# State of the Gulf Report:

# Nutrient Indicators

**Prepared for the Gulf of Maine Summit Planning Committee**

**August 2003**

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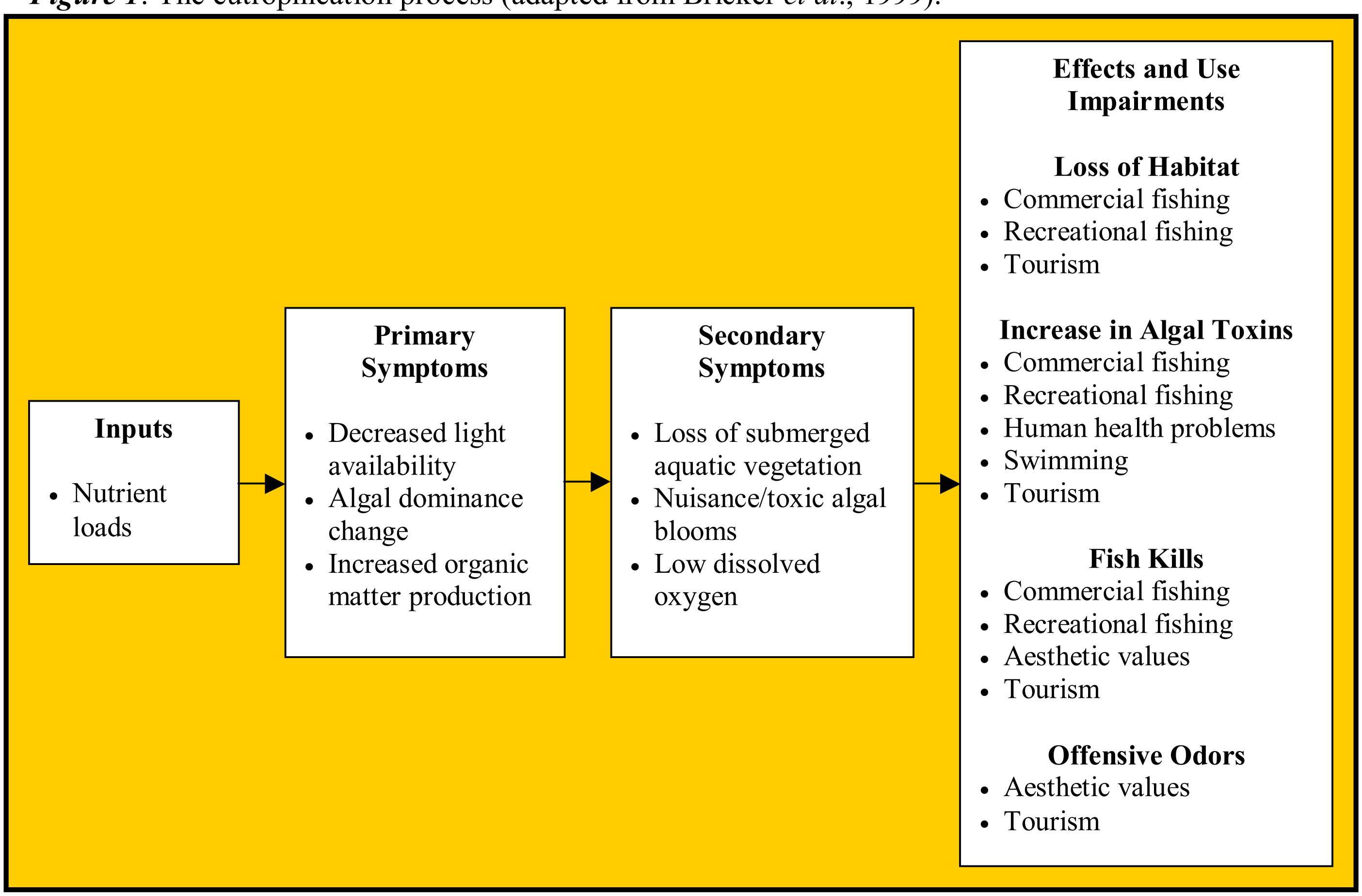
## Purpose of Report

This report provides information on potential nutrient indicators for inclusion in the Gulf of Maine Council's State of the Gulf Report. Through a review of nutrient indicators used in existing reports from organizations within the US and internationally, potential nutrient indicators for the State of the Gulf Report are suggested. General recommendations on identifying and tracking indicators are also provided.

