EcoSystem Indicator Partnership

Information on change in the Gulf of Maine

Eutrophication Issues in the Gulf of Maine

Understanding a coastal region's eutrophication issues is key to conserving its ecosystem. The Gulf of Maine is biologically diverse, which is partly due to the transport and upwelling of nutrient-rich waters from the Scotian Shelf Northeast Channel. Yet, human activity has supplemented natural nutrient sources by incrementally adding nitrogen and phosphorus to estuaries and coastal waters. Increased nutrient loads from human activities (e.g., sewage effluent, atmospheric deposition, and agricultural and urban runoff) can cause eutrophication, thus stimulating excessive growth of microalgae (phytoplankton) and macroalgae (seaweeds).

High concentrations of phytoplankton can cloud waters and cause seagrasses to die-off, resulting in decreased habitats for other aquatic organisms (i.e., finfish and shellfish). Eventually, phytoplankton cells sink to the ocean floor where they undergo microbial decay. If phytoplankton are too abundant, this process can deplete bottom water oxygen. In shallower estuaries, macroalgae or epiphytes (tiny plants that adhere to leaf surfaces) can also directly smother seagrasses and benthic organisms, leading to die-offs and further oxygen depletion. Low dissolved oxygen (hypoxia) may render areas unsuitable for biological communities and thus impact the ecosystem's overall health.

In addition to the "bottom-up" (i.e., nutrient controlled) responses described above, more complex "top-down" forces (i.e., consumer controlled – such as decreased phytoplankton grazers and the over-harvesting of fisheries) may trigger cascading effects that enhance eutrophic symptoms and further degrade estuaries or coastal ecosystems. Important geophysical factors such as size, depth, tidal exchange, and residence time can modulate estuarine responses to nutrients. While the application of these factors is beyond the scope of this fact sheet, these agents can help explain response patterns to different levels of nutrients.

Cape Enrage, Bay of Fundy, Nova Scotia

Photo: Micheal Sprague

Why use indicators?

Indicators allow us to monitor conditions in the Gulf of Maine and are one of the best tools for understanding and characterizing ecosystem changes in the gulf. Like lights on the dashboard of a car, indicators can work in concert with each other to provide an essential look at the larger system. They can be combined into complex calculations or be relatively simple. ESIP has chosen four indicators to assess eutrophication in the Gulf of Maine:

1. Nitrogen and phosphorus loading
2. Chlorophyll-*a*
3. Water clarity
4. Dissolved oxygen

Focus on the Bay of Fundy

ESIP relies upon datasets that are collected by various organizations throughout the Gulf of Maine region. At the time of the first printing for this fact sheet, there was little information available for use with eutrophication indicators for the Bay of Fundy. ESIP worked with Eastern Charlotte Waterways Inc. to address this critical data gap. A pilot study was conducted to collect information on chlorophyll-*a* and Secchi depths in the New Brunswick portions of the Bay of Fundy in 2013. The study area was expanded in 2015 to include the Nova Scotia portions of the Bay of Fundy. Chlorophyll-*a* was higher in the Nova Scotia portions of the Bay of Fundy (Chignecto, Minas, and Annapolis) and in the Passamaquoddy estuary in New Brunswick relative to other portions of the Gulf of Maine. Secchi depths indicated that water clarity in most station locations in the Bay of Fundy was higher than, or similar to, that of other portions of the Gulf of Maine. All information from the 2013 and 2015 studies is available for analysis in the Indicator Reporting Tool (discussed on the final page of this fact sheet).

Harriman Cove, Penobscot River Estuary, Maine

Photo: Angela Dubois

Nitrogen and Phosphorus Loading

Indicator 1

Nitrogen and phosphorus loading from watersheds is the primary cause of nutrient loading to estuaries that border the Gulf of Maine. Accurately estimating the magnitude of nutrient inputs into waterbodies, however, is a complicated process. The U.S. Geological Survey developed the northeast Spatially Referenced Regressions on Watershed attributes (SPARROW) model to estimate nitrogen and phosphorus loading to estuaries within the Gulf of Maine. The SPARROW model links measured stream transport rates to spatially referenced descriptors of nitrogen sources, land surface, and stream channel characteristics. The model has been verified by a comparison of estimated and observed loading values, and provides an average nutrient loading estimate.

http://water.usgs.gov/nawqa/sparrow/dss/

Based on the SPARROW estimates, nitrogen and phosphorus loadings normalized to estuary area (kg/ha/yr) for each of the estuaries of interest were proportional to the discharge volume of their tributary rivers. Generally, nitrogen and phosphorus loads were lower in the northeast sector of the geographic range and increased with distance to the south (SEE FIGURE 1). As population and land use shifts in the southern Gulf of Maine, it is expected that nitrogen and phosphorus loading will increase. Nutrient loading in the Kennebec River is significantly larger than expected from the overall regional pattern; this is likely due to the relatively small size of the receiving waters in comparison to the large watershed. The relatively low nutrient loading estimated for Boston Harbor – which has one of the largest population centers in the Gulf of Maine watershed – is a result of model estimates excluding Boston's offshore wastewater discharge as it is beyond the identified estuary area.

