic
Macroalgae Causes a detrimental impact on any natural resource.	*Frequency of problem:* Episodic (occasional/random) Periodic (seasonal, annual, predictable) Persistent (always/continuous)	No macroalgal bloom problems have been observed.	Episodic macroalgal bloom problems have been observed.	Periodic or persistent macroalgal bloom problems have been observed.
Dissolved oxygen Typical low concentration (determined as the 10[th] percentile value) in an annual cycle.	*Spatial coverage:* High >50%; Moderate 25–50%; Low 10–25%; Very low 0–10% *Frequency:* Episodic; Periodic; Persistent *State:* Anoxia 0 mg L[-1]; Hypoxia 0–2 mg L[-1]; Biol. stress 2–5 mg L[-1]	*Low symptom expression:* *State / Coverage / Frequency* anoxia / mod. - low / episodic anoxia / very low / periodic hypoxia / low - v. low / periodic hypoxia / moderate / episodic stress / any / episodic stress / mod. - v. low / periodic	*Moderate symptom expression:* *State / Coverage / Frequency* anoxia / high / episodic anoxia / low / periodic hypoxia / moderate / periodic hypoxia / high / episodic stress / high / periodic	*High symptom expression:* *State / Coverage / Frequency* anoxia / moderate - high / periodic hypoxia / high / periodic
Submerged aquatic vegetation A change in SAV spatial area observed since 1990.	*Magnitude of change:* High >50% Moderate 25–50% Low 10–25% Very low 0–10%	The magnitude of SAV loss is low to very low.	The magnitude of SAV loss is moderate.	The magnitude of SAV loss is high.
Nuisance/toxic blooms Causes detrimental impact on any natural resources.	*Duration:* Persistent, seasonal, months, variable, weeks, days, weeks to seasonal, weeks to months, or days to weeks *Frequency:* Episodic, periodic, or persistent	Blooms are either a) short in duration (days) and periodic in frequency; or b) moderate in duration (days to weeks) and episodic in frequency.	Blooms are either a) moderate in duration (days to weeks) and periodic in frequency; or b) long in duration (weeks to months) and episodic in frequency.	Blooms are long in duration (weeks, months, seasonal) and periodic in frequency.

*For further technical documentation of the methods, refer to Bricker et al. 1999 and Bricker et al. 2003.

Through the use of a simple model, the current framework was established to help understand the sequence, processes, and symptoms associated with nutrient enrichment. Despite its limitations, it represents an attempt to synthesize enormous volumes of data and derive a single value for eutrophication in each estuary, essentially representing a complex process in a simple way. Furthermore, modifications are in progress to improve the method (*Chapter 6: Improvements to the assessment*). With this foundation, the next step is to better understand the negative impacts on the human uses of estuaries and to provide insight for the development of a holistic approach to management with future outlook in mind.

Use impairments

In the original 1999 report, use impairments were evaluated to try to capture the cost that eutrophic symptoms impose on the human dimension of estuaries. These impacts may include, but are not limited to, recreational activities such as swimming, fishing and boating, commercial operations, and tourism. A list of possible impairments was developed from state 305b reporting requirements (see text box, top right). Expert judgment from the participants was used to evaluate local use impairments.

State 305b reporting requirements

Under section 305b, the Clean Water Act requires each state to prepare a biennial report on the health of their streams, rivers, lakes, and estuaries. These reports are reviewed by Congress to determine how far each state has progressed toward making the Nation's water bodies fishable and swimmable.

State 305b reports are submitted to the Environmental Protection Agency (EPA), which also provides reporting guidelines to the states during each reporting period. Then, the EPA compiles and summarizes the information that will be presented to Congress. These reports are an important tool because they are the main vehicle for evaluating current water quality conditions and the progress that has been made toward improving water quality nationwide.

Source: www.epa.gov/Region8/water/monitoring/

In addition to investigating use impairments, this update also includes information about living resource impairments. This additional information was collected in an attempt to link more directly the causes and manifestations of use impairments and to provide a stronger basis for the development of management plans.

Jane Hawkey, University of Maryland Center for Env. Science

Eutrophic symptoms can lead to use impairments such as restricted commercial and recreational fishing and closed waterways.