## Background

The Gulf of Maine is considered among the most biologically productive marine systems in the world. Without the large influx of nutrients from offshore, the Gulf of Maine could not support the commercial fisheries important to the economies of the nearby states, provinces, and nations. While nutrients are an important component of a healthy ecosystem, too many nutrients can cause detrimental ecological effects. Eutrophication refers to a process in which algal growth in waterbodies is stimulated by the addition of nutrients, primarily nitrogen in coastal and marine systems (Bricker *et al*., 1999). This algal growth can reduce the amount of sunlight reaching submerged aquatic vegetation (SAV). Decaying algae uses oxygen in the water, causing fish and shellfish kills. These eutrophic symptoms indicate degraded water quality that may negatively impact human uses of the waterbody, including commercial and recreational fishing, swimming, and tourism (Bricker *et al*., 1999).

***Figure 1***: The eutrophication process (adapted from Bricker *et al*., 1999).



eutrophication in the Gulf of Maine has only recently emerged as an environmental concern, due primarily to the desire to take a proactive approach to prevent or minimize eutrophication in the region. The Gulf of Maine is different from other areas of the country that experience eutrophication. Its watersheds are relatively small, waterbodies generally deep, riverine sediment loads are low, and the water column is relatively clear. In addition, despite hundreds of years of population growth, urban areas are serviced by municipal wastewater treatment that reduces the amount of nutrients released into waterbodies. Outside of urban areas, agriculture is generally a minor land use in the coastal zone (Sowles, 2001). These characteristics reduce the susceptibility of the region to eutrophic conditions in comparison to other regions of the country.

Nitrogen is the most important nutrient and the one of greatest concern in the Gulf of Maine coastal and marine waters (Werme, 2001). However, nitrogen is not the only nutrient driving primary production at all locations within the Gulf of Maine. Phosphorus, silica, iron, and other nutrients play key roles in ecological functions and can serve as limiting nutrients in specific waterbodies or during specific times of the year (Sowles, 2001). It is important to note that even when nitrogen is limiting, a problem associated with excess nitrogen loading may not necessarily result. Other physical factors including system dilution and residence time, vertical mixing and stratification, and wave exposure influence whether or not or how a system responds to nitrogen.

In the Gulf of Maine, the largest single source of nitrogen is the ocean itself with approximately 2,250,000 metric ton total inorganic nitrogen flowing into the Gulf from the nutrient-rich deep continental slope. Approximately 130,200 metric tons of total inorganic nitrogen also enters the Gulf from the atmosphere, after being emitted primarily from power generators and other industrial operations (Sowles, 2001). In addition to the nitrogen delivered from offshore and from the atmosphere, nitrogen enters the Gulf of Maine from land-based point and non-point sources. Point sources include industries and wastewater treatment plants. Coastal point sources contribute 25,000 metric tons of nitrogen and finfish aquaculture contributes 2,730 metric tons of total inorganic nitrogen (Sowles, 2001).

## Nutrients as a Priority Issue in the Gulf of Maine

Several efforts highlight nutrient enrichment as a priority issue of concern in the Gulf of Maine.

- On the national scale, the National Research Council (1994), the Environmental Protection Agency (1997), and the National Oceanic and Atmospheric Administration (1998) have all independently identified eutrophication as one of three top key issues in coastal management (Frankic, 1999).

- A 1997 survey by Regional Marine Research Programs identified nutrients and their effects on living marine resources as a top research priority in the Gulf of Maine region (Frankic, 1999).

- A 1999 survey by the Coastal States Organization revealed that nutrient enrichment was the second highest priority coastal management issue in the Northeast states (ME, NY, MA, NH, CT, RI) (Frankic, 1999).

