EUTROPHICATION

STATE OF THE GULF OF MAINE REPORT

Gulf of Maine Council on the Marine Environment

June 2012

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The Gulf of Maine Council on the Marine Environment was established in 1989 by the Governments of Nova Scotia, New Brunswick, Maine, New Hampshire and Massachusetts to foster cooperative actions within the Gulf watershed. Its mission is to maintain and enhance environmental quality in the Gulf of Maine to allow for sustainable resource use by existing and future generations.

The *State of the Gulf of Maine Report*, of which this document is a part, is available at www.gulfofmaine.org/stateofthegulf.

Cover photo: Eelgrass is one of the species harmed by clouded water and other changes associated with eutrophication. © Peter H. Taylor/Waterview Consulting

Cover map (background): Courtesy of Census of Marine Life/Gulf of Maine Area Program

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1. Issue in Brief

Cultural eutrophication is an ecosystem response to increases in nutrient (primarily nitrogen and phosphorus) inputs from human sources. Estuaries, bays and nearshore coastal waters in the Gulf of Maine receive nutrient inputs from land-based sources via rivers and streams, directly from human activities adjacent to and within marine environments, atmospheric deposition, and oceanic upwelling and circulation. These inputs result in predictable consequences once they enter the waterbody (Cloern 2001; Bricker et al. 2007, Figure 2). First, nutrient loading to the water column increases, which then stimulates growth and production of both phytoplankton and larger algal species such as floating mats of macroalgae, such as *Ulva* or sea lettuce. Although a certain amount of phytoplankton and macroalgae are needed to support upper trophic levels (i.e., fish), excessive algal growth can lead to other more serious water quality consequences. For example, high concentrations of phytoplankton may cloud the water and cause die-off of seagrasses (submerged aquatic vegetation), which are considered important habitat for juvenile fish. Macroalgal growth can smother seagrasses and bottom-dwelling organisms such as clams, leading to die-offs of both. In addition, episodes of low bottom water dissolved oxygen (i.e., hypoxia or anoxia) may occur if algae sink to the bottom and deplete oxygen levels during decomposition. The phytoplankton community may also shift to favor more toxic and nuisance species, or harmful algal blooms (red tides) that may also result in public health concerns. The eutrophication process, however, is more complex than portrayed here. Estuaries are part of larger systems and the development of eutrophic symptoms is influenced by both "bottom-up" (e.g., nutrient inputs) and "top-down" (e.g., phytoplankton grazers such as shellfish) effects. It is important to stress that eutrophication has potential negative impacts on our coastal habitat and recreational values that are so important to the Gulf of Maine communities.

This theme paper describes how population increases and development have altered the hydrological and biogeochemical cycles in our watersheds, resulting in more potential export of carbon, nitrogen, and phosphorus to the Gulf of Maine's estuaries and coastal waters. Urbanization has led to channelization and damming of rivers and other waterbodies, water withdrawals, loss of vegetation in riparian areas, more impervious surfaces, less infiltration of water into the ground. Because of these multifarious effects of development on water quality, reducing nutrient pollution requires action by all levels of the government and the public (Figure 1).

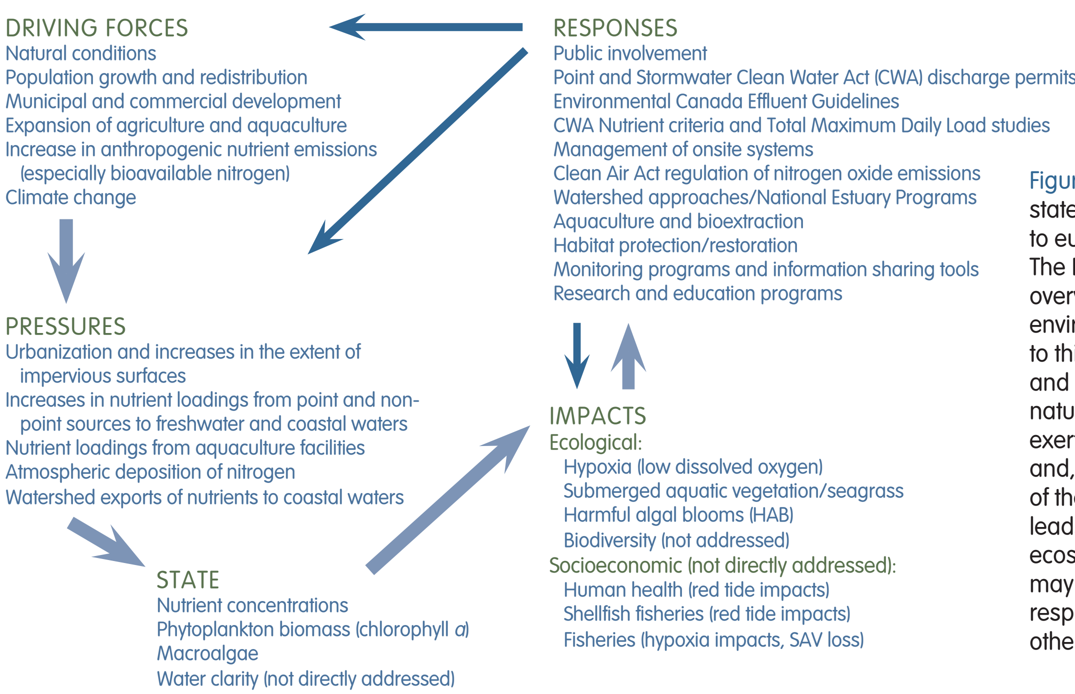


Figure 1: Driving forces, pressures, state, impacts and responses (DPSIR) to eutrophication in the Gulf of Maine. The DPSIR framework provides an overview of the relation between the environment and humans. According to this reporting framework, social and economic developments and natural conditions (driving forces) exert pressures on the environment and, as a consequence, the state of the environment changes. This leads to impacts on human health, ecosystems and materials, which may elicit a societal or government response that feeds back on all the other elements.

2. Driving Forces and Pressures

LINKAGES

This theme paper also links to the following theme papers:

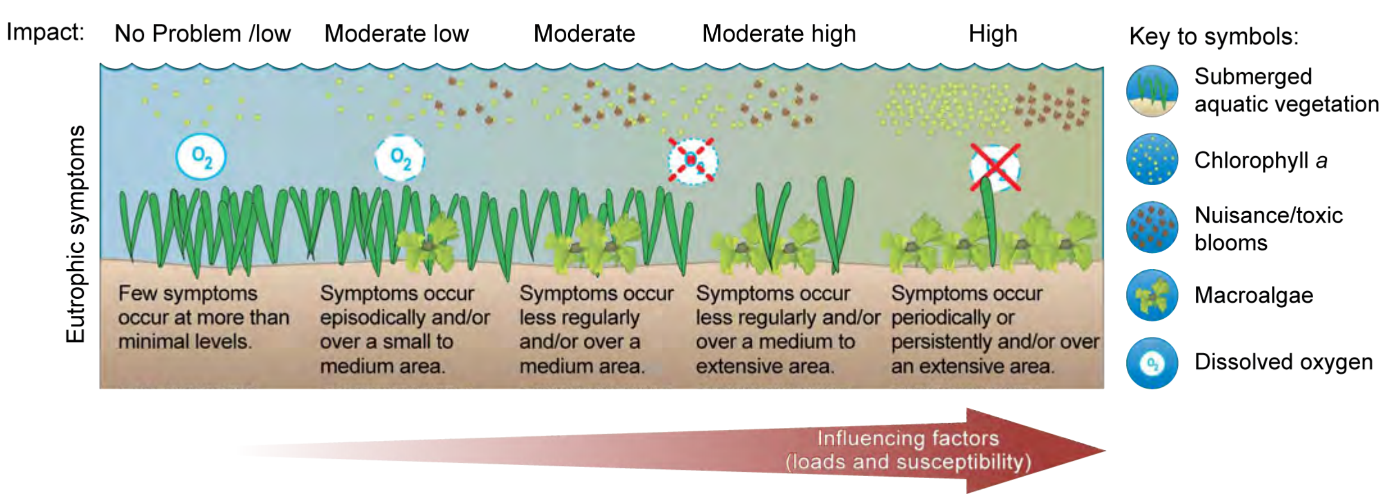
- Microbial Pathogens and Biotoxins
- Toxic Contaminants
- Coastal Ecosystems and Habitats
- Watershed Status

The primary driving forces that affect nutrient loading and the potential for eutrophication in the Gulf of Maine include natural conditions, human population demographics and migrations, land use change and coastal development, market forces that affect resource-based industries (such as agriculture, forestry, and aquaculture), and climate change. Pressures that result from these driving forces include: urbanization and increases in the extent of impervious surfaces; increases in nutrient loading from point sources and non-point (or diffuse) sources to freshwater and coastal waters. Climate change overlays all these pressures. The factors associated with climate change that are expected to have the greatest impact on coastal eutrophication are: 1) increased sea surface temperatures which may increase water column stratification, and rates of algal growth; 2) changes in precipitation and freshwater runoff which will alter hydrologic cycles and change the timing and delivery rates of nutrients; and 3) sea level rise which will alter inundation and coastal water circulation. In addition, changes in the balance of primary production and decomposition may also decrease the pH of coastal waters – with detrimental impacts to shellfish fisheries – already becoming more acidic due to the continued global increase in absorption of the greenhouse gas, carbon dioxide (CO_2). (See also *Climate Change and its Effects on Humans* and *Climate Change and its Effects on Ecosystems, Habitats and Biota*.)