EXHIBIT 10 (AR L.3)

DETERMINING FUTURE OUTLOOK

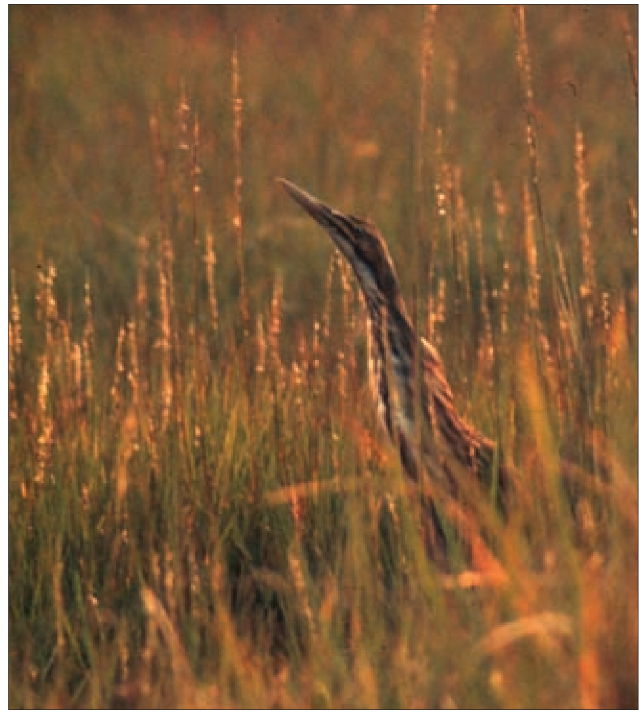
How is the future outlook for an estuary evaluated?

Like influencing factors and overall eutrophic condition, the future outlook for an estuary is ultimately determined by a matrix. This matrix combines two factors:

- System susceptibility
- Predicted future loads to the system

The future outlook is designed to estimate future changes in eutrophic condition based on expected changes in nutrient inputs to a system.

Similar to influencing factors and eutrophic conditions, future outlook is determined by a matrix that combines the susceptibility of a system with expected changes in nutrient loads. Predictions of nutrient loading (categorized as increase, decrease, or no change) are based on predicted population increase, planned and/or recently implemented management actions, and expected changes in watershed use. Results from the 2004 update will show whether conditions predicted by the 1999 report have yet been realized (predictions are for year 2020).



National Oceanic and Atmospheric Administration

An American bittern in Narragansett Bay, Rhode Island. These birds are very sensitive to changes in estuarine health. Future outlook in this study attempts to project which estuaries will remain healthy enough to support such sensitive organisms.

Calculating future outlook

The analysis for future outlook is an attempt to determine whether conditions in an estuary will worsen, improve, or remain unchanged over the next 20 years.

In this analysis, expected nutrient input changes were used to predict whether eutrophic conditions will improve or worsen. The system's susceptibility to nutrients is then used to determine the magnitude of this change. Population projections are used as a primary indicator of the level of future nutrient input changes. However, population projections are unpredictable. Therefore, experts at the NEEA update workshop were asked to predict changes in nutrient load, based on their knowledge of likely changes in land use, management measures, and other activities that affect nutrient loading.

Determination of the future outlook

***Susceptibility** (flushing and dilution)*	decreasing nitrogen load	no change	increasing nitrogen load
low susceptibility	Improve high Symptoms likely to improve substantially	No change Symptoms will most likely remain unchanged	Worsen low Symptoms likely to worsen only minimally
moderate susceptibility	Improve low Symptoms likely to improve	No change Symptoms will most likely remain unchanged	Worsen high Symptoms are likely to substantially worsen
high susceptibility	Improve low Symptoms likely to improve somewhat	No change Symptoms will most likely remain unchanged	Worsen high Symptoms are likely to substantially worsen

***Expected future load** (nitrogen input)*

EXHIBIT 10 (AR L.3)

ASSESSMENT OF ESTUARINE TROPHIC STATUS (ASSETS)

How is an ASSETS rating evaluated?*

The ASSETS rating is a combination of the following three components:

- Influencing factors
- Overall eutrophic condition
- Future outlook

**More information about ASSETS may be found at* http://eutro.org/

In an effort to simplify the comparison of the status of systems, the last step is to combine the influencing factor, overall eutrophic condition, and future outlook components into a single overall score for each system. The ratings for influencing factors, overall eutrophic condition, and future outlook are combined in a matrix to provide an overall grade or score which may fall into one of five categories: High, good, moderate, poor, or bad. These categories are color coded following international convention and provide a scale for setting reference conditions for different types of systems (Bricker et al. 2003).

