AED Peer Review '07

Stressor-Response Relationships for Nutrients: Nutrient-Chlorophyll Relationships, Classification Methods, and Modeling Techniques (Water Quality MYP)

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cy Problem:

us studies have shown that excess loading of nutrients is a major cause of impairment of water quality and ecological condition in estuaries and coastal ents. To address this issue, USEPA's Office of Water has begun developing nutrient criteria for estuaries. However, current understanding of estuary es to nutrients is inadequate for regulatory purposes. Nutrient Effects Research at AED is part of a nutrients research program for marine systems and the Great at is being conducted under the Aquatic Stressors Framework by several NHEERL divisions. Research conducted at AED, the Gulf Ecology Division and the Ecology Division is intended primarily to support the Office of Water in setting nutrient criteria in estuaries and other coastal embayments. Secondary clients s, tribes, and other local and regional planning and regulatory entities.

Effects Research at AED is focused on the effects of nutrient loading on reductions of dissolved oxygen in the water column, abundance of submerged aquatic on (SAV), and abundance of phytoplankton (an indicator for estuarine food webs). Research on dissolved oxygen and SAV is described in two companion The research described here addresses responses of phytoplankton distribution and abundance in estuaries to nutrient concentration distributions, classification ies by response to nutrients, and the modeling techniques used to support nutrient research.

rch Goals:

of our research is to inform nutrient criteria development. Ecological and water quality impacts of nutrient inputs vary among estuaries, and with position single estuary. Factors governing estuary-to-estuary differences in response, and spatial distribution of response, are not well understood, and are the focus search. This poster describes research on phytoplankton-nutrient relationships, estuary classification, and computer simulations of global and local residence estuaries. The research addresses the following questions.

- How are chlorophyll *a* and nutrient concentrations distributed in estuaries?
- What is the temporal variation in chlorophyll *a* and nutrient concentrations in estuaries?
- What factors influence spatial and temporal variation of chlorophyll *a* and nutrients in estuaries and their relationships?
- Does classification of estuaries aid understanding of chlorophyll *a* response to nutrients?
- What factors influence the ecological and water quality responses of an estuary to nutrients?
- What factors influence overall nutrient concentrations in estuaries?
- What nutrients are important in determining chlorophyll *a* concentrations in estuaries?
- How should estuaries be segmented in developing nutrient criteria?

ods/Approach:

nination of Nutrient-Chlorophyll Relationships and Estuary Classification

egression to determine relationships between concentrations of chlorophyll *a* and total nitrogen otal phosphorus (TP) in surface waters of estuaries. The main focus has been to develop hips for summer (June, July, August). Relationships are developed for individual summers, and for ar averages. Concentrations of chlorophyll *a* and TN or TP are averaged over each summer for each an estuary; for long-term response, the values for single summers are averaged over several years. our analysis includes data for ten estuaries: Boston Harbor/Massachusetts Bay, Long Island he Peconic Estuary, Delaware Bay, Chesapeake Bay and four tributaries (the Patuxent, Potomac, nnock, and James Rivers), and Tampa Bay.

oach to exploring methods for estuary classification is to compare among estuaries the response for chlorophyll *a* to nutrients, to determine similarities and differences in these responses, and to factors that affect these responses.

Figure 1: Locations of the study systems.

ng of Water Quality, Hydrodynamic Transport, and Water Residence Time

late the annual spatially-averaged concentration of total nitrogen in an estuary using the equation

$$[TN]=\left(\frac{L\tau}{V}+[N_s]\right)\frac{1}{1+\alpha\tau}$$

- [TN] is the average concentration of TN in the estuary,
- L is the loading rate of TN (mass time^{-1}),
- τ is the flushing time of the estuary,
- V is the estuary volume,
- $[N_s]$ is the background concentration in the estuary attributable to input across the seaward boundary, and
- α is the first-order rate coefficient for nitrogen loss within the estuary to processes such as denitrification and burial in sediments.

