Monitoring nutrient inputs to Northeast Atlantic Coastal Waters

The Problem - Background

Nutrient enrichment has been identified by the steering committee of the Atlantic Northeast Coastal Monitoring Summit as one of the three leading management issues that the workshop will focus on. The increasing importance of nutrient enrichment to the coastal zone is reflected by the attention this subject receives and the alarming trend in nutrient loading to coastal receiving waters as well as reported increases in global frequency of hypoxia (Diaz and Rosenberg, 2001) that has occurred within the last two decades. Several institutions and agencies convened in Washington, D.C. in the fall of 2000 to present findings of global-scale nutrient over-enrichment occurring to coastal waters. Some of the papers presented at that symposium are captured in a special issue of *Estuaries* (Estuarine Research Federation, Vol. 25, No. 4b, 2002). In New England, the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET), along with the Gulf of Maine Council on the Marine Environment and National Oceanic and Atmospheric Administration (NOAA), held a workshop on Managing Nitrogen Impacts in the Gulf of Maine (2001). This workshop clearly identified that nutrient inputs and impacts are in the forefront of concern to both environmental managers and scientists. In addition a recent American Geophysical Union publication (American Geophysical Union, 2001) details the present state of knowledge of eutrophication-linked impacts to the Gulf of Mexico.

In general, nitrogen (N) is thought to be the more important nutrient controlling coastal eutrophication. On the cover of the above-referenced issue of *Estuaries* is a compelling figure (reproduced here as Figure 1) that shows the staggering rate of total reactive N being introduced to coastal receiving waters. Anthropogenic effects on the global supply of reactive, biologically available N is far greater than the human effects on the rate of CO_2 supplied to the atmosphere (Howarth et al., 2002). Nearly one-half of the total N-fertilizer used to date has been applied within the last 15 years. What impact is this having on our coastal waters? If increases in mass loading of nutrients to surface waters are occurring at such alarming rates, how accurate are our current assessments of coastal eutrophication? Are these systems quickly approaching some threshold with respect to nutrient assimilation before dramatic responses will be observed? The extent of local and regional assessments needs to be improved and better coordinated in order to provide more reliable answers to these questions.

Sources of Nutrients to and Effects in Coastal Waters

Some recent assessments of coastal eutrophication (i.e., increasing organic production) have been conducted. On a national level, NOAA designed the National Estuarine Eutrophication Assessment (Bricker et al., 1999) to evaluate the scale, scope, and future outlook of nutrient related eutrophication effects in US coastal waters. This study found that greater than half of the systems studied had moderate to high levels of nutrient related water quality problems ranging from excessive algal blooms to depleted dissolved oxygen in bottom waters and losses of Submerged Aquatic Vegetation (SAV). In general, occurrences of these symptoms in the Gulf of Maine estuaries were less than symptoms identified in other regions. The Gulf of Mexico and Middle Atlantic regions had the greatest numbers of highly impaired systems. In reality, more systems may be experiencing problems since at least one of the estuaries originally considered at low risk from impacts, Narragansett Bay, is now exhibiting intermittent hypoxic impacts (C. Deacutis, University of Rhode Island, personal communication, 2002). Such underestimates of impact are likely due to inadequate temporal and spatial monitoring programs and data analyses. The outlook for future nutrient conditions suggests that many estuarine systems in all regions will exhibit worsening eutrophication problems by 2010.