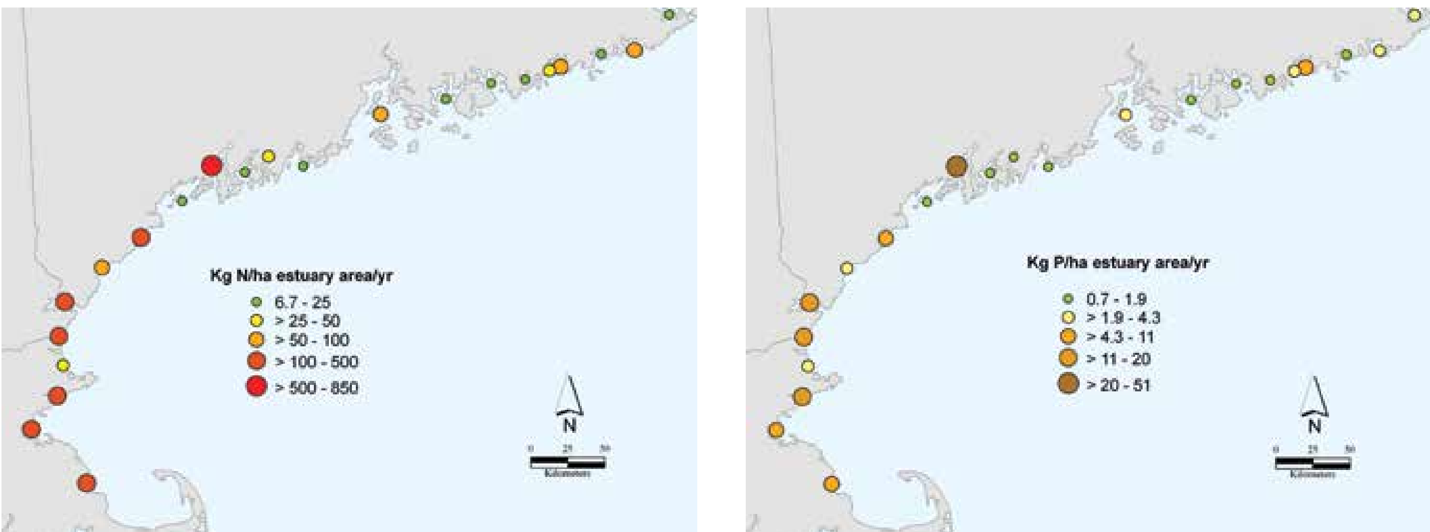

FIGURE 1
Nitrogen and Phosphorus loading (Kg N/ha/year) or (Kg P/ha/year) to estuaries of interest.

Coastal Maine

Photo: Hayley Knouff

***Zostera marina* with epiphytes**

Photo: Fred Short

*Chlorophyll-*a

Indicator 2

Phytoplankton blooms are often the first sign that excessive nutrients are being added to the water column. Chlorophyll-*a* (chl-*a*) is contained within phytoplankton cells and used as a surrogate for phytoplankton biomass. Chl-*a* is one of the most commonly measured indicators used to assess the response of the aquatic environment to excess nitrogen and phosphorus. There are many different algae that make up the phytoplankton community, most of which are good for the marine environment when in proper balance. However, surplus nutrients can disrupt this balance and cause increases in harmful populations.

Chl-*a* data collected by estuarine monitoring programs from 2000–2011 were used to assess the relative magnitude of phytoplankton biomass; specific monitoring programs are listed with the associated data in ESIP's Indicator Reporting Tool (see back page). Data were analyzed for the period from June to September, representing the summer growing season in the northern latitudes – the period when it's most likely that the effects of excess nutrients would be observed. As sampling protocols may differ among programs (i.e., depths, locations, and times), data averages were used to summarize spatial trends for chl-*a* to minimize the biasing effect of infrequent, unusual values (see text box for explanation). Chl-*a* values ranged from 1.2 to 4.4 ug/L (see figure 2) and all estuaries had average growing season values of less than 5 ug/L. The U.S. Environmental Protection Agency (EPA) and the U.S. National Oceanic and Atmospheric Administration (NOAA) consider these averages to indicate "good" water quality. Three Massachusetts sites were observed to have the highest average chl-*a* concentrations, but they were still considered to be relatively good. While these statistics represent average conditions, elevated chl-*a* concentrations have been observed on occasion during peak phytoplankton blooms.