- The 1999 National Eutrophication Assessment concluded that moderate to high levels of eutrophic conditions existed in more than half of the 18 estuary systems examined in the Gulf of Maine. Only one of the estuaries with high levels were due to high human inputs (Boston Harbor) while overall the moderate to high eutrophic conditions resulted from offshore input, and thus considered natural occurrences. However, eutrophic conditions due to human inputs from population growth are projected to worsen in about one-third of the systems by 2020 (Bricker *et al*., 1999).

The prioritization of nutrient enrichment on both national and Gulf-wide scales highlights the importance of identifying and monitoring nutrient indicators for the State of the Gulf Report. Results from the GPAC watershed and coastal forums held within the Gulf of Maine may reveal more localized awareness of and concern about nutrients in waterbodies.

## Review of Nutrient Indicators from Other Programs

Thirty reports and programs worldwide, within the US and Canada, and within the Gulf of Maine region were reviewed, with twenty tracking nutrients indicators. Figure 2 provides a matrix of the most common nutrient indicators, though actual measurements used by the different programs to track the indicators vary. *Appendix A* lists the actual indicators tracked by the programs.

***Figure 2:*** Common Indicators in "State of the Environment" Reports in the Gulf of Maine and Beyond

| | **Indicators** | Nutrient concent-rations | DO levels | Chlorophyll concentrations | Water clarity | SAV distribution /loss | Nuisance/toxic algal blooms |
|---|---|---|---|---|---|---|---|
| **International Reports** | Environment Australia's Environmental Indicators for National State of the Environment Reporting (1998) | | | | | | |
| | New Zealand Ministry for the Environment (1998) | | | | | | |
| | European Environmental Agency (1997) | | | | | | |
| | United Kingdom's Dept. of the Environment, Transport, and the Regions (1997,1999) | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **National Reports** | State of the Nation's Ecosystems (Coasts and Oceans) | | ■ | ■ | | | ■ |
| | NOAA State of the Coast Report (1998) | | ■ | ■ | | | ■ |
| | National Coastal Condition Report (2001) | | ■ | | ■ | | |
| | National Estuarine Eutrophication Report (1999) | | ■ | ■ | | ■ | ■ |
| **Gulf of Maine Region Reports** | Conceptual Framework for the Development of Long-term Monitoring Protocols at Cape Cod National Seashore (1999) | ■ | ■ | ■ | | | |
| | New Hampshire Estuaries Project Environmental Indicator Reports | ■ | ■ | | | ■ | |
| | State of the Boston Harbor Report (2002) | | ■ | ■ | ■ | | |
| | State of the [Casco] Bay Report (2002) | | ■ | | ■ | | |
| | State of the New Meadows River | ■ | ■ | ■ | | | |
| **Non-Gulf of Maine Reports** | FACT (2000) | | | | | ■ | |
| | Georgia Basin-Puget Sound Ecosystem Indicators Report (2002) | ■ | ■ | | | ■ | |
| | Sound Health 2001:Status and Trends in the Health of Long Island Sound | ■ | ■ | ■ | | | |
| | State of the Chesapeake Bay Report | ■ | ■ | ■ | ■ | ■ | |
| | State of the Great Lakes (2001) | ■ | | ■ | | | |
| | Ecological Indicators for Narragansett Bay and its Watersheds (2003) | ■ | ■ | | | | |
| | Framework for an Integrated and Comprehensive Monitoring Plan for Estuaries of the Gulf of Mexico | ■ | | | | | |

The following summarizes the trends in prevalent nutrient indicators from the review of the reports:

- **Dissolved oxygen (DO) levels** – 13 of the 20 total programs (5 of 5 in the Gulf of Maine) report on DO levels as a measurement of nutrient conditions in coastal waters.
- **Nutrient concentrations** – 12 of the 20 programs (3 of 5 in the Gulf of Maine) track nutrient concentrations in the waterbodies.
- **Chlorophyll concentrations** – 11 of the 20 programs (3 of 5 in the Gulf of Maine) monitor chlorophyll concentrations as an indicator of nutrient enrichment.
- **Submerged aquatic vegetation (SAV) distribution** – 6 of the 20 programs (1 of 5 in the Gulf of Maine) report on changes in SAV loss or accretion.
- **Water clarity** – 5 of the 23 programs (2 of 5 in the Gulf of Maine) track some indicator of water clarity as a proxy for nutrient enrichment.
- **Nuisance/toxic algal blooms** – 5 of the 23 program (0 in the Gulf of Maine) report on the frequency or areas of nuisance or toxic algal blooms.

