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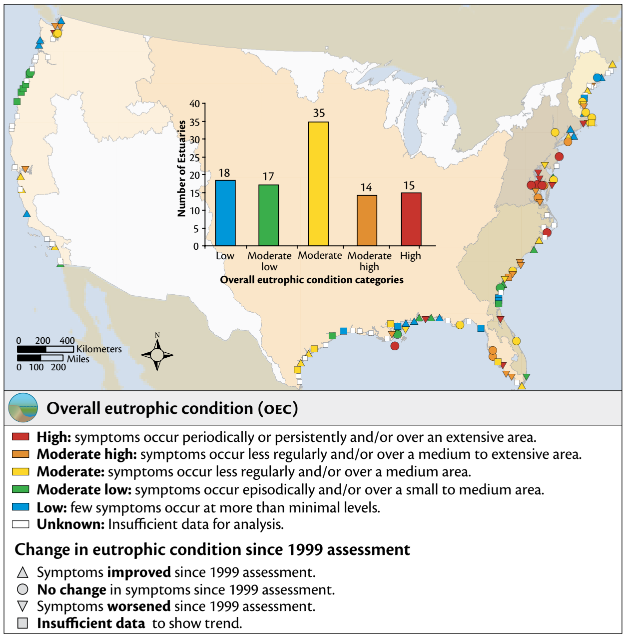
Figure 4. National overall eutrophic condition was geographically variable.

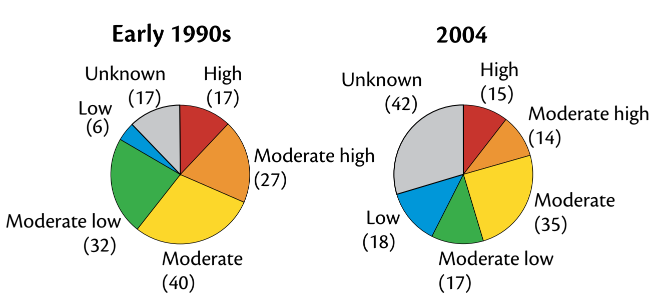


pattern of overall eutrophic conditions or symptom expressions except that the largest concentration of highly eutrophic systems was in the mid-Atlantic.

5. Comparison of eutrophic conditions assessed from the early 1990s to 2004 indicates similar levels of eutrophication.

Direct comparison of eutrophic status between assessments was impeded by reduced data availability in 2004 (70% of systems in 2004 vs. 88% in 1990s) due in part to changes in the data collection method (*see chapter 3: National assessment*). If only assessed systems are considered, conditions have improved in 13 estuaries, worsened in 13, and remained the same in 32 systems. In 1999, 69% of assessed systems (72% of assessed area) had moderate to high eutrophic conditions compared to 65% of assessed systems (78% of assessed area) in 2004 (Figure 5).

Figure 5. Number of estuaries in each eutrophication category in the early 1990s (1999 assessment) and 2004 (this assessment).



6. Considerations for management action, monitoring, research, and communication (Figure 6)

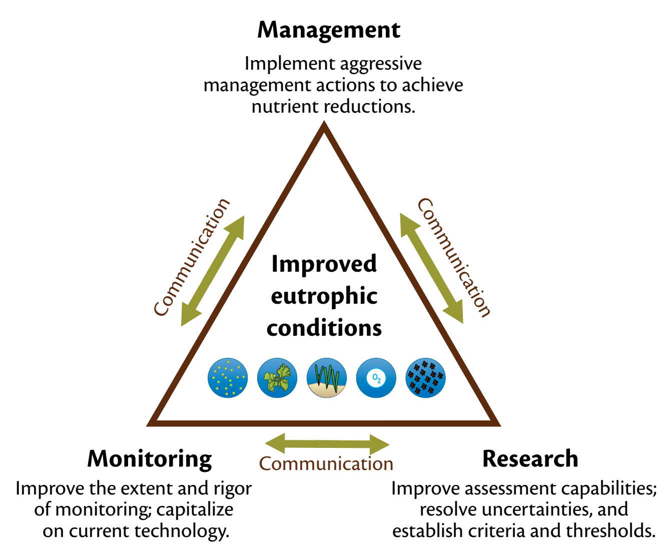
Management: Implement more aggressive action to achieve nutrient reductions for widespread reductions in eutrophic conditions. Notable improvements have been achieved (e.g., Tampa Bay and Boston Harbor) with aggressive management intervention, but these are isolated cases.