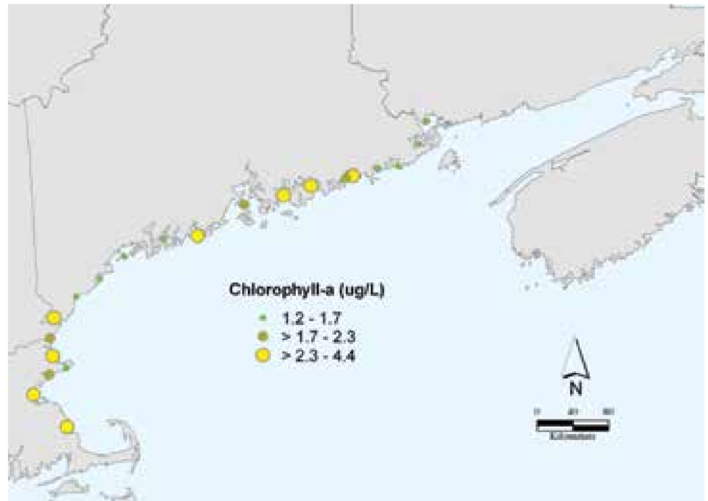

FIGURE 2
Chlorophyll-*a* concentrations (ug/L) in the estuaries of the Gulf of Maine. Circle size represents the average value during the growing season (June to Sept) for all depths and stations for each estuary from 2000–2011. It is important to note that some locations were sampled many times (Boston Harbor = 2,000 samples) and other locations were sampled very few times (Plymouth Harbor = 6 samples).

*Why use average values for chl-*a *analysis?*

When analyzing chl-*a* datasets, NOAA and EPA calculate the 90th percentile values for samples. The datasets used for this fact sheet were derived from many monitoring programs that sampled various depths and locations within the estuaries. It was decided that the best summary statistic for comparing estuary conditions is the average value for any station, depth, and date. By using the average values for all the depths (during growing season from June to September), we capture as much variation in water conditions as possible.

Water Clarity

Indicator 3

Another indicator of eutrophication is water clarity, which is negatively affected by phytoplankton blooms. "Secchi depth" is the depth of water at which a Secchi disk lowered into the water is no longer visible. Due to the simplicity of this method, the Secchi disk is used by many volunteer coastal monitoring programs and other groups. Although water clarity is affected by several factors, both phytoplankton and suspended sediments contribute to reductions in water clarity. As Secchi depth decreases, the depth to which sunlight penetrates the water decreases. This causes stress to aquatic communities as it impairs the growth of seagrasses that require sunlight for growth and reproduction.

Secchi depth data are collected by various organizations within 21 of the estuaries of interest in the Gulf of Maine. Like the chl-*a* samples, only Secchi data collected between June and September from 2000 to 2011 were used. Values for average Secchi depth ranged from shallow depths of 1.5 meters (Great Bay, NH) to greater than 4 meters in clear water (Saco Bay, ME). The majority of sampled embayments had Secchi depths of 2 meters or greater. Low average Secchi depth values (< 2 m) were recorded at four locations: Great Bay and Hampton Bay, NH; Machias Bay, ME; and Plymouth Harbor / Duxbury Bay, MA (see figure 3).

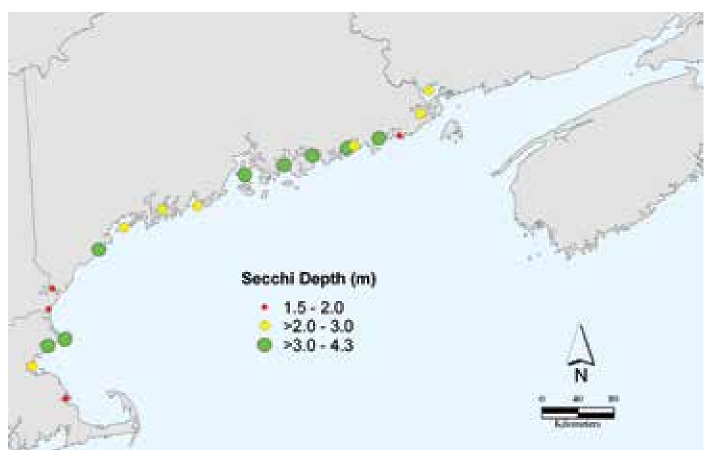

FIGURE 3
Average Secchi depths in meters. Circle sizes represent the average for embayments from 2000–2011. Two sites (Damariscotta River and Kennebec River, Maine) are not included, as the Secchi disk hit bottom and created an artificial limit during the growing season (June to Sept). It is important to note that some locations were sampled many times (Casco Bay = 2000 samples) and other locations were sampled very few times (Machias Bay = 3 samples).