## Suggested Nutrient Indicators for the State of the Gulf Report

Most "State of the…." Reports track environmental indicators that measure the condition of ecological parameters or resources. While these environmental indicators will provide the most direct picture of the state of Gulf of Maine, a more complete picture will include information on the context in which the state is changing, stressors that may be driving the changes, impacts of the changes on human uses, and management responses to the changes. While tracking the commonly-used chemical and biological nutrient indicators is necessary and informative to managers, other indicators on stressors or impacts on human uses may be more enlightening and easily understood by the public. Thus, potential environmental indicators will be suggested below, along with more general information on potential context, stressor, impact, and response indicators for consideration.

### Environmental Indicators

Various parameters of the environmental system can indicate nutrient enrichment. Nutrient concentrations signal the actual amount of nutrients in the waterbody, from all input sources (offshore, atmospheric, land). In addition to measuring the nutrient concentrations, symptoms of euthrophication can be monitored. While high levels of primary symptoms (increased levels of chlorophyll a, decreased water clarity) are strong indicators of the onset of eutrophication, secondary symptoms (depleted DO, loss of SAV) indicate more serious or highly developed eutrophication.

***Nutrient Concentrations –*** Concentrations of inorganic nutrients (ammonium, nitrate, and nitrite) as well as total nitrogen indicate the level of nutrients within the system. This concentration is a combination of offshore, atmospheric, and land-based inputs and is influenced by the characteristics of the individual estuary. In the short term, nutrient concentrations are what the phytoplankton respond to and nutrient uptake by phytoplankton will be mostly converted into organic form. Thus, total nutrient concentration (measure of a nutrient in living form in addition to unused organic and inorganic forms) will likely best reflect short-term phytoplankton growth potential (U.S. EPA, 2001)

***Chlorophyll a*** – Chlorophyll a concentration is the most direct indicator of a change in phytoplankton abundance as a response to nutrients.

***Light attenuation or water clarity*** – Water clarity serves as another measure of phytoplankton growth response to nutrients in that as phytoplankton increase in population, water clarity and light availability decreases. However, this indicator is influenced by suspended sediments and other factors not related to nutrients to a greater degree than chlorophyll measurement. Thus, measuring water clarity in conjunction with chlorophyll (preferably in the same water mass) may be needed to establish nutrient enrichment. Measuring water clarity can done using a variety of techniques which may result in differing units of measurement (Secchi depth, Kd, TSS, NTU) from different sources (Werme, 2001).

***Dissolved oxygen (DO)*** - The level of DO is one of the best and most common indicators of estuarine health. Nitrogen-fueled algal growth can substantially deplete DO levels when algae and plants die, sink, and decay.

***Submerged aquatic vegetation (SAV)*** – Areal extent of SAV provides an important indicator that is sensitive to nutrient conditions. Production of seagrasses is rarely stimulated by nutrient addition. Instead, high nitrogen concentrations can reduce or eliminate growth of estuarine SAV by both water column shading and epiphytic overgrowth. This loss can exacerbate nutrient problems when re-suspension of bottom sediments increases and introduces nutrients to the water column (Werme, 2001).

Algal dominance changes and nuisance/toxic algal blooms are two indicators used in other indicator reports that may not be useful for the Gulf of Maine. While shifts in the dominant phytoplankton species can indicate increased nutrient availability, algal community studies are generally too expensive and time consuming to be used in large-scale or regional studies, except when directed towards a specific nuisance species (Werme, 2001). In addition, while the extent or frequency of algal blooms serves as a visible indicator of nutrient enrichment, blooms are most likely to occur in open waters of the Gulf because of high flushing rates in many estuaries. However, monitoring for the frequency or area algal blooms in the offshore areas of the Gulf may be useful since phytoplankton blooms from offshore can be carried inshore by currents and harmful algal blooms offshore may contribute to fish and mammal mortality. Tracking chlorophyll levels, instead of or in addition to tracking the frequency or extent of algal blooms, in these same areas may provide an earlier indicator as well as being easier to measure through existing Gulf of Maine Ocean Observing System (GoMOOS) buoys and remote imagery sensors.