Monitoring: Capitalize on technology (e.g., observing systems, remote sensing) to improve comprehensive assessment of eutrophication in a coordinated and timely fashion. Future national assessments would benefit from rigorous, easily accessible data (both *in situ* and remotely sensed) provided on the web by local and regional assessment programs.

Research: Focus on improving monitoring and assessment of eutrophication, resolving uncertainties, and establishing criteria and thresholds. In particular, macroalgae and submerged aquatic vegetation indicators should be improved. Elucidate potential and evaluate current management options.

Communication: Engage resource managers, researchers, policy makers, and the community with frequent assessment updates at local, regional, and national levels. Environmental report cards, illustrative graphics, and maps, will foster interest and inform, and empower the public to support critical management action.

Figure 6. Improvements in eutrophic condition can only be achieved by management, research, and monitoring programs working together.



EXECUTIVE SUMMARY

Chapter 1: Introduction and Background

- The National Estuarine Eutrophication Assessment (NEEA) is a tool for evaluating both current eutrophic condition and the effectiveness of management actions aimed at reducing eutrophic condition.
- Eutrophication is caused by excess nutrients and is expressed by symptoms such as increased chlorophyll *a* and macroalgae, and decreased dissolved oxygen.
- Widespread coastal eutrophication has been reported in a previous national assessment (Bricker et al. 1999). As coastal populations continue to increase, experts are concerned that eutrophication and associated symptoms are also increasing. In response to this concern, it was decided that the 1999 assessment should be updated.
- This update of the 1999 assessment identifies current eutrophic status and changes since the early 1990s, tracks management progress, and identifies potential solutions for eutrophication.
- To facilitate this and future assessments, an online survey tool was developed. This tool allows investigators to share data and information effectively, providing a common language by which they can communicate with one another in a standardized manner.

Chapter 2: Approach

- The NEEA evaluates eutrophication by examining (1) influencing factors; (2) eutrophic symptoms; (3) overall eutrophic condition; (4) future outlook; and, (5) combining the results into one overall rating (ASSETS).
- In this report, factors influencing eutrophication are nitrogen load and the estuary's susceptibility to nitrogen (dilution and flushing rates).
- Overall eutrophic condition is based on assessment of 5 symptoms: chlorophyll *a*, macroalgae, dissolved oxygen, submerged aquatic vegetation and nuisance/toxic blooms. Eutrophic condition is determined by evaluating the occurrence, spatial coverage and frequency of these symptoms.
- Eutrophic condition is predicted for year 2020 (future outlook) based on expected changes in nutrient loads and the estuary's susceptibility to these loads.
- The influencing factors, overall eutrophic condition, and future outlook results are combined into an overall system rating (ASSETS).
- Completeness and reliability of the assessment is based on the temporal and spatial availability of data.

Chapter 3: National Assessment

- The majority of estuaries assessed were highly influenced by human-related activities. Influencing factor ratings were high from New York to Texas, low in the North Atlantic, and mostly unknown in the Pacific region.
- Eutrophication is a widespread problem, with the majority of assessed estuaries showing signs of eutrophication—65% of the assessed systems, representing 78% of assessed estuarine area, had moderate to high overall eutrophic conditions.
- The most common symptoms of eutrophication were high spatial coverage and frequency of elevated chlorophyll *a* (phytoplankton)—50% of the assessed estuaries, representing 72% of assessed area, had a high chlorophyll *a* rating.
- There were no regional or national patterns of highly eutrophic conditions found in systems along all coastlines. However, the mid-Atlantic region was the most impacted overall.
- Survey participants predicted worsening conditions by 2020 in 65% of estuaries and improvements in 20% of estuaries.
- Change analysis showed that conditions in most assessed systems remained the same since the early 1990s (32 systems, 77% assessed area). Changes were observed in smaller systems; 13 systems (9% assessed area) improved and 13 systems (14% assessed area) worsened.
- Assessment of eutrophic condition was impeded by reduced reporting in 2004 as there were inadequate data for 30% of surveyed estuaries, compared to only 12% of estuaries in the early 1990s. This was largely a result of the data collection method, the online survey for the 2004 data versus use of site visits and workshops in addition to a survey for the 1999 assessment.

Chapter 4: Regional Assessments

- This assessment 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 and application to management.

North Atlantic (Maine to Cape Cod)

- North Atlantic estuaries are small, deep, and well-flushed by tides, with generally small watersheds. Factors influencing eutrophication were low for all reported systems.
- North Atlantic estuaries were the least impacted nationally: no estuaries had a high overall eutrophic condition rating. However, the outlook for this region raises concern, with conditions predicted to worsen in most estuaries.