Dissolved Oxygen

Indicator 4

Low dissolved oxygen (DO) is a well-established indicator of eutrophication. Microbial decay of organic matter in the water column and the associated sediments consume oxygen and contribute substantially to community respiration under highly enriched conditions. As a result, inadequate supplies of DO are left for fish and benthic communities, causing stress and die-offs. DO fluctuates daily and seasonally. The variations are caused by water temperature (the solubility of oxygen decreases with increasing temperature), respiration (which uses oxygen), and algal photosynthesis (which generates oxygen during the day). These daily and seasonal changes can be captured by *in-situ* instrumentation that measures DO continuously for set time intervals.

The DO water quality standards in marine waters vary among states and provinces. In the Gulf of Maine, most jurisdictions require that DO be no less than 5 to 6 milligrams per liter (mg/L). The term "hypoxia" is used when DO concentrations fall to levels that cause immediate stress to fish and other aquatic life. Regionally, hypoxia is considered to exist when DO drops below 3 mg/L, although some research suggests serious adverse effects to sensitive organisms may occur at DO levels between 3 and 5 mg/L. For our purposes, a low DO event was defined as a two-hour period during which DO fell below 4 mg/L.

DO is measured commonly across the Gulf of Maine estuaries, but long-term, high-resolution data sonde measurements of DO are mostly limited to the National Estuarine Research Reserves in the southern coast of Maine and New Hampshire (SEE FIGURE 4). In general, low DO events do not occur in the open ocean, large embayment areas, or areas that are well flushed by tidal exchange. DO results were calculated from June to September, 2000 to 2008. Hypoxia was detected at six sites in Great Bay, NH, and Wells, ME, but only for short time periods. Two Wells sites and two Great Bay sites experienced severe, but brief hypoxia events (< 2 mg/L).

Oceanic Buoy

Photo: Neal Pettigrew

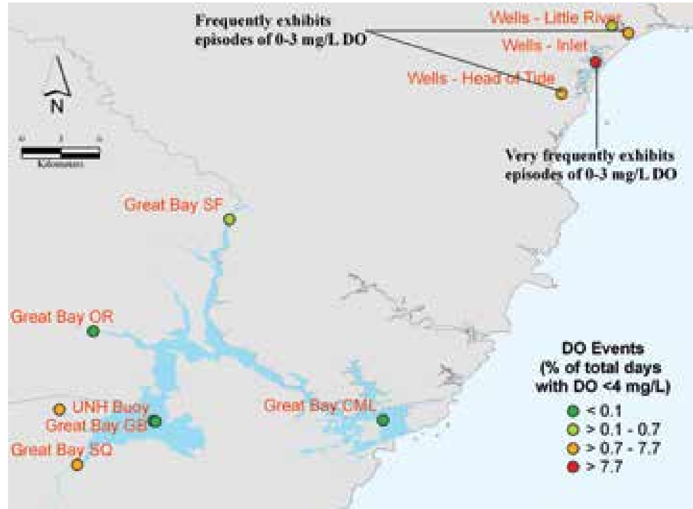

FIGURE 4
Dissolved oxygen events (greater than two hours < 4 mg/L) for the continuous dissolved oxygen sondes in the Gulf of Maine from spring to fall. Findings reflect the percentage of dates with data available that involve dissolved oxygen events (number of days during which one or more two-hour events occurred divided by the number of days sampled). Two other sites in the open ocean were analyzed but had no low DO events (Bowdoin Buoy and NERACOOS A). See the Indicator Reporting Tool for more information.

Obtaining Data

Indicator Reporting Tool

All data used for the four indicators discussed in this fact sheet are available through ESIP's Indicator Reporting Tool. The tool (available at www2.gulfofmaine.org/esip/reporting) uses familiar mapping platforms to enable users to locate eutrophication data in the region. The tool produces snapshots of data that can provide critical information.

Questions such as those below can be answered using the tool:

1. Has nitrogen loading been estimated for the estuary I live on?
2. Did water clarity change during the last dry season?
3. Is there a monitoring group close to home that I can join?

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Gulf of Maine Council on the Marine Environment

www2.gulfofmaine.org/esip

In 2006, the Gulf of Maine Council on the Marine Environment created the EcoSystem Indicator Partnership (ESIP) to assess the ecological integrity of the Gulf of Maine through the use of indicators. This fact sheet is one outcome supporting this goal. Funding, in part, was provided by the Department of the Interior (DOI), Environment Canada (EC), and the US Environmental Protection Agency (EPA). For more information on any of the ESIP products, please visit our website at www2.gulfofmaine.org/esip.

You may also contact the ESIP Program Manager at ESIPmail@gulfofmaine.org. We always welcome new members to our work.

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