## Supplemental Indicators

**Context Indicators -** Context indicators such as current and projected human population growth in the region or land development trends provide information about changes in the sources of stressors.

**Stressor Indicators –** Indicators of activities that threaten the environment health, such as nitrogen loads delivered to the Gulf, provide a way of tracking the inputs of nutrients. These loads can potentially be calculated and tracked from not only land-based sources but also atmospheric and offshore contributions. Since managers can mainly influence land-based human inputs, understanding nitrogen loads would be an integral part of measuring outcomes of management actions. However, because increased or decreased loads will not necessarily cause significant changes in the nutrient concentration or the expression of eutrophic symptoms, these indicators should be included as part of a suite of indicators.

**Impact Indicators –** Impact indicators reflect changes in the ability of humans to use or enjoy the environment as a result of changes in condition. For example, fishing and swimming may be deterred by fish kills resulting in harmful algal blooms or low DO. While the level of nutrient enrichment in the Gulf of Maine is at a level not yet impairing human uses, tracking indicators such as number of days beaches are closed due to algal blooms or fish kills may be needed in the future if impairments occur.

**Management Response Indicators -** Management response indicators provide a measure of what is being done to alleviate the sources of stress or to improve environmental conditions. Indicators to track the effectiveness of Best Management Practices (BMPs) in managing nutrients may provide useful information to managers and the public, especially BMPs related to aquaculture operations (finfish, shellfish, and marine plants), lawns and golf courses, stormwater, and sewage treatment.

## Recommendations on Identifying and Tracking Nutrient Indicators

**Articulate measurable goals and objectives**
Ideally indicator development is preceded by the development of measurable goals and objectives. Knowing a target environmental condition or change may help craft a more effective indicator and may clarify the trends as indicators are tracked over time.

The Gulf of Maine Council's Action Plan 2001-2006 identifies a goal and several objectives related to nutrients in the Gulf.

<table>
<tr><th colspan="3">GOAL</th></tr>
<tr><td colspan="3">Contaminants [sewage, nutrients, mercury] in the Gulf of Maine are at sufficiently low levels to ensure human health and ecosystem integrity.</td></tr>
<tr><th colspan="3">OBJECTIVES</th></tr>
<tr><td>Increase awareness and improve management of priority contaminants.</td><td>Identify reduction strategies for priority contaminants</td><td>Enhance citizen stewardship</td></tr>
<tr><th colspan="3">SUB-OBJECTIVES</th></tr>
<tr><td>Increase to 30% the number of people in the region's coastal resource management community that are aware of human and environmental health threats posed by priority contaminants and are working actively to address them.</td><td>Working with local, state, provincial, and federal agencies and stakeholders, strategize ways to reduce priority contaminants.</td><td>The Gulf's 650 coastal and marine stewardship programs will continue serving as local leaders in protecting human health and ecosystem integrity from contaminants.</td></tr>
</table>

These goals and objectives aim to reduce the pressures causing nutrient enrichment and improve the management response to the environmental conditions of the Gulf as affected by nutrient enrichment.

Articulation of measurable goals and objectives related to nutrient conditions or use impairments may help refine the identification of effective indicators. Knowledge of thresholds after which environmental conditions are degraded and uses of the waterbody are impaired by additional nutrients is needed to set realistic and scientifically sound targets.