e of α is 0.3 mo^{-1} (Dettmann, 2001). The value of $[N_s]$ can be estimated from the mean salinity in the estuary and the salinity and concentration of total at the seaward boundary of the estuary (Dettmann, 2001).

wo-dimensional models (RMA2 and RMA4) to simulate hydrodynamics and contaminant transport, and to determine global and local water residence times es. Residence times are simulated by beginning the model run with initial concentrations of a conservative tracer in each estuary, and calculating e-folding tracer concentrations in the estuary as a whole or in estuary segments. This modeling is being conducted in support of other components of our Nutrient esearch, e.g. development of models of seagrass and benthic response to nutrient loading and for the e-Estuary Program. These components are described in npanion posters.

ts:

Distribution of Nutrients and Chlorophyll *a* in Estuaries

and 3 show multi-year average summer concentrations of nitrogen and chlorophyll *a* in surface waters at individual stations in Long Island Sound and the nnock River. These concentrations are plotted as a function of distance along the longitudinal axis from a point in the inner estuary. In each case, points at the d side of the graph are near the seaward boundary. The concentration gradients shown here are representative of spatial trends seen in all our study systems.

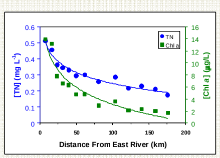

Figure 2. Average summer TN and chlorophyll *a* concentrations for 1995–2001 vs. distance along the longitudinal axis of Long Island Sound. Concentrations are highest near New York City.

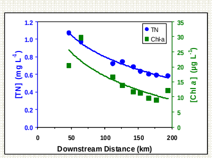

Figure 3. Average summer TN and chlorophyll *a* concentrations for 1999–2004 along the length of the Rappahannock River. Concentrations are highest in the upper river reaches.

Temporal Variability in the Response of Chlorophyll *a* to Total Nitrogen in Long Island Sound:

Between-season and year-to-year variations in the response of chlorophyll *a* to nutrients were examined in Long Island Sound. Data were from all stations shown in Figure 4 except Station A2. Data were collected by the Connecticut Department of Environmental Protection.

The average (1995–2001) response of chlorophyll *a* to TN by season is shown in Figure 5. Each season is a three-month period (winter = December–February, spring = March–May, summer = June–August, fall = September–November). Regressions are for a power function ($[\mathrm{Chl}\ a] = a\,[TN]^b$), where square brackets indicate concentrations, and "a" and "b" are regression coefficients. There are substantial differences in chlorophyll *a* response to TN among seasons, with summer response strongest and winter response weakest.

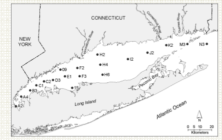

Figure 4. Long Island Sound, with sampling stations. The East River enters the Sound at Station A2.

Year-to-year differences in summer response of chlorophyll *a* to TN are shown in Figure 6. The regression parameter "a" is the concentration of chlorophyll *a* at a TN concentration of 1 mg L^{-1}, "b" is the slope of the regression on a log-log plot. The response relationships differ among years in the value of their intercept with the [TN] = 1 mg L^{-1} axis ("a"), but ANCOVA analysis strongly indicates that there is no statistical difference among slopes for all years except (marginally) 1996. Examination of environmental variables that could influence nutrient inputs and phytoplankton response indicates that 1996 had the highest river flows, and that 1997, 1998, and 1999, the years with the lowest values of "a", were preceded by winters having the highest water temperatures.

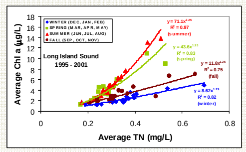

Figure 5. Average seasonal response of chlorophyll *a* to total nitrogen in Long Island Sound. Concentrations of chlorophyll *a* and TN for each season are averaged for 1995–2001.