2.1 NATURAL CONDITIONS

The natural conditions of the Gulf of Maine influence the sensitivity of coastal waters to nutrient enrichment. Proximity to land-based nutrient sources (e.g., coastal bays and estuaries versus the open waters of the Gulf of Maine) and the

Figure 2: Conceptual diagram of the predictable consequences of increased nutrient discharges (low on left to higher on right) into coastal waterbodies. The response to nutrient loads within the waterbody is conditioned/modulated by the physical characteristics of the estuary such as the tidal exchange and the residence time (from Bricker et al. 2007).



physical characteristics of the waterbody determine the likelihood of a eutrophic response. Coastal bays, estuaries and tidal rivers with a longer residence time (and more restricted exchange of water with the ocean) are expected to be more sensitive to land-based nutrient inputs (Kelly 1997; Cloern 2001; Bricker et al. 2007; Glibert et al. 2008). This is particularly important with regard to harmful algal blooms, since they have slower growth rates and are less likely to occur if water residence time is short (Ferreira et al. 2005).

Circulation patterns in the Gulf of Maine have been described in *The Gulf of Maine in Context*. Three attributes of the Gulf's physical and chemical oceanography are worth highlighting here because of their importance in stimulating biological production. First, the Gulf of Maine is biologically productive due to the upwelling of nutrient-rich, deep continental slope water from the Northeast Channel and inputs from the Scotian Shelf (Townsend 1998). This is the primary source of nutrients to Gulf of Maine waters and contributes over 90% of the inventory of nitrogen in the Gulf of Maine. Upwelled waters mix with Scotian Shelf waters and with runoff from Maine and New Brunswick to form the Maine Coastal Current, which is important in transporting harmful algal blooms. Second, the Maine Coastal Current is supplemented with nutrient-rich freshwater sources (the largest of which are the St. John, Penobscot, Kennebec, and Merrimack rivers), which creates a "freshwater plume" along the coast and influences productivity of important coastal habitats such as salt marshes and seagrass habitats. Fortunately, the third attribute, a large tidal range in the Gulf, reduces sensitivity of estuarine and coastal waters to nutrient enrichment. These conditions combine to make the Gulf of Maine and Georges Bank one of the most productive coastal seas in the world.

2.2 HUMAN POPULATION DEMOGRAPHICS AND MIGRATIONS

Cultural (human-induced) eutrophication has been shown to be a problem in many coastal areas due primarily to the high density of population along the shoreline (Bricker et al. 2007).Though the overall population of the Gulf of Maine region continues to grow (static in Canada; growth in the US), the major demographic trends are migration from rural to metropolitan centers along the coast and a sprawl-like expansion of these metropolitan areas (Collins 2004; see *The Gulf of Maine in Context*). Urbanization in the coastal zone has also expanded because the coast attracts retirement and seasonal residences, especially in the United States. This increase in coastal development has shortened and altered the time-of-travel and flow pathways for nutrients from their sources to coastal waters in several ways. First, nutrients that may have once entered groundwater from septic systems scattered across the landscape are increasingly being routed through municipal facilities, processed, and released as point source effluents directly to rivers or estuaries. Second, formerly rural coastal communities (e.g., on Cape Cod, Massachusetts) served primarily by septic systems increase the demand for better treatment of nitrogen and phosphorus with municipal or decentralized wastewater treatment facilities. And finally, the application of fertilizers for residential lawn care and recreational facilities, such as golf courses, further adds to the potential for nutrients to enter watercourses. In sum, nutrients within metropolitan centers have more direct pathways to streams and rivers due to the extent of impervious surfaces and loss of vegetation; water and nutrient movement is mainly overland rather than downward into the soil profile.

2.3 ANTHROPOGENIC NUTRIENT INPUTS

Nitrogen and phosphorus are natural elements of the biosphere and necessary for plant growth, but elevated levels are harmful. As opposed to freshwater systems, nitrogen tends to be the limiting nutrient[1] controlling algal production in estuarine and marine waters (Paerl 2008). This means that nitrogen tends to be the nutrient of concern that can have the most impact on marine waters and thus, this report focuses more on controlling nitrogen rather than phosphorus loadings to coastal waters in the Gulf of Maine.

Through human population growth, industrialization, and agricultural expansion (resulting in increased use of fertilizers), excessive amounts of these nutrients are entering freshwater and marine ecosystems (Galloway et al. 1995; Vitousek et al. 1997; Howarth 1998). Globally, reactive (i.e., bioavailable) nitrogen has increased dramatically over the last 100 years due to the combined effects of fossil fuel combustion, industrial production of ammonia for fertilizer, and agricultural cultivation of nitrogen-fixing plants, such as legumes (Galloway et al. 2008). Since 1970, it is estimated that reactive nitrogen creation has more than doubled. There is increased recognition that nitrogen has cascading effects in the ecosystem, moving from system to system (e.g., air to coastal waters) and linking with other processes (e.g., energy production is linked to eutrophication) (Galloway et al. 2003). In addition to causing cultural eutrophication, reactive nitrogen contributes to: acidification and loss of biodiversity in freshwater lakes and rivers (acid rain); loss of productivity in forests; formation of ground level ozone; and is a potent greenhouse gas.

Across the Gulf of Maine watershed, mean annual inputs of nitrogen and phosphorus from rivers vary widely, mainly according to the size of the basin, population density, and agricultural extent (Table 1; Moore et al. 2011; Roman et al. 2000; Castro et al. 2003). The most important sources of anthropogenic nutrient inputs to coastal waters are wastewaters, fertilizers and, for nitrogen only, atmospheric deposition (Whitall et al. 2007). Estimates from the Northeast SPARROW model and unpublished data show that the greatest sources of nitrogen are via atmospheric deposition and developed lands (which includes urban runoff and onsite septic system sources), followed by agricultural sources and municipal wastewater (see Table 1 for sources). Consistent with the population density

[1] A limiting nutrient is one which is essential for cell growth, but is in short supply relative to other nutrients and which would therefore limit continued population growth.

Table 1: Watershed-based sources of nitrogen and phosphorus from select Gulf of Maine river basins. Estimates derived from Moore et al. (2011) and G.A. Benoy (Environment Canada, unpublished data).

RIVER BASIN	DRAINAGE AREA (km^2)	TOTAL NITROGEN (metric tons)	PREDICTED PERCENT OF NITROGEN LOAD FROM			
			Atmospheric Deposition	Agricultural Sources	Developed Lands	Municipal Wastewater
Charles	749	539	15	7	64	15
Merrimack	12950	8229	25	8	29	38
Piscataqua	2574	1084	29	13	41	17
Saco	4389	1208	50	11	32	7
Androscoggin	9129	2511	52	9	24	15
Kennebec	15348	4218	55	14	23	8
Penobscot	21908	4912	66	12	18	4
Saint John	55100	16020[a]	-	-	-	-

[a] Estimated sum of agricultural land, forested land, food processing plants and pulp and paper mills, and rural and urban inhabitants (G.A. Benoy, Environment Canada, unpublished data).

RIVER BASIN	DRAINAGE AREA (km^2)	TOTAL PHOSPHORUS (metric tons)	PREDICTED PERCENT OF PHOSPHORUS LOAD FROM			
			Forested Lands	Agricultural Sources	Developed Lands	Municipal Wastewater
Charles	749	26	5	6	47	42
Merrimack	12950	524	14	5	21	60
Piscataqua	2574	71	15	9	42	33
Saco	4389	70	43	15	27	15
Androscoggin	9129	138	37	15	18	30
Kennebec	15348	245	34	20	18	28
Penobscot	21908	270	48	29	16	7
Saint John	55100	2242	34	24	16[b]	26

[b] Not estimated, assumed to be equivalent to neighboring watersheds in Maine.

gradient in the Gulf of Maine region, the contribution of nitrogen from urban areas (e.g., from wastewater treatment facilities and urban runoff) is about 75% in the most southern watersheds of the Gulf of Maine (e.g., Charles and Merrimack river basins) with upland forests (represented by the atmospheric contribution) contributing as little as 15%. Similar variation in source contributions is observed for phosphorus. In comparison with nitrogen, relatively greater contributions of phosphorus are derived from agricultural sources and municipal wastewater and relatively less from forested lands.

Non-point sources of nitrogen and phosphorus to estuaries and coastal waters include waste discharges from septic systems through groundwater and surface runoff from agriculture and, in urbanized areas, from the land. Where permeable soils are common and in high density coastal developments (e.g., Cape Cod, Massachusetts) groundwater inputs of nitrogen from septic systems directly to estuaries and coastal waters may be at least as important as surface runoff (Valiela et al. 1990). In more northern basins, more people are dependent on septic systems. Mixed-use farms, livestock operations, and manure applications occur throughout the watershed but are most concentrated in Massachusetts, coastal regions of New Hampshire and Maine, and major river valleys in New Brunswick (Kennebecasis) and Nova Scotia (Annapolis). In the largest basin of the Gulf of Maine watershed, the Saint John River basin, potato is the dominant cash crop and production regions in northeastern Maine and northwestern New Brunswick have expanded through fertilizer applications and inclusion of nitrogen-fixing legumes in crop rotations.

Another important diffuse source of nitrogen to estuarine and coastal systems is atmospheric deposition (Paerl 1997). Phosphorus deposition via this pathway is considered negligible. Nitrogen emissions from agricultural operations, fossil-fuel combustion, and electrical utilities are responsible for a major portion of the increase in nitrogen availability globally. Once airborne, nitrogen can be deposited in a watershed, and in urban areas be discharged to rivers and streams as stormwater, or directly on marine waters.

Within some estuaries the primary local anthropogenic source of nutrients may be finfish aquaculture (see *Aquaculture in the Gulf of Maine*). By one estimate, finfish farms that add fish food lose approximately 60% of nitrogen to the environment as metabolic wastes, feces, and uneaten food fragments (Strain and Hargrave 2005), though such loss rates and their risk to ecological systems must be interpreted in the context of prevailing nutrient regimes (Sowles and Churchill 2004). The potential for aquaculture to enrich marine ecosystems with nutrients and contribute to eutrophication partly depends on whether farming operations are located in nitrogen-limited waters, a likelihood that is greater towards the southern end of the Gulf of Maine.