**Establish criteria for choosing indicators**
In general, establishing criteria for identifying indicators assures that the information collected is most useful and appropriate to the audience. While a variety of criteria have been established, common criteria include the following:

- Meaningful – a concern of and valued by the audience
- Feasible – implementation and collection methods are technically feasible and efficient
- Conceptually sound – indicator relevant to measurable objective or resource of interest
- Sensitive – enable identification of changing conditions but not hypersensitive to natural variability or sampling methodologies
- Data availability – data is available with acceptable quality and timeliness; if data not available, resources and methodologies available to initiate collection in the future

**Identify a suite of indicators**
Many programs and reports reviewed advocate development of a suite of indicators that represent a range of ecosystem functions. A suite of indicators provides several key characteristics to track in communicating the condition of the ecosystem, and can be supplemented with indicators which provide information on the activities affecting the ecosystem, impacts of the changes in the condition of the ecosystem, and management responses to reduce the impacts and improve the condition. This suite of indicators tells a more complete story about the state of the ecosystem and often increases understanding by the public and decision-makers.

**Consider a tiered approach**
Some categorization of identified indicators into a tiered system according to the priority of indicators or data availability may be desired. For example, in the Barataria-Terrebonne Estuary System, indicators were categorized by data availability: (1) supported by datasets produced under current monitoring efforts; (2) supported by planned future monitoring; (3) not supported by current or planned monitoring efforts so a critical indicator gap and need (Battelle, 2003). By using the tiers of categories, the program could start collecting and reporting on indicators with current datasets while working to get monitoring programs in place for future indicator data collection.

**Partner with existing efforts to collect nutrient data in the Gulf of Maine**
While indicators should not be chosen solely according to data availability, understanding what nutrient data is available will allow assessment of compatibility between data sets (i.e. same measurement, same season, etc) for aggregating to a regional level and will also reveal gaps in data. Such data gaps may focus current and future monitoring efforts and better refine research agendas for agencies, nonprofits, and universities.

Several efforts are currently underway to compile nutrient information in the Gulf of Maine. NOAA is in the process of compiling nutrient data from various sources (federal and state agencies, universities, watershed groups, non-profit organizations) in the Gulf of Maine for an update of the National Estuarine Eutrophication Assessment (NEEA) (Bricker *et al.,* 1999). *Appendix B* lists the core variables for which data will be compiled.

The NEAA group is also working to classify estuaries into types based on physical and ecological characteristics to describe their susceptibility to eutrophication. Factors important in characterizing the susceptibility of estuaries to nutrient loading include system dilution and residence time, vertical mixing and stratification, wave exposure, and depth distribution.

EPA is also in the process of establishing a typology of estuarine and coastal waters according to their susceptibility to eutrophication using physical and ecological characteristics. This effort will be coordinating with the NOAA effort. This classification of estuarine and coastal waters will assist EPA in their current effort to establish nutrient criteria for coastal and estuarine waters. Using the resulting classification system, EPA will develop regionally representative nutrient criteria for estuarine and coastal waters for various ecoregions or coastal provinces across the US. These criteria may then be used by states and tribes to establish water quality standards for estuarine and coastal waters within their jurisdictions (U.S. EPA, 2001). EPA's proposed criteria for estuarine and coastal waters are Total Nitrogen, Total Phosphorus, chlorophyll a, and water clarity, with the addition of DO in some systems. As the national criteria are put into place and integrated into state water quality standards, more standardized data will likely become available on the criteria and can inform trends in the health of the Gulf of Maine.

Several monitoring efforts in the Gulf of Maine may provide important data for tracking nutrient indicators. The Canadian Department of Fisheries and Oceans' (DFO) Atlantic Zonal Monitoring Program (AZMP) assesses the distribution and variability of nutrients and plankton through data collected through a network of sampling locations, including the Gulf of Maine. The Gulf of Maine Ocean Observing System (GoMOOS) also has 10 buoys in the Gulf that monitor conditions such as temperature, salinity, currents, color, turbidity, and DO. There are plans to deploy an additional buoy with new technology for remotely monitoring nutrients in the waters between Georges Bank and Brown Bank. In addition, the Northeast Atlantic Indicator Group is in the process of compiling data tracked by the multiple existing monitoring efforts in the Northeast U.S. and identifying indicators for tracking the environmental conditions, including nutrients, in the area.