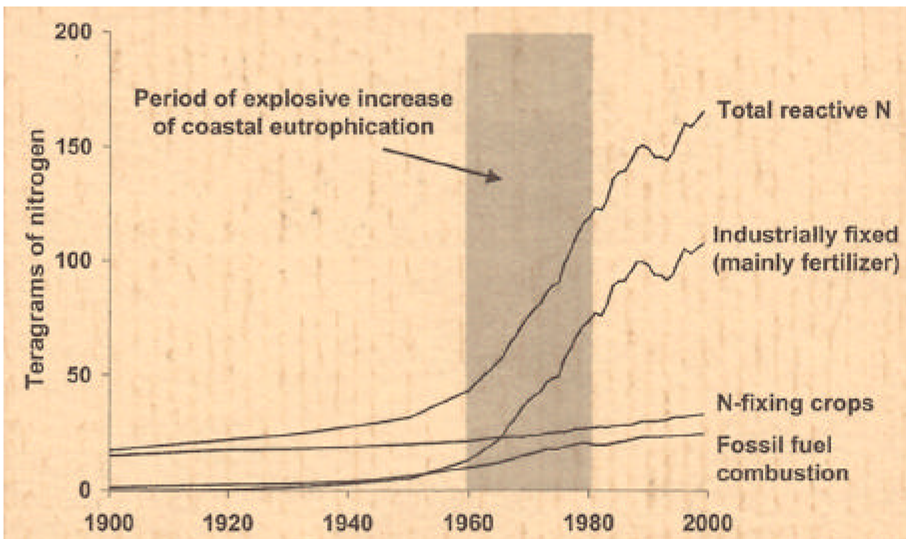

Figure 1. Reprinted from the cover of *Estuaries* (Estuarine Research Federation, V. 25, # 4B, 2002).

Sowles (2001) eloquently summarized sources of N to the Gulf of Maine (GOM). This highly-productive system receives a substantial, if not most of, its “new” nitrogen from nutrient-rich continental slope water. The sensitivity of the coastal waters of the GOM to increases of anthropogenic nutrient loading is unclear. In one sense, GOM coastal waters may be more sensitive because of the relatively high “background” of N that is supplied from the nutrient rich deep continental slope water (Table 1). Conversely, because of the 1) high rate of water exchange from macrotides, 2) low human population density and domination of forested land cover or relatively undeveloped watersheds in surrounding land areas, and 3) cooler temperatures, Northeastern coastal waters may not be as near their nutrient assimilative capacity as other coastal systems.

Table 1 Source and sinks of nitrogen in the Gulf of Maine (Sowles, 2001)

Sources		Annual Nitrogen (metric tons)
Inputs		
	Offshore	2,511,600 TIN
	Precipitation	130,200 TIN
	Coastal Point Sources	25,000 Total
	River	11,200 TIN
	Finfish Aquaculture	2,730 Total
	Non-Point Sources	Not estimated
Total Input		**2,680,730**
Losses		
	Outflow	-1,373,400 TIN
	Denitrification	-463,400 Total
	Burial	-61,600 Total
	Particulate and DON	-711,200 Total
	Commercial Harvest	-11,400 Total
Total Loss/Removal		**-2,621,00**

(TIN=total inorganic nitrogen)

Long Island Sound (LIS) has been experiencing symptoms of severe eutrophication for several decades. In 1989, hypoxia was observed in nearly 40% of the Sound's bottom water. By 1995 the occurrence of low dissolved oxygen in the Sound was observed in 22% of its bottom water. These reductions in bottom water hypoxia may be attributed to annual variations in hydrologic conditions and reductions in oxygen demanding substances and nutrients in wastewater effluent. Because of present and planned controls on point sources, nutrients supplied by atmospheric deposition, other non-point sources, and ground water (both shallow and deep-water aquifers) will become more and more important to the nutrient budget of LIS. State environmental protection agencies from New York and Connecticut (2000) report that approximately 48,000 metric tons of N is added annually to LIS. Approximately 73% is the result of point sources, and atmospheric deposition (both directly deposited onto the surface of LIS and indirectly) accounts for another 13-16%.

Coastal development, atmospheric deposition, and agriculture are important aspects necessary for understanding the delivery of nutrients to coastal waters. Export of N from agricultural activity has been shown to have contributed greatly to the over-enrichment and eutrophication of such areas as the Mississippi River Basin and the Southeastern United States. However, a significant source of human controlled N to the Northeast coastal waters is thought to be from atmospheric deposition (Pearl et al., 2002; Howarth et al., 2002; Smith and others, 1997).