In sum, urbanization and coastal development has increased significantly the anthropogenic contribution of nutrients delivered to our coastal waters; by some estimates up to ten times the natural background levels in the Northeast United States (Howarth 2008).

2.4 CLIMATE CHANGE

For estuaries and coastal waters of the Gulf of Maine, there are a multitude of ways by which climate change may affect nutrient delivery and loading (see *Climate Change and its Effects on Ecosystems, Habitats, and Biota*). In the marine environment, warmer atmospheric and oceanic temperatures may increase sensitivity of coastal waters to nutrient enrichment. Specifically, warmer waters may increase algal productivity—leading to expanded ranges or growing seasons of some undesirable species. Warmer waters might also increase stratification, and since warmer waters also hold less dissolved oxygen, the potential for hypoxic events might increase. Climate change impacts on the distribution of rainfall and snowfall and the intensity of storm events may alter hydrologic cycles and the timing and delivery rates of nutrients to the Gulf of Maine from rivers. Indirectly, alteration of global circulation patterns may actually decrease delivery rates of nutrients from offshore upwelling sources (Townsend et al. 2010). On land, warmer temperatures may affect the phenology (the timing and seasonality of life cycle events) of floral and faunal communities, potentially altering biogeochemical cycling of nutrients. Similarly, changes in mean annual temperatures may affect river freeze-up in the fall and the timing of spring melt and ice break-up in the spring.

Sea level rise may gradually inundate coastal lands, causing increased erosion and sediment delivery to waterbodies, and potentially flooding wetlands. The increased sediment load and subsequent turbidity increase may cause submerged aquatic vegetation loss. The positive feedback between increased erosion and algal growth (as erosion increases, sediment associated nutrients also increase, stimulating growth) may also increase turbidity. The loss of wetlands, which act as nutrient sinks, will further increase nutrient delivery to estuaries.

Some recent research internationally and in Casco Bay shows that eutrophication increases the susceptibility of coastal waters to ocean acidification impacts (Green et al. 2009). The decomposition of organic material from algal mats in estuarine and coastal waters has already enhanced the acid content of coastal subsurface waters. With the expected increases of atmospheric carbon dioxide, further increases in acidification of coastal waters are predicted. This acidification is likely to impact shell formation in shellfish (such as clams) with concomitant losses in commercial shellfish yields.

3. Status and Trends

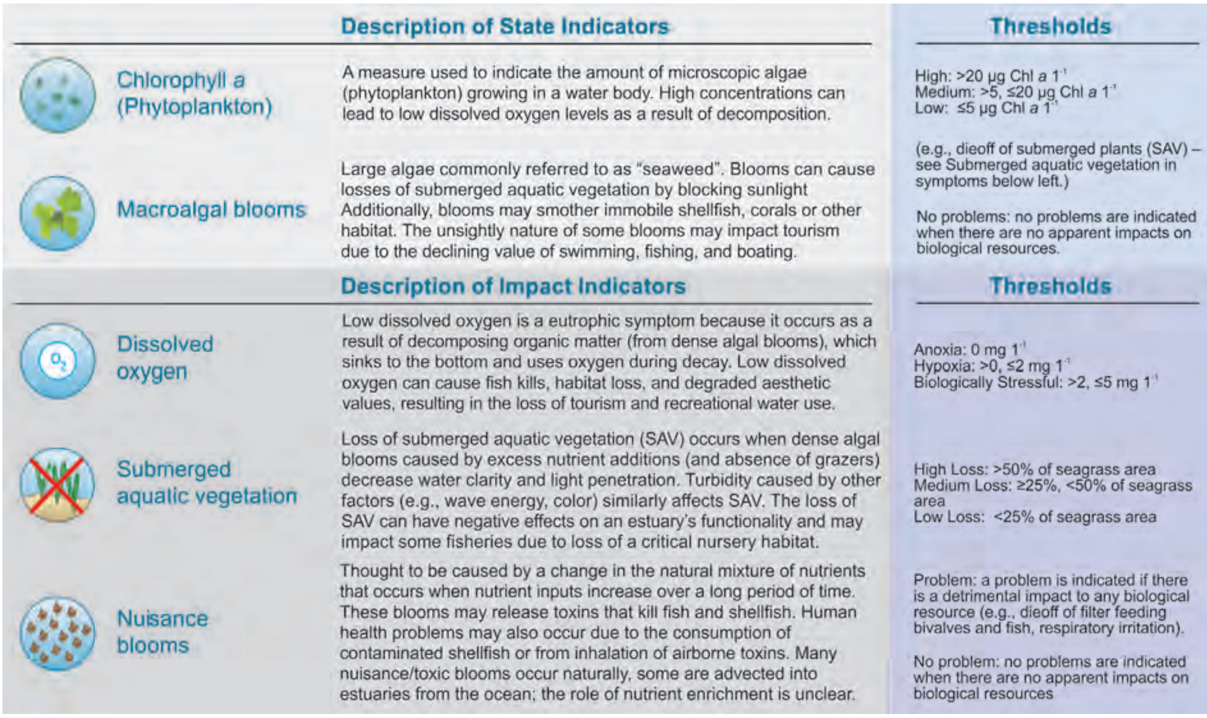
The state or status of eutrophication is represented by specific measurements of water quality indicators – the level of nutrients in the water and the biological (phytoplankton and macroalgal biomass) and chemical (dissolved oxygen) changes that occur as a result of those nutrient inputs. Because of the interactions among these indicators in an ecosystem, scientists use multiple indicators to get a picture of the nutrient related status or condition of a waterbody.

There is no one comprehensive dataset that specifically evaluates conditions within the Gulf of Maine as a whole. Most data that are available are for estuaries along the border of the Gulf rather than the open waters. These include studies on individual bays and estuaries in the Gulf of Maine (e.g., Great Bay, Casco Bay, and Bedford Basin) and ongoing monitoring by, for example, the Massachusetts Water Resources Authority in Massachusetts Bay (MWRA 2010).

The status summaries detailed here are drawn primarily from two comprehensive regional assessments of eutrophication in the Gulf of Maine. The first is the United States Environmental Protection Agency (EPA) National Coastal Assessment (NCA) (EPA 2008), which took samples once per year in the summertime from 2000 to 2006 and reported results on a per-area basis, not by individual waterbody. This monitoring program was supplemented with additional sampling (from 1997 to 2003) to better evaluate conditions in National Estuary Program waterbodies (Casco Bay, Great Bay, and Massachusetts Bay and Cape Cod Bay; EPA 2006). Measured values are compared to regionally based thresholds (Figure 3 and Table 2). The second assessment is the National Oceanic and Atmospheric Administration (NOAA) National Estuarine Eutrophication Assessment (NEEA), which used data from local, state, federal and academic studies for nineteen individual waterbodies from Maine to Massachusetts and then summarized results for the region (see Figure 5 for list of estuaries; Bricker et al. 2007; Bricker et al. 2006). Although Canada has no comprehensive eutrophication assessments in place, information on indicators which assess the state of eutrophication is gathered through programs, such as Fisheries and Oceans Canada's Atlantic Zone Monitoring Program (AZMP).

The ratings displayed here represent an evaluation of the concentration, spatial coverage, and frequency of occurrence of indicator data compared to thresholds of impacts. These thresholds are determined from national studies, and based on the judgment of scientists from across the United States who are considered to be experts on the effects of nutrients in coastal waters. Results represent conditions in the early 2000s with comparison to results from Bricker et al. (1999), representing conditions in the early 1990s.

Figure 3: Indicators (except nutrients) that are used in the evaluation of eutrophication (adapted from Bricker et al. 2007). The NEEA and NCA use the same thresholds for chlorophyll *a* and dissolved oxygen.



Indicator	Description of State Indicators	Thresholds
Chlorophyll *a* (Phytoplankton)	A measure used to indicate the amount of microscopic algae (phytoplankton) growing in a water body. High concentrations can lead to low dissolved oxygen levels as a result of decomposition.	High: >20 μg Chl *a* l^{-1} Medium: >5, ≤20 μg Chl *a* l^{-1} Low: ≤5 μg Chl *a* l^{-1}
Macroalgal blooms	Large algae commonly referred to as "seaweed". Blooms can cause losses of submerged aquatic vegetation by blocking sunlight Additionally, blooms may smother immobile shellfish, corals or other habitat. The unsightly nature of some blooms may impact tourism due to the declining value of swimming, fishing, and boating.	(e.g., dieoff of submerged plants (SAV) – see Submerged aquatic vegetation in symptoms below left.) No problems: no problems are indicated when there are no apparent impacts on biological resources.
	Description of Impact Indicators	**Thresholds**
Dissolved oxygen	Low dissolved oxygen is a eutrophic symptom because it occurs as a result of decomposing organic matter (from dense algal blooms), which sinks to the bottom and uses oxygen during decay. Low dissolved oxygen can cause fish kills, habitat loss, and degraded aesthetic values, resulting in the loss of tourism and recreational water use.	Anoxia: 0 mg l^{-1} Hypoxia: >0, ≤2 mg l^{-1} Biologically Stressful: >2, ≤5 mg l^{-1}
Submerged aquatic vegetation	Loss of submerged aquatic vegetation (SAV) occurs when dense algal blooms caused by excess nutrient additions (and absence of grazers) decrease water clarity and light penetration. Turbidity caused by other factors (e.g., wave energy, color) similarly affects SAV. The loss of SAV can have negative effects on an estuary's functionality and may impact some fisheries due to loss of a critical nursery habitat.	High Loss: >50% of seagrass area Medium Loss: ≥25%, <50% of seagrass area Low Loss: <25% of seagrass area
Nuisance blooms	Thought to be caused by a change in the natural mixture of nutrients that occurs when nutrient inputs increase over a long period of time. These blooms may release toxins that kill fish and shellfish. Human health problems may also occur due to the consumption of contaminated shellfish or from inhalation of airborne toxins. Many nuisance/toxic blooms occur naturally, some are advected into estuaries from the ocean; the role of nutrient enrichment is unclear.	Problem: a problem is indicated if there is a detrimental impact to any biological resource (e.g., dieoff of filter feeding bivalves and fish, respiratory irritation). No problem: no problems are indicated when there are no apparent impacts on biological resources

3.1 NUTRIENTS

Nutrients are considered primary indicators and are typically measured in two ways; as Total Nitrogen (TN) and Total Phosphorus (TP), or in the dissolved state (DIN is Dissolved Inorganic Nitrogen, DIP is Dissolved Inorganic Phosphorus). There is a debate in the scientific community over which are the better indicators, TN and TP or DIN and DIP. The dissolved forms of nutrients (DIN and DIP) are used for this discussion because they are relatively easy to measure, and are suitable for evaluating patterns over large spatial scales.