Mid-Atlantic (Cape Cod to Chesapeake Bay)

- Mid-Atlantic estuaries and coastal lagoons are relatively large, moderately deep, have a moderate watershed size, and are poorly flushed. Factors influencing eutrophication were high for the majority of estuaries.
- Mid-Atlantic estuaries were the most impacted nationally: the majority of estuaries recorded a moderate high or high overall eutrophic condition rating, with

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more than one third of the estuaries having worsened since the early 1990s.

South Atlantic (North Carolina to Florida)

- South Atlantic estuaries are mostly of medium size, shallow, and well flushed. They have moderately sized watersheds with relatively high population. Factors influencing eutrophication were spatially variable, with high influencing factor ratings in over one third of the assessed estuaries.
- Problematic levels of chlorophyll *a* and dissolved oxygen were the main symptoms of eutrophication in this region, although the majority of estuaries had moderate or low eutrophic condition.

Gulf of Mexico (Florida to Texas)

- Gulf of Mexico estuaries are mostly large, shallow, and poorly flushed. They tend to have very large watersheds with low to moderate populations. Factors influencing eutrophication were high for most assessed estuaries.
- A small proportion of estuaries had high or moderately high overall eutrophic condition. Gulf of Mexico estuaries were characterized by high, and often worsening, chlorophyll *a* symptoms.

Pacific region (California to Washington)

- The Pacific region has numerous small, deep, and moderately well flushed estuaries with moderately sized watersheds. Very few estuaries in this region have nutrient load data available.
- Most estuaries with high to moderate eutrophic condition were located in Washington and central California with chlorophyll *a* and dissolved oxygen being the symptoms of concern.

Chapter 5: Case studies

- A diversity of national and international case studies are presented to illustrate the various impacts of eutrophication. In some cases, the associated management and monitoring responses are presented. Themes of the case studies include:
  - *Diversion of sewage effluent to offshore discharge reduced eutrophic symptoms (Boston Harbor).*
  - *Monitoring suggests anthropogenic and riverine sources of nutrients (Casco Bay).*
  - *Reduction in point source nutrients ameliorated hypoxia in the 1990s (Long Island Sound).*
  - *Trend reversal in water quality improvements likely caused by recent increase in diffuse nutrient load (Maryland Coastal Bays).*
  - *Predictable large scale hypoxia from nation's largest drainage basin due to nutrient loads (Mississippi-Atchafalaya Plume).*
  - *Deteriorating dissolved oxygen conditions occurring in a well mixed coastal waterway (Skidaway River Estuary).*
  - *Seagrass recovery after historic losses due to nitrogen load reductions (Tampa Bay).*
  - *Continuous water quality monitoring data helps to explain extreme events such as fish kills (Corsica River).*
  - *The complex factors causing low dissolved oxygen events require ongoing research, monitoring and modeling (Hood Canal).*
  - *Ecosystem transition occurred with initiation of brown tides (Laguna Madre).*
  - *Nutrients and climate change pose threat to coral reefs (Looe Key).*
  - *Holistic ecosystem evaluation needed to discern causes of chlorophyll* a *increases (San Francisco Bay).*
  - *Eutrophication symptoms, due to increased nitrogen load, include increased phytoplankton and macroalgae, and decline in seagrass (Waquoit Bay).*
  - *Rapid large scale increase in eutrophic symptoms (nuisance/toxic blooms, chlorophyll* a*, and dissolved oxygen) have occurred (Changjiang Estuary, China).*
  - *Threats from eutrophication to large scale aquaculture stimulate nutrient management (Jiaozhou Bay, China).*
  - *Seasonal macroalgae blooms lead to seagrass loss (Mondego River, Portugal).*
  - *Sewage plume mapping tracks nutrient reductions (Moreton Bay, Australia).*
  - *Flood protection measure can accentuate eutrophic symptoms (e.g., dissolved oxygen, macroalgae, and loss of submerged aquatic vegetation) (Venice Lagoon, Italy).*

Chapter 6: Improvements to the methods

- The NEEA aims to improve the methods used to assess eutrophic condition of the nation's estuaries. Some of these improvements are based on recommendations of survey and workshop participants.
- Some improvements currently being addressed (and summarized in the report) are: (1) exploring linkages with EPA's National Coastal Assessment; (2) developing indicators of socioeconomic/human-use impacts; (3) developing a type classification scheme for the nation's estuaries; and (4) improving methods of evaluating eutrophic condition, especially for submerged aquatic vegetation and macroalgae abundance.