**Establish baseline information and reference conditions**
To effectively use indicators, it is highly informative to have baseline data against which to compare changes in indicators. Such baseline information may be the initial data collected when measuring begins or past information collected by monitoring programs. It is also useful to have reference conditions against which to compare changes in nutrients and their symptoms. Reference conditions may be set according to information from models of "best possible conditions" given the natural environmental parameters of the areas, from a scientific literature review, or from "reference sites" (preferably local) with the most pristine conditions. It is possible that individual estuaries or parts of estuaries to have a different reference conditions but may be more efficient to determine reference

conditions for similar types of estuaries, especially since the State of the Gulf Report will provide a regional view of nutrient conditions.

## Summary

- In reviewing the nutrient indicators tracked by programs around the world, the prevalent common indicators that are also most applicable to the Gulf of Maine include DO level, nutrient concentrations, chlorophyll levels, SAV distribution, and water clarity. These five indicators should be the starting point of indicator collection and reporting in the Gulf of Maine, though some prioritization of these indicators may need to occur based on data and resource availability.

- The data available for DO, chlorophyll levels, SAV, and water clarity indicators seem fairly abundant for some coastal and estuarine systems, though they are collected by varying and scattered agencies and organizations, recorded on varying time scales, and measured using varying units and methodologies. For the more open water area of the Gulf of Maine, data is likely more scarce and further development of monitoring programs and additional GoMOOS buoys may be necessary in the future to accurately monitor nutrients away from the coast.

- Nutrient concentration data will likely be the most difficult in terms of finding existing data as well as setting up a monitoring program to collect new data, though it is an important indicator to monitor to better understand how the input of nutrients influence eutrophication symptoms.

- Many efforts are underway in the Gulf of Maine to investigate the issue of nutrients and should be tapped into in compiling information for the State of the Gulf Report. The NOAA and EPA classification of estuaries by susceptibility to eutrophication should be considered as a framework for collecting and reporting nutrient indicator information. The database being established for the NOAA NEEA update will be an important source of the current data available on nutrients in the estuaries and coastal waters of Gulf of Maine region. Finally, the effort by the Northeast Atlantic Monitoring Network to improve coordination of monitoring in the Northeast, including the Gulf of Maine, may provide easier access to monitoring data and provide an avenue for proposing data needs as indicators are tracked in the future.

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# Appendix A: List of Indicators for Other Reports and Programs

## International Reports

**Environment Australia's "Environmental Indicators for National State of the Environment Reporting" (1998)**

- Seagrass area
- Algal blooms
- Seagrass species
- Chlorophyll concentrations
- Turbidity
- Water nutrients (nitrogen)

**New Zealand Ministry for the Environment (1998)**

- Chlorophyll a or trophic index
- Algal blooms

**European Environmental Agency (1997)**

- Tons of nitrogen and phosphorus entering the sea (river, dredged material, coastal zone point sources, air)
- Total concentration of phosphorus and nitrogen in water in winter season

**United Kingdom's Department of the Environment, Transport, and the Regions (1997 and 1999)**

- Estuarial water quality
- Concentrations of key pollutants

**United Kingdom's Environment Agency (2001)**

- Estuary water quality
- Loads of major contaminants to coastal waters

**United Kingdom's Kent County Council (2001)**

- Eutrophication
- Treatment of sewage
- Industrial discharges

## National Reports

**The Heinz Center's "The State of the Nation's Ecosystems" (2002)**

- Average value of chlorophyll a for the season with the highest concentration
- Percentage of area with depleted DO
- Harmful algal blooms

**NOAA State-of-the-Coast (1998)**

- DO level
- Extent/frequency of harmful algal blooms

- Level of chlorophyll a

**National Coastal Condition Report (2001)**
- Water clarity
- DO levels
- Eutrophic condition (components from National Estuarine Eutrophication Assessment)

**National Estuarine Eutrophication Assessment (1999)**
- Chlorophyll a
- Macroalgal abundance
- Epiphyte abundance
- Low DO
- Nuisance/toxic algae
- SAV loss

**<u>Gulf of Maine Region Reports</u>**

**Cape Cod National Seashore (1999)**
- Nutrient loading
- Hypoxia/anoxia
- Algal abundance
- Eelgrass decline

**New Hampshire Estuaries Project Environmental Indicator Reports (2003)**
- Eelgrass distribution and restored beds
- Estuarine nutrient concentrations
- DO levels