Table 2: Thresholds, ranges (mg/L), and ratings for DIN and DIP for the National Estuarine Eutrophication Assessment (NEEA) and the National Coastal Assessment (NCA) methods (from Bricker et al. 1997; US EPA NCA 2008).

	HIGH* POOR+	MODERATE* FAIR+	LOW* GOOD+
DIN (mg/L)			
NEEA	>1.0	0.1–1.0	<0.1
NCA	>0.5	0.1–0.5	<0.1
DIP (mg/L)			
NEEA	>0.10	0.01–0.10	<0.01
NCA	>0.05	0.01–0.05	<0.01

The name of the ratings for NEEA are indicated with * and for NCA are indicated as +. Note that the thresholds for ratings of the worst case conditions (High and Poor) are higher for the NEEA method than the NCA. DIN is Dissolved Inorganic Nitrogen. DIP is Dissolved Inorganic Phosphorous.

Results from summertime sampling for the National Coastal Assessment (EPA NCA 2008 data as summarized by John Kiddon, EPA, pers. comm.) show that 96% of the United States portion of the Gulf of Maine region is considered good quality for DIN, and 99% of the region shows fair-to-good DIP

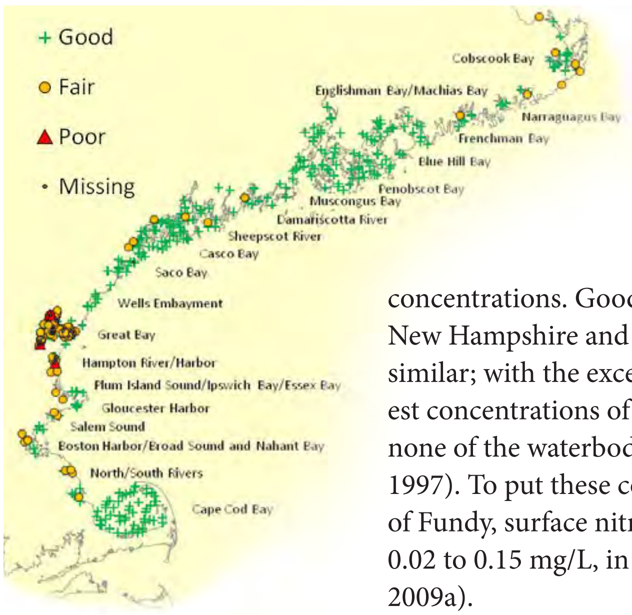


Figure 4: Dissolved inorganic nitrogen results by station sampled from 2000 to 2006 by the National Coastal Assessment. Source: extract of data from EPA NCA 2008, by John Kiddon, EPA.

concentrations. Good-to-fair conditions are found predominantly in Great Bay, New Hampshire and in coastal Massachusetts (Figure 4). The NEEA results are similar; with the exception of Hampton Harbor and Cape Cod Bay, the highest concentrations of nitrogen in surface waters reach only moderate levels and none of the waterbodies have high concentrations of phosphorus (Bricker et al. 1997). To put these coastal measurements in context, at a deep station in the Bay of Fundy, surface nitrate concentrations during the summer typically range from 0.02 to 0.15 mg/L, in the “good” range of the NCA and NEEA evaluation (DFO 2009a).

3.2 CHLOROPHYLL A

Phytoplankton biomass, represented as chlorophyll *a* (a major component of all algal cells), is also considered a state indicator since phytoplankton directly take up nutrients for growth. The EPA NCA results show that 97% of the Gulf of Maine region has chlorophyll a concentrations considered to be good (less than 5 μg/L; EPA NCA 2008 data as summarized by John Kiddon EPA, pers. comm.). On Georges Bank and at the deep Bay of Fundy station in Canada, chlorophyll a concentrations also generally range from 1-5 μg/L during the summer period (DFO 2009b, East Coast Aquatics 2011). Fair-to-poor conditions are found predominantly in the Great Bay estuary and tributaries in New Hampshire; some of the more elevated nutrient and chlorophyll conditions are found in the tributary areas. Chlorophyll a results from the NEEA are a combined rating that includes the concentration, spatial coverage, and the frequency of occurrence of higher concentrations. These results show that most systems have low-to-moderate conditions of chlorophyll a. Casco Bay, Maine, Plum Island Sound, Massachusetts, Massachusetts Bay, Massachusetts and Cape Cod Bay, Massachusetts however, have a high level of chlorophyll *a* and three of the four bays have had worsening conditions since the early 1990s, which is cause for concern (Figure 5).

3.3 MACROALGAE

Macroalgae, both attached and floating forms such as *Ulva* spp. (i.e., “sea lettuce”), have a large capacity to assimilate nitrogen. Although part of the natural community, they become a nuisance when large algal mats develop that float onto beaches and decay causing a smelly, unappealing condition called “stinky beach” or “green slime” on mudflats. Macroalgae also smother seagrasses and shellfish beds causing die-offs due to low dissolved oxygen events (i.e., hypoxia or anoxia) when they sink and decay in bottom waters. Macroalgal biomass or abundance is a status indicator, but they are difficult to evaluate quantitatively because of their mobility and variation in thickness. The NEEA results show that one third of the systems exhibit moderate-to-high-level problems from macroalgae and the spatial extent of macroalgae has increased in Great Bay, New Hampshire, Hampton Harbor, New Hampshire and Cape Cod Bay, Massachusetts since the early 1990s (Figures 5 and 6). In Great Bay, macroalgae have replaced 6% of seagrass meadows between 1996 and 2007 specifically in areas of high nitrogen concentrations (NHDES 2009). Unfortunately, for many of the estuaries there are no data with which to make an evaluation; assessing the abundance of macroalgae is an important need due to the potential for macroalgal proliferation to reduce habitat and recreational uses (see *Coastal Ecosystems and Habitats* theme paper).

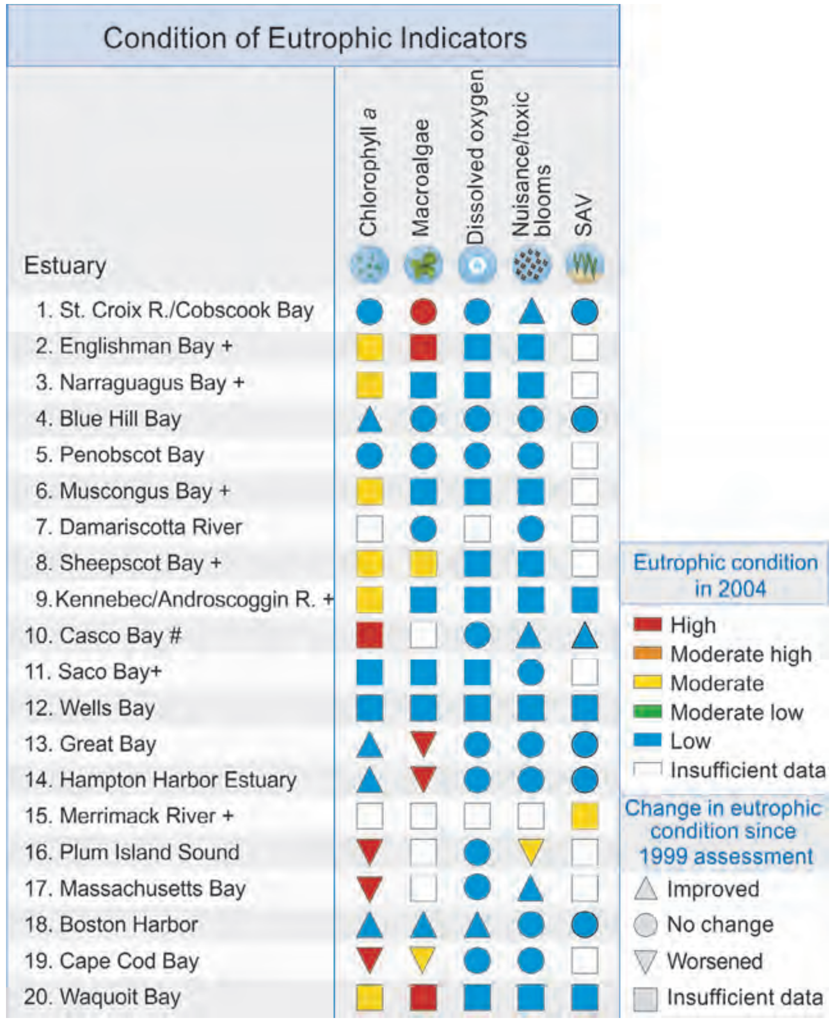
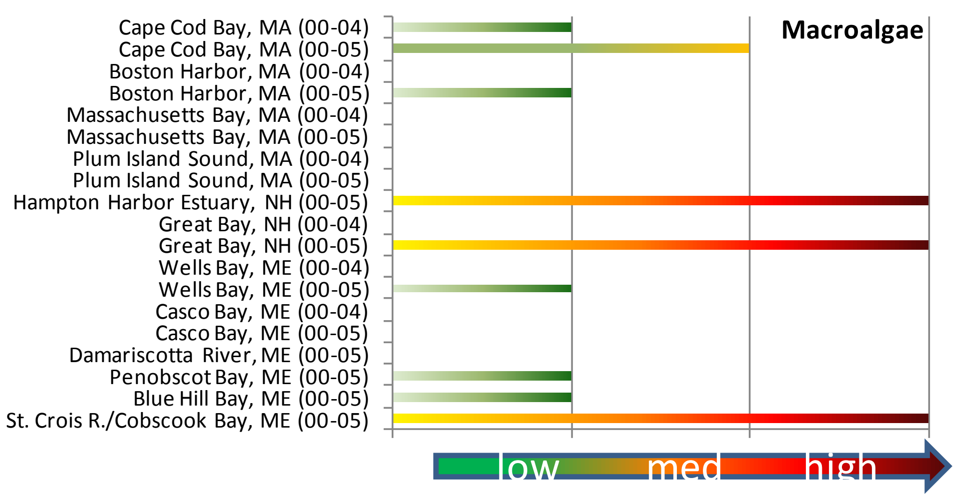


Figure 5: National Estuarine Eutrophication Assessment results for individual indicators of eutrophication (adapted from Bricker et al. 1999 (indicated with +), 2006 (indicated with #), 2007 (all others).