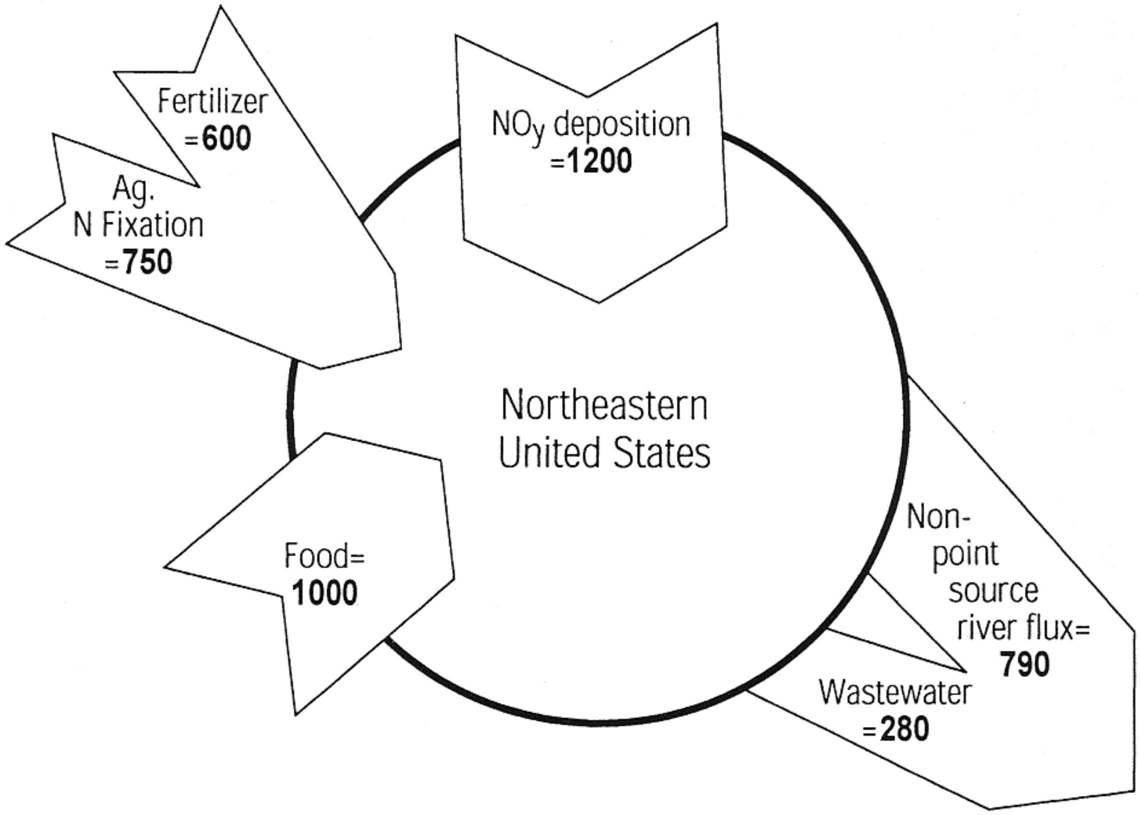

Figure 2. Anthropogenic inputs and losses of nitrogen to the northeastern U.S. Units are in kg N km^{-2} yr^{-1} (Note, 1000kg = 1 metric ton). From Howarth et al., 2002.

If management of N is key to protecting and preserving coastal systems in the northeast region, consideration must be given to the atmospheric deposition of N to coastal watersheds or directly onto the surface waters of coastal embayments and estuaries (Valigura, et al., 2000). Nearly 40% of new N entering into the New York Bight is thought to come from atmospheric deposition (Valigura et al. 1996). Valiela et al. (1992) estimated that nearly 30% of new N in Waquoit Bay, Massachusetts was derived from atmospheric deposition. For Long Island Sound, approximately 13-16% of the total nitrogen load is attributed to atmospheric deposition. How atmospheric N is deposited onto coastal watersheds and transported into estuaries is poorly understood. Estimates of N flux that rely on landuse export coefficients often are derived from empirical data and extrapolated from watershed to watershed. In many cases, little consideration is given to the differing role of atmospheric deposition when applying these coefficients across watersheds. These estimates may provide considerable error to nutrient budgets (Valiela et al. 2002, Howarth et al., 2002).