The high grade will not be assigned if the expected future outlook is for worsening conditions, but a system may be rated as good based on high or good eutrophic condition and influencing factors, even if the expectation is that it will worsen in the future. Poor and bad grades reflect a range of undesirable pressure and state conditions, even if there are management plans for recovery.

Data completeness and reliability

In order to evaluate the reliability of the assessment, a measurement of data completeness and reliability (DCR) of the dataset was calculated. This is important because the assessment uses a combination of symptom indicator data, which are derived from a variety of sources and levels of certainty. Additionally, data for all indicators were not available for all systems. The robustness of the assessment is affected by missing data (e.g., spatially or temporally limited), and data that are judged to be based upon speculative inference.

The DCR is defined as the percent of the total estuarine area for which data are considered highly certain for all or most indicators. A DCR rating is made for each of the five symptom variables, incorporating scores for both completeness (whether data is entered for symptoms [e.g., concentration] and symptom characteristics [e.g., spatial coverage, frequency]), and the level of confidence of data used for the assessment. The symptom DCR values are averaged for an overall eutrophic condition DCR rating. A score of 76–100%, or high DCR, means that there are complete data of high certainty for the majority of the estuary. A system with moderate DCR has complete, high certainty data in 51–75% of its area and a low DCR means that there are complete, high certainty data in 50% of the system or less.

National Oceanic and Atmospheric Administration

Participants at the National Estuarine Eutrophication Assessment Update workshop held in Maryland in May 2006.

EXHIBIT 10 (AR L.3)

3. NATIONAL ASSESSMENT

SUMMARIZING THE NATION'S EUTROPHIC CONDITION

- Majority of estuaries showed signs of eutrophication.
- Most common symptom of eutrophication was high chlorophyll *a*.
- High overall eutrophic conditions were observed in many systems.

The majority of U.S. estuaries assessed displayed at least one symptom of eutrophication, suggesting a large-scale, national problem. Of the systems assessed, 29 had moderate high to high eutrophic condition (Figure 3.1). Estuaries in this category are characterized by symptoms that are extensive (covering 50% or more of the system) and/or are persistent. Estuaries with high eutrophic conditions occurred in all regions of the nation except for the North Atlantic region (Figure 3.3). The mid-Atlantic region recorded the greatest proportion of highly eutrophic systems. Estuaries with high overall eutrophic conditions were generally those that received the greatest nitrogen loads.

A large proportion of the estuaries surveyed had moderate eutrophic condition ratings (Figure 3.1). Estuaries in this category are characterized by symptoms that are periodic and occur over a moderate proportion of the estuary. Systems with low eutrophic condition occurred in all regions, with the highest proportions recorded in the Gulf of Mexico and North Atlantic (Figure 3.3). During the decade between the two NEEA studies (the 1999 report reflected conditions in the early 1990s), conditions in 13 systems (9% of area assessed) had improved and in 13 systems (14% of assessed area) had worsened, but most remained the same (77% of assessed area). However, the number of systems with inadequate data for assessment has increased from 17 in the 1999 assessment to 42 systems in the current study. This is likely due to a change in data collection methods: an eight-year process for the 1999 assessment involving site visits, and regional and national workshops, compared to a two-year process for 2004 involving an online survey and a national workshop.

The overall eutrophic condition rating is based on the combined level of expression of five symptoms: chlorophyll *a*, macroalgae, dissolved oxygen, nuisance/toxic blooms, and submerged aquatic vegetation (SAV). The large number of estuaries with high chlorophyll *a* symptom expression is a clear signal that eutrophication is a widespread problem (Figure 3.2). The high symptom expression indicates that increased nutrient loads are stimulating phytoplankton growth. Although macroalgae data were relatively sparse, symptom expression was moderate or high for 33 systems.

Elevated phytoplankton and macroalgae biomass can lead to drops in dissolved oxygen levels resulting from microbial breakdown. The data for dissolved oxygen indicate that while a few areas are affected, the vast majority of systems do not experience dissolved oxygen problems (Figure 3.2).