**State of Boston Harbor (2002)**
- Chlorophyll a levels
- Patterns of DO
- Average DO
- Water clarity

**State of the [Casco] Bay Report (2000)**
- Water quality (water temperature, ph, salinity, dissolved oxygen, and clarity)

**State of the New Meadows River (2001)**
- DO levels
- Chlorophyll a
- Nitrogen concentrations

## Non-Gulf of Maine Region Reports

**Florida Assessment of Coastal Trends (FACT)**
- Acreage of seagrass coverage

**Georgia Basin/Puget Sound (2002)**
- Abundance and distribution of eelgrass beds (affected by nutrients and suspended sediments)
- Marine water quality (components include fecal coliform bacteria, DO, dissolved inorganic nitrogen, ammonium, and stratification)
- Total nitrogen
- Total phosphorus
- Dissolved inorganic nitrogen
- Ammonium

**Sound Health 2001: Status and Trends in the Health of Long Island Sound**
- DO levels
- Biological nutrient removal (remove nitrogen from wastewater)
- Point source nitrogen loads
- Chlorophyll a levels

**Chesapeake Bay Program**
- Nutrient and sediment loads delivered to the Bay
- Nitrogen trends in rivers entering the bay: monitored loads
- Phosphorus trends in rivers entering the Bay: monitored loads
- Municipal wastewater flow and municipal nitrogen discharges
- Municipal wastewater flow and population
- Municipal nitrogen loads and population
- Point source nitrogen loads delivered to the Bay
- Municipal wastewater flow and municipal phosphorus discharges
- Municipal phosphorus delivered loads and population
- Point source phosphorus loads delivered to the Bay
- Chesapeake Basin sewage disposal and septic tanks loads
- Sources of nutrient loads to the Bay
- Chlorophyll a in the mainstream bay and tidal tributaries
- Secchi depth in mainstream bay and tidal tributaries
- Bottom DO concentrations in the mainstream bay and tidal tributaries
- Mainstream bay summer DO concentrations
- Acres of underwater baygrasses

**State of the Great Lakes (2001)**
- Phytoplankton concentrations
- Phosphorus concentrations and loadings

**Ecological Indicators for Narragansett Bay and its Watersheds (2003)**
- DO levels
- Phosphorus concentrations

- DIN concentrations

**Gulf of Mexico Program's "A Framework for an Integrated and Comprehensive Monitoring Plan for the Estuaries of the Gulf of Mexico"**

- Concentration of inorganic nutrients – ammonium, nitrate, nitrite, and phosphate
- Total nitrogen
- Total phosphorus

## Appendix B: Variables of National Estuarine Eutrophication Assessment Update

**Input Variables**

- Nutrient loading
- Freshwater flow

**Physical-chemical Variables**

- Temperature (surface/bottom (profile) in stratified areas)*
- Salinity (surface/bottom (profile) in stratified areas)*
- Dissolved Oxygen (concentration/saturation: surface & bottom water, sample depth, total depth, time of the day, tidal stage)
- Turbidity (Secchi depth, NTU, TSS, $K_D$)
- Nutrients dissolved (inorganic & organic components ($NO_3^-$, $NO_2^-$, $NH_4^+$, $PO_4^{3-}$, Si) total nutrients (TN, TP, Si), N:P:Si ratios),
- Sediment organic content
- CDOM (Colored Dissolved Organic Material)

**Biological Variables (during growing season)**

- Phytoplankton
  Chlorophyll a
  Indicator species (4 – 5 spp)
  Ratio diatoms : flagellates

- Seagrass/SAV
  Spatial coverage
  Ratio spatial coverage : potential coverage

- Macroalgae
  Spatial coverage at maximum growth/maximal coverage
  Dominant/indicator species, relative abundance (*Ulva, Gracilaria*)

- [Epiphytes]
  Epiphyte biomass / area of SAV leaf or surface

* NOTE: These two variable should perhaps be sampled at the same level of distinction that DO is sampled in systems where stratification is known. (Ex.: surface & bottom water, sample depth, total depth, etc.)