Knowledge on the transport, sources, and attenuation of nutrients from terrestrial areas to coastal waters is necessary if we are to understand the responses of chemical, biological and physical features in coastal waters. In addition to the importance of understanding N delivery to coastal waters, other nutrients such as phosphorus (P), silica and iron also play critical roles in coastal ecosystems.

Nutrient Monitoring in Rivers and Coastal Waters

Monitoring of riverine systems tributary to coastal waters for the concentrations, loads and yields of nutrients are an important and necessary component in understanding how these nutrients influence coastal ecosystems. This monitoring information can then be used to prepare calibrated assessments of nutrient contributions over time to coastal waters and provide insight or direct knowledge on nutrient trends over time and the sources of the nutrients. Results of monitoring and research efforts have important implications to the success of management since they potentially identify the primary sources and also can be used to evaluate the success of implemented management actions.

Present (2002) monitoring of nutrients in United States tributaries to the coastal waters of the Northeast Atlantic Ocean has been extremely limited over the past 10 years. From the mid-1970s to early 1990s the U.S. Geological Survey (USGS) operated National Stream Quality Accounting Network (NASQAN) monitoring at the downstream end of many of the larger tributaries to coastal waters. This monitoring consisted of routine (6-12 times yearly) sample collection for dissolved ions and nutrients. Stream flow data was collected at or near the location of quality monitoring so that loads and yields could be determined. In the mid 1990s this network was significantly modified and all monitoring for this network was discontinued in the Northeast US. In the mid 1990s the USGS began the National Water-Quality Assessment Program (NAWQA) that include routine monitoring of selected rivers for dissolved ions and nutrients. In New England, two NAWQA studies have been conducted. Presently, monthly monitoring of the Connecticut, Charles, and Merrimack Rivers near the head of tide are being performed by the NAWQA Program. The States of Connecticut and Rhode Island also have been conducting routine water-quality monitoring of rivers for the past 2-3 decades, often in conjunction with USGS; this monitoring also includes dissolved ions and nutrients. Other states in the Northeast Region have conducted routine chemistry monitoring of rivers in the past, but have, for the most part, reduced their monitoring to certain years or times of the year or have adopted alternative monitoring strategies (e.g. biomonitoring).

It is unfortunate that recent declining federal and state budgets are resulting in many Northeastern states unable to maintain a commitment to long-term monitoring efforts. These “routine” monitoring programs are often categorized as “nonessential” in comparison to required regulatory monitoring efforts, such as those required for the total maximum daily loads (TMDLs). This is extremely ironic, since the long-term datasets are much more useful in recognizing real trends in sources vs climate-driven changes, while short-term monitoring efforts (usually 1 yr surveys) are plagued by significant inter-annual variability due to year-to-year changes in weather patterns and hydrologic conditions.

Academia has also been conducting nutrient monitoring at selected research sites or areas in the Northeast US. The University of New Hampshire has monitored selected coastal New Hampshire and Maine rivers during the past decade and used this data to generate regional nutrient flux estimates. The Plum Island Long-term Ecological Research Site has been collecting nutrient data for the Ipswich and Parker Rivers and Plum Island Sound area of northern Massachusetts since the late 1980s (http://ecosystems.mbl.edu/PIE/over.htm).

Regional monitoring data has been used by NOAA and USGS to conduct regional assessments of nutrient loads to and effects within coastal waters. NOAA 's National Estuarine Eutrophication Assessment (Bricker et al., 1999) used a knowledge engineering approach and the participation of nearly 400 experts who provided water quality data for six variables (Chl a, epiphyte and macroalgae abundance, dissolved oxygen concentration, occurrence of HABs, and losses of SAVs) to assess the status of nutrient related water quality in 139 coastal systems along the Pacific, Gulf of Mexico and Atlantic coasts of the U.S. The condition assessments were complemented by source inputs estimated by the USGS SPARROW model (see below) and with data showing the susceptibility to eutrophication based on flushing and dilution characteristics. Experts were asked to make evaluations of the future outlook for 2010 based on historical trends, present condition, and knowledge of water shed activities including management actions either implemented or planned.