Figure 6: Summary of combined information from the NOAA assessments for macroalgae bloom frequency. Green indicate no problems, red indicates periodic or persistent problems; assessment periods are in parentheses by each estuary name. Estuaries with no bars indicate unknown status. Sources: Bricker et al. 2006; Bricker et al. 2007.



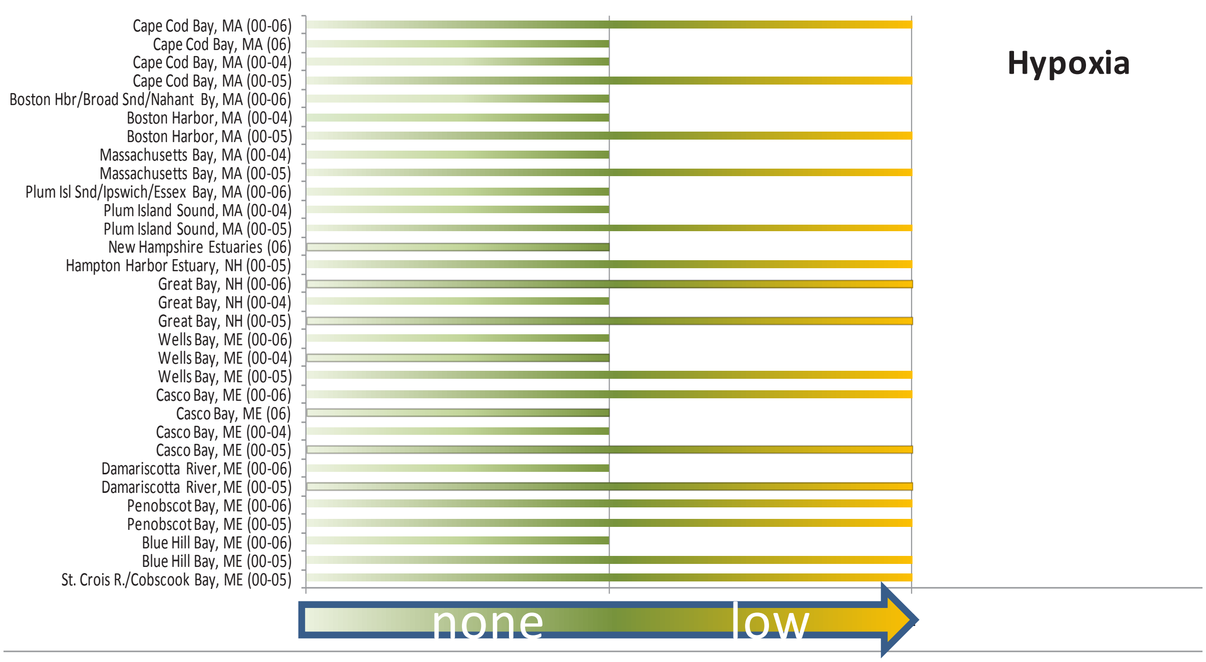
4. Impacts

Impact indicators include dissolved oxygen levels, losses of seagrass, and occurrence of nuisance and toxic phytoplankton blooms (also known as harmful algal blooms or HABs), which represent a more severe stage of eutrophication and are of particular concern due to their representation of the loss of habitat and recreational uses (see *Coastal Ecosystems and Habitats*). These indicators stem directly from elevated levels of the state indicators. For example, lowered dissolved oxygen is sometimes caused by the decay of algal blooms. The impact summaries detailed here are developed primarily from the same two comprehensive regional assessments that were used for the status summaries (NEEA and EPA NCA).

4.1 LOW DISSOLVED OXYGEN/HYPOXIA

Dissolved oxygen is measured because hypoxia (low dissolved oxygen) or anoxia (no dissolved oxygen) in the marine environment is a major cause of environmental degradation and loss of habitat in the world's oceans (Jewett et al. 2010; Díaz et al. 2009). Low dissolved oxygen is typically observed in deeper zones of estuaries and coastal waters that do not allow exchange with the atmosphere. Both the EPA NCA and the NEEA show that there are no major problems with dissolved oxygen in the Gulf of Maine region, and with one exception, no change from the early 1990s to the early 2000s (Figures 5 and 7). In fact, using NCA data, 98% of

Figure 7: Summary of combined information from the NOAA and EPA assessments for hypoxic conditions. Green indicates no problem and yellow indicates low problem with low dissolved oxygen; assessment periods are in parentheses by each estuary name. Sources: Bricker et al. 2006; Bricker et al. 2007; EPA 2006; EPA NCA data 2000-2006, John Kiddon, EPA pers. comm.



the region is considered in the good category (EPA NCA 2008 data as summarized by John Kiddon EPA, pers. comm.). This is not unexpected since the estuaries in this region are strongly flushed due to the large tidal range, and except for coastal cities with high populations, nutrient loads are considered to be relatively low. Boston Harbor is an exception to the general trend among coastal population centers—the improved sewage treatment and relocation of the metropolitan Boston wastewater outfall from Boston Harbor to 15 km offshore into Massachusetts Bay resulted in improved oxygen levels in Boston Harbor (Taylor 2005, 2006; see box in Responses section).

4.2 SEAGRASS

Seagrasses provide important ecological services, including: fish, shellfish, and shore-bird feeding habitats; nutrient and carbon cycling; sediment stabilization; and biodiversity throughout the world (Duarte et al. 2008; Orth et al. 2006; see *Coastal Ecosystems and Habitats*). Loss of seagrasses (primarily *Zostera marina*) in the northeast is often associated with light limitation due to algae-associated turbidity, smothering by phytoplankton or macroalgae, or epiphytic shading (Duarte 1995; Hauxwell et al. 2003; Leschen et al. 2010), as well as from sediment sulfides (which are toxic to plants) that occur with high sediment organic matter levels in greatly enriched estuaries (Figure 8).

Observed losses in the Gulf of Maine are consistent with losses of more than half of the seagrass beds within North Atlantic region estuaries during the past century (GOMCME 2004, 2009; Gustavson 2010) and are also consistent with global patterns; nearly 20% of seagrass species are threatened and are decreasing in abundance (Short et al. 2011). Importantly, the response of seagrass appears to be non-linear, above a specific nitrogen loading threshold; seagrass loss is precipitous (Figure 9). Evidence from southern New England estuaries combined with global data reveal that nitrogen loading must be kept well below 50 kg N ha^{-1} yr^{-1} to prevent eelgrass loss (Latimer and Rego 2010). As noted above, Great Bay shows a loss of 6% of seagrass area due to macroalgal growth between 1996

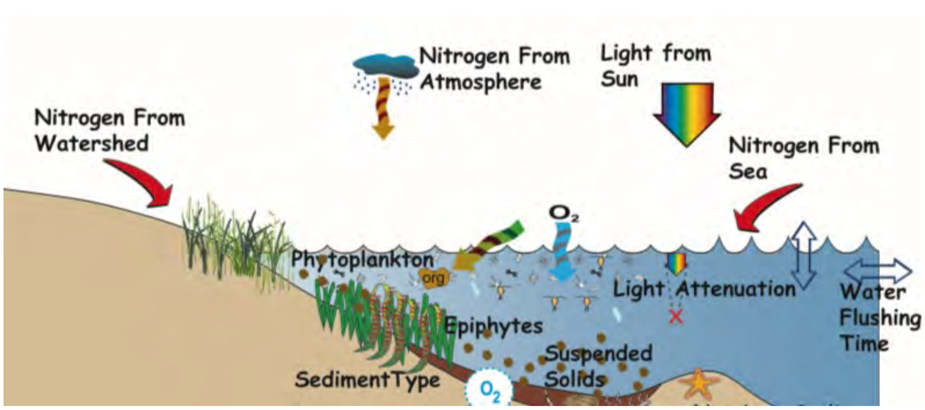


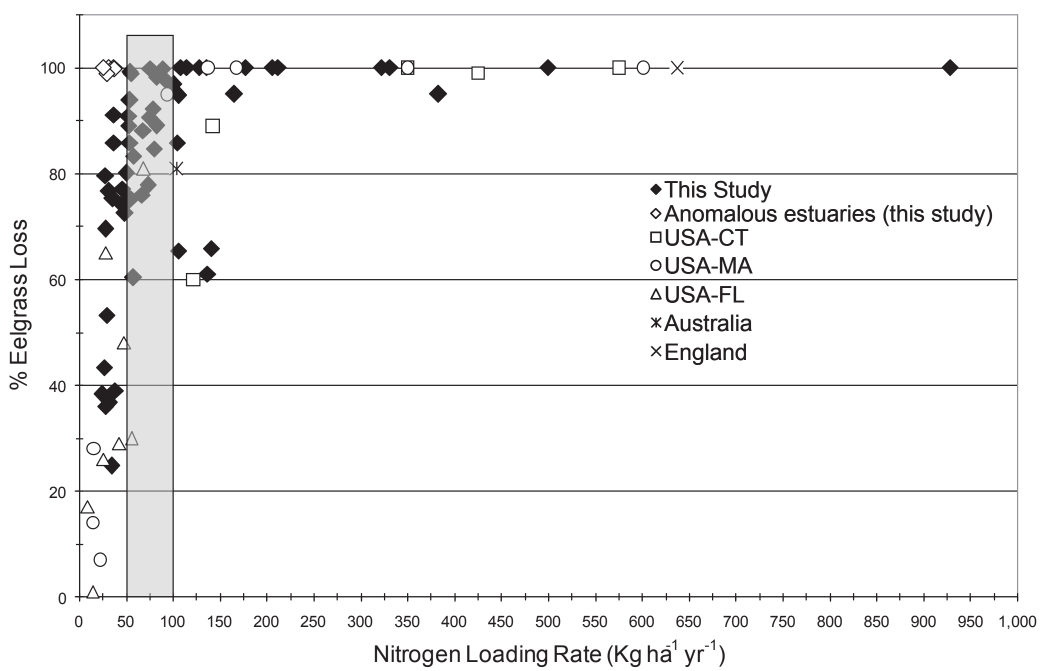
Figure 8: Threats to seagrasses derived from nutrient enrichment. Source: J. Latimer, U.S. EPA, pers. comm., 2012.