Another eutrophic symptom, nuisance/toxic blooms, can have human health, ecological, and aesthetic effects on an estuary. This assessment shows that most of the nation's estuaries are not affected by these blooms, and those that do are located primarily in the mid-Atlantic region.

Submerged aquatic vegetation is often a critical habitat within an estuary, providing protection from predators and a food source for juvenile organisms. This assessment showed that most SAV beds remained stable between the early 1990s and 2000s.

Figure 3.1. Number of estuaries in each of the overall eutrophic condition categories.

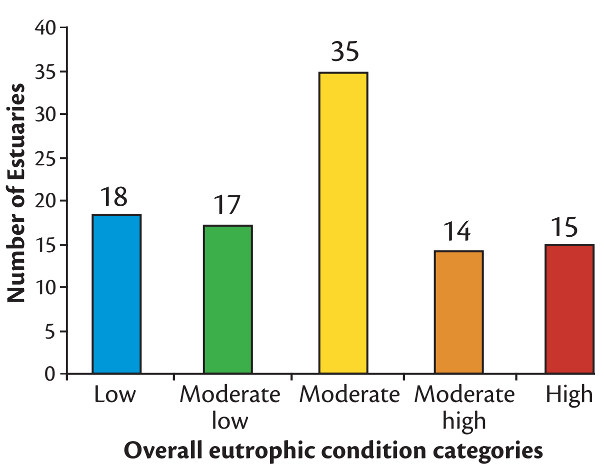


Figure 3.2. Distribution of symptoms and symptom expressions.

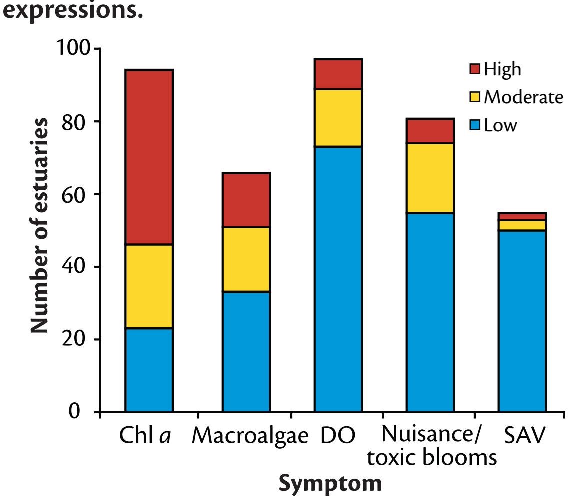


EXHIBIT 10 (AR L.3)

Figure 3.3. Summary of overall eutrophic conditions (OEC) in the five regions. Bar graphs show the % of estuaries in each category; ratios above graphs are the number of estuaries able to be assessed for OEC/number in each region.

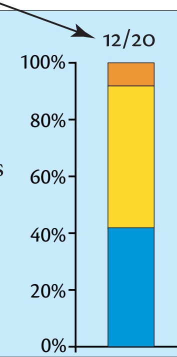
This report divides the Nation's estuaries into five regions: North Atlantic, mid-Atlantic, South Atlantic, Gulf of Mexico and Pacific Coast. Estuaries are divided into these regions to facilitate discussion at regional scales. Chapter 4 provides a detailed assessment and discussion of the eutrophic condition of each region. At right is a brief summary of the eutrophic conditions within each region.

Overall eutrophic condition

- **High:** symptoms occur periodically or persistently and/or over an extensive area.
- **Moderate high:** symptoms occur less regularly and/or over a medium to extensive area.
- **Moderate:** symptoms occur less regularly and/or over a medium area.
- **Moderate low:** symptoms occur episodically and/or over a small to medium area.
- **Low:** few symptoms occur at more than minimal levels.

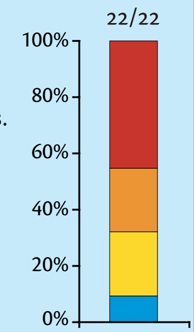
North Atlantic region

- Factors influencing eutrophication were low for all assessed systems.
- The least impacted region: no systems recorded a high OEC rating.
- Some systems had worsening chlorophyll *a* and macroalgae symptom expressions.