Results of this study show that more than half of the systems studied (84 of 139) have moderate to high levels of nutrient over-enrichment effects. The future outlook assessment indicated that overall eutrophication, conditions will worsen in 86 systems, and improve in only 8 systems, during the next 20 years. For most systems with high level eutrophic conditions, human related nutrient inputs were identified as the primary influencing factors. However, many of these systems also had contributing natural characteristics, such as low tidal exchange that enhance the expression of symptoms. It is believed that systems that are highly susceptible and show high level of problems will require greater effort to reduce symptoms than systems with high level problems that have good flushing characteristics. A note of caution is provided however, because flushing is linked to rainfall for many systems, and estuaries, such as Narragansett Bay, which are considered “low risk” for impacts due to classification as a well-mixed estuary” may in fact be experiencing significant but intermittent hypoxia and other negative impacts due to the dynamic cyclic nature of the tides (neap vs spring) as well as increased variability in the temporal delivery of seasonal rainfall / stormwater.

The USGS prepared a national water-quality model for N and P called SPARROW (Spatially Referenced Regressions on Watershed Attributes) that consisted of a calibrated statistical model that related observed nutrient loads to upstream watershed characteristics and nutrient sources and then used these relations to predict loads in unmonitored waters (Smith et al, 1997). Currently USGS is developing a customized SPARROW model for New England. This model will provide estimates of annual mean N and P loads for all streams in New England and the sources of the N and P. Preliminary results of the New England SPARROW model show that atmospheric deposition, municipal wastewater discharges, and urban and agricultural land uses are the significant predictors of N in New England streams. In addition, the preliminary model does not detect significant amount of attenuation of N in streams.

The Need for a Comprehensive Monitoring Program in the Northeast Atlantic

Nutrient over-enrichment is often first observed in localized systems. In reality, total nutrient loadings are clearly increasing on larger scales (Howarth et al, 2002, Paerl et al, 2002, Seitzinger et al, 2002) Management responses therefore need to occur at many scales, from national and regional (for atmospheric N) to local for more specific sources such as land use, stormwater, and wastewater. National leadership can assist in providing new technologies for monitoring, managing nutrient source in watersheds that transcend jurisdictions, and managing large regional sources such as atmospheric deposition (Greening and Elfring, 2002). Despite the work that has been done, and that is currently ongoing, there is presently no regionally coordinated monitoring of Northeastern US rivers for nutrient conditions and trends. In addition, the atmospheric contribution of nutrients (largely N) within watersheds needs to be more clearly quantified spatially as does the contribution of long-range transport versus local atmospheric sources. This lack of adequate monitoring limits our present ability to conduct regional and smaller scale nutrient loading assessments. A routine regionally -based riverine and atmospheric deposition monitoring program is needed to assess how our coastal waters are being influenced by activities on the land, both in terms of determining how nutrient amounts are being driven by certain sources and how the nutrients are changing over time. A well thought out selective and coordinated monitoring program could determine nutrient loads from the larger US drainages (Connecticut, Blackstone, Charles, Merrimack, Saco, Androscoggin, Kennebec, Penobscot, and St. Croix drainages) efficiently over time.

Recommendations

Recommendations from the CICEET Nitrogen workshop should be used as the basis for a coordinated nutrient monitoring program. Foremost is 1) the development of a classification scheme for embayments and estuaries of the North Atlantic region in order to guide the development of a consistent and coordinated monitoring approach, 2) developing standardized nutrient monitoring protocol that are based on the classification scheme above, and 3) initiating routine nutrient monitoring at the downstream end of all major tributary inputs to coastal waters. This monitoring strategy should also be sympathetic to the apparent rapid intra- and inter-annual changes of nutrient flux that our coastal waters are experiencing.