and 2007 (NHDES 2009; PREP 2009). The annual nitrogen loading estimate to Great Bay is 320 kg N ha^{-1} yr^{-1} (PREP 2009), well above the threshold reported by Latimer and Rego (2010); moreover, the median water column concentration (0.42 mg/L; NHDES 2009) is above the recommended TN concentration threshold (0.25 to 0.30 mg/L; NHDES 2009) to be protective of seagrass habitat. While seagrass losses are easily observed, it is likely they would be far worse if Great Bay was not a macro-tidal estuary in which a large portion of the seagrass beds are exposed to sunlight at low tide. In contrast to observations in most locations where seagrasses are being lost, seagrass appears to be increasing within Casco Bay (Bricker et al. 2006), probably due to low to moderate levels of nutrients and sufficient light levels in areas which are suitable habitat.

4.3 OCCURRENCE OF HARMFUL ALGAL BLOOMS

Harmful algal blooms (HABs) are considered here to be any bloom that is either a nuisance (e.g., causing low dissolved oxygen events or shellfish and/or seagrass die-off due to high biomass blooms), or that causes a toxic reaction in humans or other animals (see *Microbial Pathogens and Biotoxins*). Studies of the linkage between nutrient loadings and HABs suggest that the magnitude and ratios of nutrients (i.e., nitrogen:phosphorus) may play a role in developing and maintaining blooms (Heisler et al. 2008; Anderson et al. 2008). The noted global increase in HAB outbreaks have consequences to human health and the economy (Johnson et al. 2010) and thus are considered an important indicator of the nutrient impacts in coastal marine environments. For more information on HABS in the Gulf of Maine, see the *Microbial Pathogens and Biotoxins* theme paper.

Figure 9: Relationship between nitrogen loading and loss of eelgrass (from Latimer and Rego 2010). Units are kilograms of nitrogen per hectare per year.



5. Actions and Responses

Reducing nutrient pollution to protect existing uses, or to ensure that emerging problems do not get worse, is a major challenge. It requires voluntary actions, individual actions by homeowners and developers, as well as governmental regulation and initiatives at local, regional, state, and federal levels. Importantly, citizen advocacy is a critical motivator to ensure that coastal water quality can be restored, or that they are not polluted in the first place. Many of the responses described below have been discussed at many fora and workshops, including one co-sponsored by the Gulf of Maine Council and the National Oceanic and Atmospheric Administration (NOAA)/University of New Hampshire Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET 2001). An overarching response to eutrophication, as well as to all threats to the coastal ocean, is improved regional management. Coordination among federal, state/provincial, and local governance structures is critical to protect and restore the coastal ocean in the Gulf of Maine. The United States National Ocean Policy, which was established in 2010, calls for improvements to manage the ocean, including coastal and marine spatial planning, regional ecosystem protection and restoration, and improved scientific data sharing capabilities, among others. Organizations such as the Gulf of Maine Council, the Northeast Regional Ocean Council (NROC), and the Northeast Regional Association of Coastal Ocean Observing Systems (NERACOOS) provide tools and information to coastal scientists and managers to reduce the stresses and impacts associated with eutrophication. Described below are regulatory tools (such as establishment of nutrient criteria) as well as other actions that promote information sharing or stewardship to help restore and protect the Gulf of Maine from eutrophication, specifically in the nearshore or estuarine areas, where eutrophication effects are most apparent. Although most of these examples are from the United States, the approaches described may also be applicable to Atlantic Canada.

Boston Harbor Cleanup

An example of how combined federal, state, and local activities can reduce nutrient pollution is the successful cleanup of Boston Harbor (Massachusetts). This cleanup got a major push in the 1980s when Boston Harbor was considered among the dirtiest harbors in the country. The Deer Island and Nut Island treatment plants performed primary treatment only and therefore discharged sewage effluent and sludge, rich in nutrients, organic matter, and other pollutants, into Boston Harbor. Algal blooms were frequent, water clarity was poor, and dissolved oxygen in the water and the sediments was below standards for the protection of aquatic life. With a combination of citizen advocacy, federal enforcement of the Clean Water Act (and an aggressive and vigilant judge), reorganization of a state agency, federal and local financing, and continued public interest (from both the water quality and harbor access perspectives), sewage discharge into Boston Harbor was dramatically improved.

After significant environmental assessment, transfer of the discharge location out of the harbor was approved by both the state and federal governments. Part of this review included a consultation with the National Marine Fisheries Service, which was concerned about the potential for nutrient enrichment in Massachusetts Bay to affect protected marine mammals. Ultimately this review concluded that there would be no harm to the marine mammals, but required establishment of a monitoring plan to determine whether nutrients discharged to Massachusetts Bay might alter the ecosystem.

Today, thanks to improved treatment levels and the new outfall pipe, Boston Harbor is cleaner and both nutrient and chlorophyll levels have decreased to acceptable levels (Taylor et al. 2011). Because of dilution and the vigorous mixing in Massachusetts Bay at the outfall site, there does not seem to be significant harm to marine life caused by the discharge of 350 Million Gallons a Day (MGD) of treated sewage. The message here is that solutions take a mosaic of local, state, and federal controls, along with support from the legislature, the public, and, in some cases, the judiciary, which is especially critical for obtaining project financing.

5.1 WATER LEGISLATION AND REGULATIONS

The following (not all-inclusive) examples of legislative, regulatory, programmatic, and research and monitoring efforts have been implemented to limit the impacts of nutrient pollution in the Gulf of Maine. These are listed in Table 3, and described in more detail below.

Table 3: Policy and legislation actions related to controlling nutrient pollution in the Gulf of Maine.

JURISDICTION	LEGISLATIVE ACTION	AGENCY	DESCRIPTION
United States	NPDES permits	US Environmental Protection Agency and State environmental agencies	Limits discharge of pollutants from wastewater treatment plants based on technology or water quality to maintain water quality standards.
Canada	*Canadian Environmental Protection Act* of 1999 *Fisheries Act*	Environment Canada	Governs the release of potentially toxic contaminants into the environment.
United States	NPDES Stormwater permits	US Environmental Protection Agency	Limits discharge of pollutants from defined stormwater pipes based on best management practices.
United States	State and local health guidelines	States and Provinces and local health officials	Management of onsite sewage disposal systems.
United States	*Clean Water Act* regulatory tools: nutrient criteria and TMDLs	United States Environmental Protection Agency and State environmental agencies	Numeric criteria are important targets that can be used in setting permit limits, preventing degradation of unimpaired waterbodies, and determining whether waterbodies are meeting designated uses, and if not, in setting targets for a Total Maximum Daily Load (TMDL) study to restore uses.
United States	*Clean Air Act*	United States Environmental Protection Agency and State environmental agencies	National Ambient Air Quality Standards for six criteria pollutants including nitrogen oxides, protect public health (primary standards) and protect against environmental damage (secondary standards).
United States	Management of fertilizers	State and local officials	Limits application of high levels of phosphorus in fertilizer.

Point sources and the U.S. Clean Water Act National Pollutant Discharge Elimination System Program

One of the major sources of phosphorus and nitrogen to estuaries and the coastal zone is municipal sewage wastewater treatment plants (WWTPs). In the United States, these facilities are regulated by EPA and state permitting programs under the Clean Water Act National Pollutant Discharge Elimination System (NPDES) program. Under the NPDES program, all municipal, industrial, and commercial facilities that discharge wastewater directly from a point source (a discrete conveyance such as a pipe, ditch, or channel) into a receiving waterbody (lake, river, and ocean) require an NPDES permit. The state or federal agencies that issue permits determine the amount of pollutants (and volume of effluent) that can be discharged from a given facility and set limits in the permit to ensure that water quality standards will be met.

Most municipal WWTPs discharge to rivers or to tributaries of estuaries, or directly into the coastal ocean. Due to increased concern about nutrient enrichment in estuaries, more attention is being paid to whether nitrogen discharged from WWTPs is causing or contributing to violations of water quality standards in the receiving waters. Most secondary treatment facilities do not effectively remove nitrogen from the effluent (most of which is usually in the form of ammonia). Typical effluent concentrations range from 10 to 25 mg/L total nitrogen and efforts are underway in many communities to reduce nitrogen discharges to levels protective of water quality or aquatic resources (D. Pincumbe, EPA Region 1 environmental engineer, pers. comm., April 2011).