Chapter 7: Conclusions and Considerations for Management

- Reducing eutrophic conditions in estuaries requires coordinated and integrated action that balances management action, efficient monitoring to assess the effectiveness of the management, targeted research, and a communication campaign aimed at engaging the broader community. Major recommendations are:
  - *Implement more aggressive management actions to reduce nutrients for improvements in eutrophic condition.*
  - *Capitalize on monitoring technological innovations (e.g., observing systems, remote sensing, web resources) to improve comprehensive assessment of eutrophication status in a coordinated and timely fashion.*
  - *Focus research on improving assessment capability, resolving uncertainty, and establishing criteria/thresholds.*
  - *Engage resource managers, researchers, policy makers, and the community with frequent assessment updates at local, regional, and national levels.*
  - *Develop tools to quantitatively relate the effectiveness of mitigation strategies in response to policy actions.*

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1. INTRODUCTION AND BACKGROUND

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UNDERSTANDING EUTROPHICATION

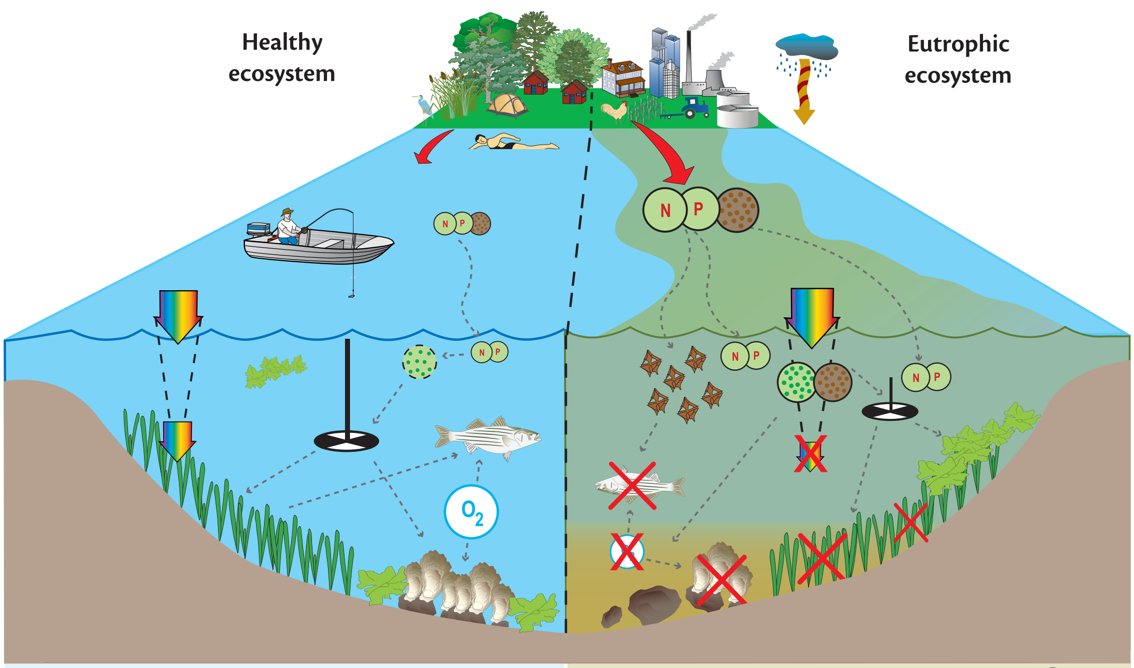
What is eutrophication?

- Eutrophication is a process in which the addition of nutrients (largely nitrogen and phosphorus) to water bodies stimulates algal growth. Excessive nutrient inputs may lead to other more serious problems such as low dissolved oxygen and loss of submerged aquatic vegetation (SAV).
- In recent decades, human activities and population growth have greatly increased nutrient inputs to systems, leading to degraded water quality and impairments of estuarine resources for human use.

Source: Bricker et al., 1999

Nutrient additions to aquatic systems occur naturally due to geological weathering and inputs from ocean upwelling. However, in recent decades, population growth and its related nutrient sources, such as agriculture, wastewater treatment plants, urban runoff, and consumption of fossil fuels (atmospheric deposition), have increased nutrient inputs to many times their natural levels, accelerating eutrophication (Figure 1.1). Nutrient increases can threaten biota, as well as lead to impairment to aesthetics, health, fishing opportunities and success, tourism, and real estate value. For this reason, management efforts should address nutrient inputs to restore and protect coastal resources.