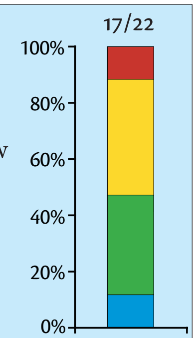
Mid-Atlantic region

- Factors influencing eutrophication were high for the majority of systems.
- The most impacted region: a majority of systems recorded a moderate high or high OEC.
- High chlorophyll *a* expression was observed in the majority of systems.



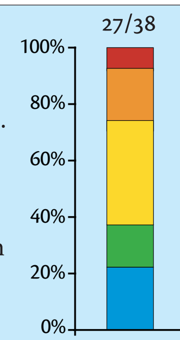
South Atlantic region

- Factors influencing eutrophication were spatially variable.
- A similar number of estuaries had low and high OEC ratings.
- Almost half of those systems had moderate problems with dissolved oxygen.



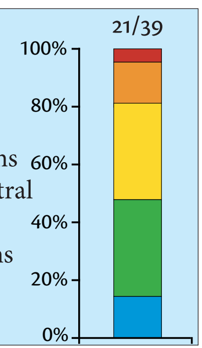
Gulf of Mexico region

- Factors influencing eutrophication were high for most assessed estuaries.
- A small proportion of estuaries had high or moderate high overall eutrophic condition. These systems were characterized by high, and often worsening, chlorophyll *a* symptoms.



Pacific Coast region

- Very few estuaries have nutrient load data available.
- Most estuaries with reported problems were located in Washington and central California, with chlorophyll *a* and dissolved oxygen being the symptoms of concern.



EXPLORING PHYSICAL CHARACTERISTICS ON A NATIONAL SCALE

The great diversity of the 141 estuarine and coastal systems included in this assessment lies in their geographic location, physical and hydrologic characteristics (e.g., landscape elevation and climate), watershed population, and land use. These characteristics have strong influences on the potential for eutrophication.

Although this assessment does not include all U.S. estuaries, it represents greater than 90% of the total freshwater flow into coastal systems and covers an equal water body surface area. Headwaters of Atlantic coast estuaries mostly originate from the Appalachian Mountains, a relatively low-lying range that follows the eastern U.S. shoreline (Figure 3.4a). In the north, the Appalachian Mountains are relatively close to the coast, leading to short and steep watersheds of higher elevation (Table 3.1). Toward the south, the range is farther inland, leading to longer and flatter watersheds of lower elevation (typically half that of northern watersheds). Estuary type also changes from river mouth estuaries in the north to lagoon systems in the south. The headwaters of Pacific Coast estuaries also originate in the mountains, but from a diversity of ranges including the Rocky Mountains, Coastal Range, and Sierra Nevada. The north Pacific coastal systems have the highest watershed elevations of any region (Table 3.1) due to the coastal mountain ranges. While most systems in the Gulf of Mexico are located in low-lying watersheds, some watersheds in the west extend into the Sierra Nevada, giving them higher mean elevations than the rest of the region.

Estuary size varies nationally and regionally (Table 3.1). The mid-Atlantic region, for example, includes the large Chesapeake Bay and much smaller coastal lagoonal systems. The fjords in the northern Pacific Coast and North Atlantic regions are the deepest systems. Watershed size is also variable within regions. For instance, the Gulf of Mexico region includes the massive Mississippi River basin as well as the small coastal watersheds of Florida. The ratio of watershed area to estuarine area may exert a significant influence on the development of eutrophication, especially in areas of dense watershed population. This ratio can be used as an indicator of the influence of watershed-based inputs on the estuary. The systems in the Gulf of Mexico and Pacific Coast regions have the highest ratios, showing input from a large watershed into a smaller water body. The potential influence on these systems is greater than for systems in the North and mid-Atlantic regions where the ratio is much smaller.