In a recent example of efforts to address this problem, EPA issued a draft permit to the town of Exeter in New Hampshire (EPA 2011b). The town's sewage treatment plant discharges into the Squamscottt River which is exhibiting signs of eutrophication, and is a tributary to the Great Bay estuary which has lost much of its eelgrass habitat. The New Hampshire Department of Environmental Services identified violations of water quality standards in the tributaries to the estuary, and EPA determined that the estuary could not assimilate any additional nutrients. The draft permit requires a reduction of total nitrogen in the effluent from an annual average of 14.4 mg/L to 3 mg/L during the growing season of April through October and optimized removal of nitrogen using all available equipment at the facility from November through March. To comply with the effluent limitation of 3 mg/L, Exeter and a number of other communities within the watershed (there are 17 other WWTP in the Great Bay watershed) may require significant upgrades to their wastewater treatment facilities to include denitrification.[2]

Point sources in Atlantic Canada

There is no federal Canadian legislation that specifically regulates discharge of sewage from municipal WWTPs. The *Canadian Environmental Protection Act* of 1999 (supplemented by the *Fisheries Act*, 1985), however, which is implemented by Environmental Canada with Provincial agencies and municipal authorities' input, governs the release of potentially toxic contaminants into the environment. Atlantic Canada appears to be lagging behind the United States in terms of sewage treatment. For example, as of 2002, only about 60% of sewage from New Brunswick's largest city (Saint John, population 74,000) was treated – the remainder was discharged raw (Hinch et al. 2002). Recently, however, the *Canada-wide Strategy for the Management of Municipal Wastewater Effluent* strengthened and clarified performance standards for discharges and reinforced efforts to provide financing for upgrading WWTPs (CCME 2009).

Non-point sources and the U.S. Clean Water Act NPDES stormwater permits

As described in Section 2.3, non-point sources are major contributors to nutrient enrichment in many estuaries in the Gulf of Maine. State and federal agencies are

[2] The Exeter permit is under review and the permittee and a coalition of communities in the watershed may object to the limits on the grounds that other pollutants, and not nitrogen discharged from the WWTPs, are causing eutrophication in the estuary or loss of eelgrass habitat.

increasing efforts to reduce pollution by requiring NPDES permits for stormwater that is discharged as a point source through a pipe, such as through a municipal stormwater collection system. These types of discharges are widespread, typically associated with impervious surfaces, and challenging to control.

Since the 1990s, federal and state agencies in the United States have regulated discharges from municipal separate storm sewer systems (MS4s), construction activities, industrial activities, and other activities designated by EPA as having adverse water quality impacts. In contrast to municipal WWTP permits, which typically require numeric limits, these permits require several related minimum measures, including public education and involvement, illicit discharge detection and elimination, construction site control and management, and pollution prevention.

Each municipality that operates a stormwater collection system is required to develop and implement a stormwater management plan (SWMP) designed to prevent discharge of pollutants such as nitrogen and phosphorus to streams and estuaries. While most municipalities conduct regular street sweeping, mapping of infrastructure and pumping of catch basins as part of the SWMP, many are exploring or requiring improved best management practices (BMPs) to treat stormwater at the source. Non-point source management has been improved over the years with implementation of the NOAA/EPA Coastal Nonpoint Pollution Control Program (Section 6217 of the *Coastal Zone Act* Reauthorization Amendments) which addressed non-point pollution problems in coastal waters. Although not currently active, this program historically provided excellent technical guidance for "management measures", or BMPs, in the coastal zones.

Phosphorus is more readily removed from stormwater than nitrogen because it attaches to particles and can be removed in catch basins or in detention ponds. Treatment or removal of nitrogen from stormwater, however, is more complicated as it requires infiltration into the ground followed by a sequence of biological processes referred to as nitrification (an aerobic process) and denitrification (an anaerobic process), which converts nitrogen into a form that is not reactive in the environment. More traditional stormwater BMPs, such as detention ponds, have been shown to be less effective for pollutant removal than infiltration or bioretention practices, such as vegetated swales, sand filters, and constructed wetlands. This is an area of active research. Land-use planners are promoting these new techniques using the term "Low Impact Development" or LID, which is defined as "an approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible.[…] LID minimizes effective imperviousness, creating functional and appealing site drainage that treats stormwater as a resource rather than a waste product" (EPA 2011a).

Management of onsite sewage disposal systems

In general, most environmental protection is addressed or implemented at the local level. This is especially true in the Gulf of Maine where enforcement and oversight of small residential on-site sewage disposal systems ("OSDS" or "septic systems") is often managed by local health officials using regulations developed by state or provincial environmental or health agencies. A well maintained and functioning septic system will remove significant loads of phosphorus, but only about 25% of nitrogen in the leach field (Costa et al. 2002). Further attenuation occurs within the watershed, but less if septic systems are located more directly near tributaries or estuaries. Septic systems are the preferred sewage treatment approach in areas of low residential density because of cost considerations, but poorly maintained systems are a threat to estuaries. Thus, regional decentralized wastewater treatment districts, which ensure ongoing monitoring, are highly recommended. Alternative treatment systems, which are designed to remove additional nitrogen, are proven technologies and are now recommended for siting in areas of sensitive resources (e.g., estuaries) or in retrofitting failing systems.

U.S. Clean Water Act regulatory tools: Nutrient criteria and TMDLs

Water quality standards are an important tool to protect coastal waters from nutrient enrichment, however, most states employ a narrative, or descriptive, standard, which is difficult to enforce or employ because it is not always objectively determined. In the United States, EPA and state environmental agencies have been working for many years on determining appropriate numeric levels of causal (nutrient) and response variables (chlorophyll *a*, macroalgae, dissolved oxygen, and transparency) that protect aquatic life, such as submerged aquatic vegetation, or prevent hypoxia. Numeric criteria are important targets that can be used in setting permit limits, preventing degradation of unimpaired waterbodies, and determining whether waterbodies are meeting designated uses, and if not, in setting targets for a Total Maximum Daily Load (TMDL) study.

As an example, the New Hampshire Department of Environmental Services has developed numeric nitrogen criteria for Great Bay that was used for determining attainment of water quality standards and was one of many scientific factors in determining appropriate nitrogen limits for the Exeter WWTP draft permit (NHDES 2009). Maine is also making progress and the United States EPA Region 1 office has conducted a significant level of sampling (2009 to 2011) to establish coastal nutrient criteria for the Gulf of Maine. Although developing numeric nutrient criteria may take several years, EPA recommends that while criteria are being developed, it is important to "prioritize watersheds on a statewide basis for nitrogen and phosphorus loading reductions … and set watershed load reduction goals based upon best available information" (Stoner 2011).

TMDLs are restoration plans designed to address a specific pollutant(s) to return a waterbody to a condition where it meets water quality standards. They are required when waterbodies, such as estuaries or coastal waters, are not meeting water quality standards. A major nutrient-related TMDL is currently being developed by the Massachusetts Department of Environmental Protection (MassDEP) and is partly funded by EPA. Called the Massachusetts Estuaries Project, this program will set TMDL targets for total nitrogen in more than eighty small estuaries in coastal Massachusetts, many of which are in the Gulf of Maine (MEP 2011). These targets were developed based on a combination of monitoring and modeling, linking nitrogen loads to predicted nitrogen concentrations in embayments and determining levels necessary for protection of important resources, such as eelgrass habitat. When implemented, these plans may result in diversion of sewage from onsite sewage disposal systems to more centralized wastewater treatment facilities.

5.2 AIR LEGISLATION AND REGULATIONS

Because a significant amount of nitrogen in the Gulf of Maine is delivered via atmospheric deposition, it is important to discuss the government response to limiting nitrogen emissions in the air. In the United States, the *Clean Air Act* requires EPA to set National Ambient Air Quality Standards (NAAQs) for six criteria pollutants to protect public health (primary standards) and to protect against environmental damage (secondary standards). One major class of air pollutants are nitrogen oxides (or NO_x), which are produced by fossil fuel combustion. NO_x is a precursor to generation of ozone and is the major component of acid rain, which contributes bioavailable nitrogen to watersheds and to estuaries and coastal waters, causing eutrophic symptoms (Paerl et al. 2002). EPA works with states and local air quality agencies to reduce both NOx emissions from both mobile (e.g., vehicles) and stationary sources (e.g., power plants). Recognizing that the current secondary standards for NO_x may not provide adequate protection against environmental damage (such as to lakes, forests and estuaries), EPA recently (July 12, 2011) proposed more protective standards (EPA 2011c). For mobile sources, EPA is implementing a number of regulations to reduce NO_x, including clean diesel regulations for trucks and buses and non-road engines, as well as for locomotives and smaller marine vessels. The agency is also developing new and revised regulations for stationary sources that emit NO_x, such as electric utilities and industrial boilers. On July 6, 2011, EPA finalized the Cross-State Air Pollution Rule (CSAPR or Transport Rule), which replaces the Clean Air Interstate Rule. The rule will reduce the interstate transport of NO_x emissions from power plants in up to 28 eastern and mid-western states. Although this rule does not include any New England states, by 2014, EPA estimates that compared to 2005 levels, NO_x emissions should be reduced by 54% and the Gulf of Maine, downwind of both the mid-western and New England power plants, is likely to benefit.

5.3 WATERSHED AND RESTORATION APPROACHES

United States National Estuary Programs (NEPs)

The United States NEPs are ecosystem-based and geographic-based management programs established in 1987 as part of the *Clean Water Act* to protect and restore the water quality and ecological integrity of significant estuaries. NEPs utilize management conferences—partnerships among government and non-government organizations—to develop and implement a Comprehensive Conservation and Management Plan, or CCMP. The goal of each plan is to identify actions designed to improve water quality and protect and restore habitat and living resources in the estuary, and the watershed. There are three NEPs in the Gulf of Maine—the Casco Bay Estuary Partnership, the Piscataqua Region Estuaries Partnership, and the Massachusetts Bays Program. Here are two examples of how the NEPs implement approaches to address sources nutrients.