Figure 1.1. Conceptual diagram comparing a healthy system with no or low eutrophic condition to an unhealthy system exhibiting eutrophic symptoms.



In healthy ecosystems, nutrient inputs, specifically nitrogen and phosphorus (N P), occur at a rate that stimulates a level of macroalgal and phytoplankton (chlorophyll *a*) growth in balance with grazer biota. A low level of chlorophyll *a* in the water column helps keep water clarity high, allowing light to penetrate deep enough to reach submerged aquatic vegetation. Low levels of phytoplankton and macroalgae result in dissolved oxygen (O_2) levels most suitable for healthy fish and shellfish so that humans can enjoy the benefits that a coastal environment provides.

In a eutrophic ecosystem, increased sediment and nutrient loads (N P) from farming, urban development, water treatment plants, and industry, in combination with atmospheric nitrogen, help trigger both macroalgae and phytoplankton (chlorophyll *a*) blooms, exceeding the capacity of grazer control. These blooms can result in decreased water clarity, decreased light penetration, decreased dissolved oxygen, loss of submerged aquatic vegetation, nuisance/toxic algal blooms and the contamination or die off of fish and shellfish.

Impacts of eutrophic symptoms

Increased nutrient inputs promote a progression of symptoms beginning with excessive growth of phytoplankton and macroalgae to the point where grazers cannot control growth. These blooms may be problematic, potentially lasting for months at a time and blocking sunlight to light-dependent submerged aquatic vegetation (SAV). In addition to increased growth, changes in naturally occurring ratios of nutrients may also affect which species dominate, potentially leading to nuisance/toxic algal blooms. These blooms may also lead to other more serious symptoms that affect biota, such as low dissolved oxygen and loss of SAV.

Once water column nutrients have been depleted by phytoplankton and macroalgae and these blooms die, the bacteria decomposing the algae then consume oxygen, making it less available to surrounding aerobic aquatic life. Consequently, fish and invertebrate kills may occur due to hypoxia and anoxia, conditions of low to no dissolved oxygen.

In some estuaries, the assimilative capacity, or inherent ability to absorb nutrients, is initially reduced by poor flushing or other factors. These particularly sensitive estuaries may be adversely affected by even slightly increased inputs, impacting such activities as commercial and recreational fishing, boating, swimming, and tourism.

Ben Longstaff, EcoCheck (NOAA/University of Maryland Center for Environmental Science)

A nuisance algal bloom grows rapidly, consuming resources and potentially blocking light to SAV in Chesapeake Bay.

Key terms and phrases

Assimilative capacity—the ability of water bodies to receive wastewater or toxic materials without harmful effects and without damage to aquatic life or humans who consume the water.

Eutrophic symptoms—the signs of poor ecosystem health in water bodies brought on by increased nutrient inputs (see Figure 1.1).

Flushing time—the time it takes for freshwater entering an estuary to pass through to the ocean.

Low dissolved oxygen—low (hypoxic) to no (anoxic) levels of oxygen (vital for aquatic life) in the water.

Nuisance algal blooms—algal growth so rapid or extensive that it influences water clarity, decreases oxygen levels (upon decomposition), clogs filter-feeder siphons, and crowds out other organisms.

Toxic algal blooms—large growths of toxin-producing algae that directly impact the health of organisms and may also contain toxins dangerous to humans.

Source: Estuarine Research Federation (http://erf.org/).

Eutrophic symptoms may also cause risks to human health, resulting from consumption of shellfish contaminated with algal toxins or direct exposure to waterborne toxins.

Other causes of eutrophic symptoms

It should be noted that although nutrients cause eutrophic symptoms, other human and natural influences may affect symptom expression. These influences include engineered water flow, development, dredging, overfishing, and disease. For example, engineered water flow can contribute to eutrophic symptoms by decreasing flushing rates in estuaries. Disease lowers assimilative capacity by decimating wetlands, submerged aquatic vegetation, and filter feeders. In addition to nitrogen and phosphorus, there are other nutrients (e.g., carbon) and trace elements (e.g., silica) that may affect the onset of symptoms, but their role is less understood.

Climate change may also be a significant influence on the development of future eutrophic symptoms. Because warmer water holds less oxygen, global warming may lower dissolved oxygen. Or, flushing times and exchange rates may increase with rising sea levels and increased rainfall. With changing hydrology, there is also a possibility of the exacerbation or novel occurrence of stratification (see page 38, *Eutrophication and Climate Change*).