References and Additional Readings

American Geophysical Union, 2001, Coastal and Estuarine Studies. No 58. Coastal Hypoxia, Consequences for Living Resources and Ecosystems. N. Rabalais and R.E.Turner, Eds. Washington, D.C. 463 p.

Bricker, S.B., Clement, C.G., Pirhalla, D.E., Orlando, S.P., and Farrow, D.G.G., 1999, National estuarine eutrophication assessment: effects of nutrient enrichment in the nation's estuaries. Special Projects Office and the National Centers for Coastal Ocean Science. National Ocean Service, National Oceanic and Atmospheric Administration, Silver Spring, MD.

Diaz, R.J. and Rosenberg, R., 2001, Overview of anthropogenically-induced hypoxic effects on marine benthic fauna. pp.129-145. *In:* Coastal and Estuarine Studies. No 58. Coastal Hypoxia, Consequences for Living Resources and Ecosystems. N. Rabalais and R.E.Turner, Eds. AGU, Washington,D.C. 463 pp.

Greening, H. and Elfring, C., 2002, Local, state, regional, and federal roles in coastal nutrient management, *Estuaries*, 25(4B), p. 838-847.

Howarth, R.W., Sharpley, A., and Walker. D., 2002. Sources of nutrient pollution to coastal waters in the United States: Implications for nutrient over-enrichment of coastal waters, *Estuaries*, 25(4B), p. 656-676.

New York State Department of Environmental Conservation and Connecticut Department of Environmental Protection, 2000, A Total Maximum Daily Load Analysis to Achieve Water Quality Standards for Dissolve Oxygen in Long Island Sound.

Paerl, H.W., Dennis, R.L., and Whitall, D.R., 2002, Sources of nutrient Pollution to coastal waters in the United States: implications for achieving coastal water quality goals, *Estuaries* 25(4B) p. 677-693.

Seitzinger, S.P.,Kroeze, C., Bouwman, A., Caraco, N., Dentener, F., and Styles, R. 2002. Global patterns of dissolved inorganic and particulate nitrogen inputs to coastal systems: recent conditions and future projections. *Estuaries* 25(4B) p. 640-655.

Smith, R.A., Schwarz, G. E., and Alexander, R.B., 1997, Regional interpretation of water-quality monitoring data, *Water Resources Research*, 33(12), p. 2781-2798.

Sowles, J. 2001. Nitrogen in the Gulf of Maine: sources, susceptibility, and trends. White Paper No. 1 *in* Workshop Report- 2001: Managing Nitrogen Impacts in the Gulf of Maine prepared by the NOAA/UNH Cooperative Institute for Coastal and Estuarine Environmental Technology, the Gulf of Maine Council on the Marine Environment, and NOAA's National Ocean Service.

Valiela, I., Foreman, K., LaMontagne, M., Hersh, D., Costa, J., Peckol, P., DeMeo-Anderson, B., D'Anvanzo, D., Babione, M., Sham, C.-H., Browley, J., and Lajtha, K. , 1992, Couplings of watersheds and coastal waters: sources and consequences of nutrient enrichment in Waquoit Bay, Massachusetts., *Estuaries*, 15, p. 443-457.

Valiela, I., Bowen, J.L., and Kroeger, K.D., 2002. Assessment of models for estimation of land-derived nitrogen loads to shallow estuaries, *Applied Geochemistry*, 17 p. 935-953.

Valigura, R.A, Alexander, R.B., Castro, M.S., Meyer, T.P., Paerl, H.W., Stacey, P.E., and Turner, R.E., editors, 2000, Coastal and Estuarine Studies – Nitrogen Loading in Coastal Water Bodies – An Atmospheric Perspective, American Geophysical Union, Washington, D.C., 254 p.

Valigura, R., Luke, W., Artz, R., and Hicks, B., 1996, Atmospheric nutrient inputs to coastal areas: reducing the uncertainties. U.S. National Oceanic and Atmospheric Administration Coastal Ocean Program Decision Analysis Series No. 9. Washingtion, D.C.,