Much progress has been made toward managing stormwater through a regional, or watershed, approach. The Casco Bay Estuary Partnership (CBEP), for example, assists communities by providing technical information, mapping tools, and citizen advocacy to encourage municipalities and individual citizens to reduce nutrient pollution (CBEP 2011). In an urban environment, most stormwater is not effectively treated before discharge to tributaries or estuaries. To address this challenge, the CBEP provides training and technical assistance in stormwater best management practices (BMPs) including LID, promotes subwatershed management planning and implementation, and monitors progress in reducing stormwater discharges.

The Massachusetts Bays Program (MBP) in 2011 established a dedicated grant program to assist communities implementing projects consistent with their management plan, including prevention of nutrient enrichment. For example, in 2011 and 2012 the MBP funded projects to design stormwater best management practices in Kingston Bay, assess turbidity in Salem Harbor, and evaluate sites for eelgrass restoration in Plum Island Sound.

A watershed receiving major attention is the Long Creek Watershed in Portland, Maine, and three surrounding towns. CBEP, along with the Cumberland County Soil and Water Conservation District, were key organizations that led the development of a plan to restore water quality and habitat in both urban and rural parts of this watershed.[3] This plan is funded and implemented through an innovative public-private partnership, the Long Creek Watershed Management District. Already, the District has installed more than $2 million worth of BMPs with funding from the State Revolving Loan (SRF). A comprehensive stormwater BMP maintenance and inspection database has been developed to assist landowners and environmental managers in Maine to monitor the progress of the plan.

[3] Year 16 CBEP workplan, 2011.

Habitat protection and restoration

As described above, the landscape has been altered significantly, resulting in less attenuation of nitrogen in watersheds and more export to the coastal ocean. Wetlands are a key component of the landscape and their protection and restoration is a key tactic in successfully managing stormwater impacts from impervious surfaces. The mission of various watershed associations and government agencies (e.g., Coastal America, Fisheries and Oceans Canada Habitat Management Program) is to protect wetlands. As is the case for management of on-site wastewater systems, protecting riparian areas is a local and regional concern. For more information about habitat protection and restoration in the Gulf of Maine see the Gulf of Maine Council on the Marine Environment Ecosystem Indicator Partnership (ESIP) fact sheet on aquatic habitats (ESIP 2011b).

Aquaculture and bioextraction

Attempts to reverse eutrophication have focused on reducing land-based sources of nutrients, such as fertilizer applications and wastewater treatment plant discharges. Recent studies have shown that removal of nutrients through growth and harvest of shellfish through aquaculture activities can contribute to nutrient reductions, complementing traditional watershed-based management methods. Modeling results from Sweden (Lindahl et al. 2005) and Long Island Sound (HydroQual 2009) show that nutrient bioextraction (defined here as removal of nutrients from an aquatic ecosystem through the harvest of enhanced biological production, including but not limited to the aquaculture of suspension-feeding shellfish and/or algae) can potentially be very effective in improving dissolved oxygen levels and in helping to attain water quality standards in a cost-effective manner. Further evaluation of bioextraction is needed as part of a systems approach that integrates watershed load reduction programs with enhanced nutrient processing to attain water quality standards, restore designated uses, and restore ecosystem services, though these recent and ongoing studies show great promise for this approach. Aquaculture farming operations can reduce nutrient release from aquaculture operations and thus reduce environmental impacts through the adoption of integrated multi-trophic aquaculture, using shellfish and macroalgae where the shellfish reduce the particulate nutrients through filtration and removal of particles from the water and the macroalgae take up the dissolved nutrients from the water. Nutrients are removed from a waterbody when the shellfish and macroalgae are harvested. This is a practice that is increasingly common in the region. For more information on aquaculture in the Gulf of Maine, see the ESIP fact sheet on aquaculture (ESIP 2011a) and the proceedings from the Gulf of Maine workshop on Marine Habitats in the Gulf of Maine (GOMCME 2005).

5.4 MONITORING, RESEARCH AND INFORMATION PROGRAMS

There are several water quality monitoring programs in the Gulf of Maine estuaries, coastal bays, and offshore, some of which are significant long-term programs. These monitoring programs typically provide information to managers and the public on water quality, identify spatial and temporal trends, and determine whether water quality is responding to management actions, such as reductions in nutrient loads from WWTPs. For example, the Massachusetts Water Resource Authority (MWRA) outfall monitoring program is a permit requirement (and a long-term investment) that ties results directly to the operation of the sewage treatment plant and to model predictions. The ESIP program has catalogued many of these programs and has made strong efforts to ensure that ecosystem indicators based on data collection efforts allow decision makers to understand the connection between ecosystem health and environmental actions (ESIP 2011c).

In the United States, government agencies (such as the EPA and NOAA), National Estuary Programs (such as the Piscataqua Region Estuaries Partnership and the Casco Bay Estuary Partnership), and marine "stewardship" organizations (such as the Friends of Casco Bay in Maine) and other community based initiatives make regular measurements of a set of eutrophication indicators to assess the condition of their aquatic resources. The indicators are based on conceptual models of eutrophication in coastal waters (e.g., Bricker et al.1999, 2003, 2006, 2007; CICEET 2001; Figures 2 and 3) and are measured at programmatically dependent spatial and temporal intervals (i.e., monthly, seasonally, etc). Some indicators are used to evaluate the status of the estuary (i.e., chlorophyll *a*, macroalgal abundance, and nutrient concentrations; see section 3: Status and Trends) and others are used to evaluate the impacts of eutrophication (i.e., dissolved oxygen, changes in seagrass distribution, and occurrences of nuisance and toxic blooms; see section 4: Impacts). Although some programs monitor year round, most measures are taken during the summer, the presumed optimum growing period, and a period when symptoms are worst (e.g., low dissolved oxygen is typically observed in the late summer).

In the Atlantic provinces, Fisheries and Oceans Canada (DFO) operates the Atlantic Zone Monitoring Program (DFO 2011) which is aimed at increasing the Department's understanding of the marine environment to better forecast the state of the environment and to quantify the changes in ocean physical, chemical and biological properties and predator-prey relationships of marine resources (DFO 2009a). This long term monitoring program was implemented in 1998.

There are several programs in the Gulf of Maine that combine research efforts with communicating results to the public focusing on assessing and evaluating loads of nutrients to the coastal zone. The results of this research usually are (or hopefully are) incorporated into science based action plans for restoration. These include the Lamprey River Hydrologic Observatory (LRHO) conducted by the University of New Hampshire Water Resource Research Center (www.wrrc.unh.edu/lrho/about.htm); the Plum Island Ecosystem-Long Term Ecological Research site operated by the Marine Biological Laboratory and primarily funded by the National Science Foundation (ecosystems.mbl.edu/pie), and the Wells National Estuarine Research Reserve (Wells NERR) funded and operated by NOAA's National Ocean Service (www.wellsreserve.org/). The Woods Hole Oceanographic Institution has been researching and monitoring red tide blooms in the Gulf of Maine for many years, most recently funded by the NOAA ECOHAB program, but also to some degree by the EPA and the MWRA (McGillicuddy et al. 2005). Dalhousie University operates a long running research and monitoring program in the Bedford Basin, near Halifax (bbomb.ceotr.ca/aboutbbomb.php).

Several web sites have been developed to share information among managers and the public. These include the ESIP eutrophication fact sheet and indicator reporting tool (www2.gulfofmaine.org/esip) and the Northeast Ocean Data Portal (northeastoceandata.org): "a decision support and information system for people involved in ocean planning in the region from the Gulf of Maine to Long Island Sound."

It is hoped that with increased availability of data and information, the Gulf of Maine will be better protected from nutrient enrichment.

INDICATOR SUMMARY

INDICATOR	POLICY ISSUE	DPSIR	TREND*	ASSESSMENT
Nutrients	Relates to nutrient loading	State	-	Fair to Good
Chlorophyll *a*	Symptom of eutrophication	State	-	Fair to Good
Macroalgae	Potential negative impact on aesthetic use and fish and shellfish habitat	State	-	Fair to Good
Dissolved oxygen	Potential negative impact on fish and shellfish habitat	Impact	/	Good
Loss of seagrass	Potential negative impact on fish and shellfish habitat	Impact	-	Poor
Harmful Algal Blooms	Possible connection to nutrient enrichment	Impact	-	Poor

* KEY:
– Negative trend
/ Unclear or neutral trend
+ Positive trend
? No assessment due to lack of data

Data Confidence

Results in this report for the various driver, pressure, state and impact indicators are derived from published papers, reports, and databases; the degree of confidence of each indicator is dependent on the confidence of data use which is contained in the published documents themselves or in the metadata files of the databases utilized. For example, the confidence of NEEA state and impact indicators is based on the representativeness of spatial and temporal sampling, as well as the confidence in the analytical method used to measure the specific parameter. Methods for parameters such as chlorophyll *a* and dissolved oxygen are standardized and thus the confidence in the data for these indicators is typically very high. For other parameters such as macroalgae, for which there is no standard measure, and for nuisance and toxic blooms, for which there are not much data available, there is not as high a level of confidence in the results.

Data Gaps

- There is a paucity of data and information from the Canadian portion of the Gulf of Maine for all components (drivers, pressures, state, impacts) of the assessment.
- Although there are data for the estuarine areas of the Gulf of Maine, more data are needed for central Gulf waters. While there are adequate data in many estuarine and near coastal areas to determine the impact of human related nutrient inputs, due to the lack of data, is not possible to say what the impacts are to waters that are further offshore.
- Data on the conditions of estuaries from the time period of this assessment to the present and into the future.
- Quantification of the linkages between watershed activities, nutrient loading, and ecological responses
- With the exception of a few estuaries within the Gulf (e.g. Great Bay, Boston Harbor) there is no adequate data to develop numeric nutrient criteria to guide management measures. Additionally, there are only adequate data in a few places (e.g. Boston Harbor) for performance evaluation of management measures.

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