Rainfall also influences the delivery of nutrients to a system. The driest watersheds are located in the southern Pacific Coast and western Gulf of Mexico regions (Table 3.1). Land cover in these areas tends to be dominated by grassland, shrub land, and savanna (Figure 3.4b). Rainfall along the north and mid-Atlantic coast is higher, with land cover in these regions dominated by deciduous and evergreen forests. The northern Pacific Coast region is also dominated by deciduous and evergreen vegetation. The South Atlantic and eastern Gulf of Mexico regions have a subtropical climate, with higher annual rainfall and land cover dominated by

Table 3.1. Summary of physical characteristics for each region and within regions.*

Region	Mean estuarine area (km²)	Mean depth (m)	Tidal range (m)	Mean watershed area (km²)	Mean watershed elevation (m)	Mean annual precipitation (m)	Average annual temperature (° C)	Average frost days (days)
North Atlantic	**264**	**12.9**	**2.8**	**4284**	**100**	**1.16**	**8**	**156**
mid-Atlantic	**923**	**4.7**	**0.80**	**13,521**	**116**	**1.12**	**13**	**106**
estuaries	1140	5.7	0.86	17,137	147	--	--	--
lagoons	189	1.4	0.59	1232	12.6	--	--	--
South Atlantic	**534**	**2.9**	**1.21**	**15,043**	**58**	**1.32**	**19**	**36**
NC to GA	522	3.2	1.32	15,678	66	1.31	19	41
Florida	761	1.4	0.48	11,018	9	1.33	23	5
Gulf of Mexico**	**822**	**1.7**	**0.41**	**109,545**	**107**	**1.33**	**22**	**12**
FL MS LA AL	882	1.8	0.47	133,068	73	1.46	22	13
TX	667	1.6	0.26	46,031	198	0.98	22	9
Pacific	**182**	**14**	**1.5**	**25,209**	**401**	**1.14**	**12**	**57**
fjord	438	66	2.4	5,822	477	1.07	10	73
river mouth	133	6.9	1.4	42,039	459	1.71	12	66
lagoons	75	3.5	1.1	1,297	271	0.29	16	23

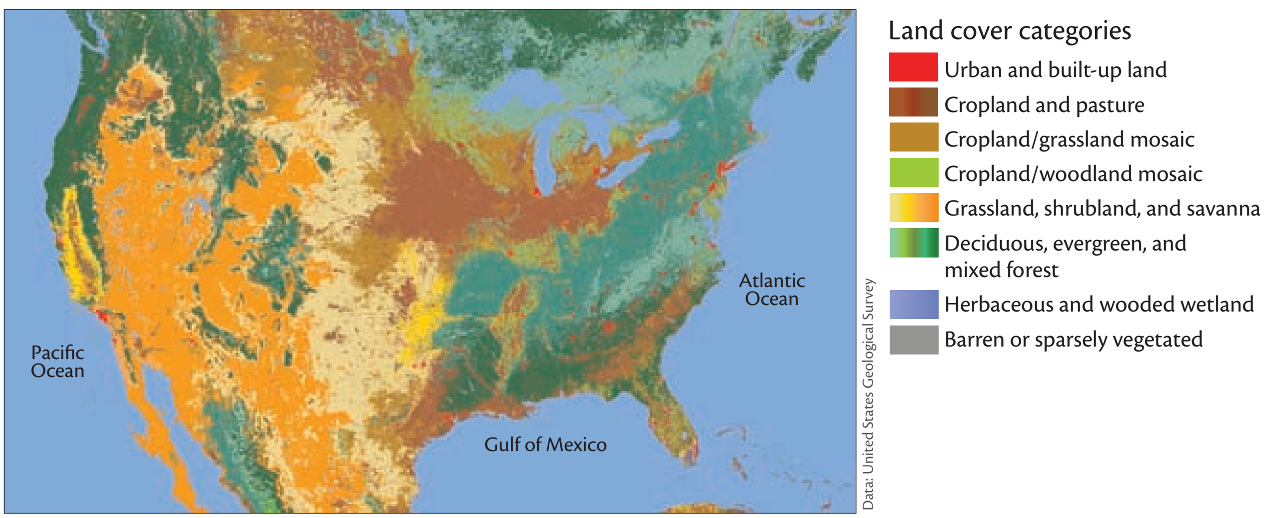
*Data source: S.V. Smith (2003).
**Does not include Mississippi River to avoid biasing the results due to its extreme watershed size.

EXHIBIT 10 (AR L.3)

Figure 3.4. Elevation and major rivers, land cover, and sea surface temperature on a national scale.

a. *elevation and major rivers in the United States.*

b. *1993 land cover in the United States.*



c. *average (1985-2001) summer (July-September) sea surface temperature.*