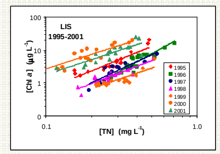

Figure 6. Average concentrations of chlorophyll *a* vs. TN for individual summers. This plot has logarithmic axes.

Comparability Among Estuaries/Classification

The other estuaries in our study showed year-to-year variability in the response of chlorophyll *a* to TN comparable to that in Long Island Sound. Therefore, only multi-year averages of summer data were used to perform comparisons among systems.

Figure 7 shows chlorophyll *a* vs. TN concentrations for all ten estuaries in our study. This plot indicates that there are striking similarities in the response of chlorophyll *a* to TN in most of these estuaries, although there is considerable scatter about the regression.

Data for the four estuarine embayments (Boston Harbor, Long Island Sound, the Peconic Estuary, and Tampa Bay) are plotted separately in Figure 8. Power law regressions for individual systems are strong. ANCOVA analysis shows that the values of parameter "b" for these four systems are not significantly different. However, each system has a characteristic value of the intercept parameter "a".

Water clarity, as measured by total suspended solids (TSS), varied within narrow margins for each of these systems, except at isolated stations, but there were differences in mean TSS concentrations among systems (Dettmann and Kurtz, 2006). Regression of "a" on mean TSS for these systems yielded a strong regression, shown as the dashed line in Figure 9. Therefore, all four model lines in Figure 8 can be approximated using a single equation:

$$[\mathrm{Chl}\ a]=(-6.19[TSS]+115)[TN]^{2.28}$$

where the quantity in parentheses is the regression equation for estuarine embayments in Figure 9 and 2.28 is the mean of the four values for "b" in Figure 8.

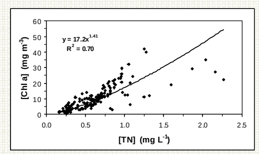

Figure 7. Chlorophyll vs. TN concentrations for all 10 estuaries.

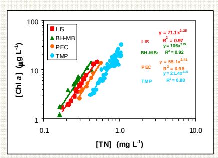

Figure 8. Mean long-term summer concentrations of TN vs. chlorophyll *a* at individual stations in estuarine embayments: Long Island Sound (LIS), Boston Harbor-Massachusetts Bay (BH-MB), the Peconic Estuary (PEC), and Tampa Bay (TMP).

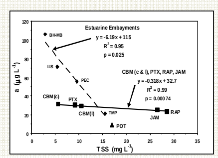

Figure 9. Relationships between average TSS and intercept parameter "a" for estuarine embayments (dashed line) and segments of river-dominated estuaries having narrow TSS ranges (solid line). Symbols for estuaries are defined in Figs. 8, 10, and 11.

The behavior of river-dominated estuaries is more complicated than that for embayments. Data and regression equations for river-dominated estuaries are shown in Figure 10. The Patuxent River is not included because no significant regression was obtained for the overall estuary. Regression models vary greatly from system to system. Concentrations of TSS within these systems are highly heterogeneous, with regions of high and low values, and regions with strong gradients within many systems. Regressions for regions within these estuaries having relatively homogeneous TSS concentrations are shown in Figure 11. Slopes of these regression models are less variable than those shown in Figure 10. The mean slope parameter "b" is somewhat smaller than that for the estuary embayments (see relationship for Tampa Bay, included for comparison). Values of the intercept parameter "a" for all these regressions (except the Potomac) are strongly correlated with TSS (solid line in Figure 9). The regression equation for "a" vs. TSS in river-dominated systems has a much smaller slope than that for estuarine embayments.

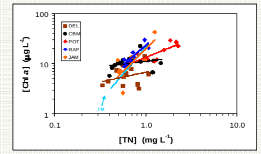

Figure 10. Data and regression line for all data in river-dominated estuaries: Delaware Bay (DEL), Chesapeake Bay Mainstem (CBM), Potomac River (POT), Rappahannock River (RAP), James River (JAM). The Patuxent River is not included. Regression line for Tampa Bay (TMP) is included for comparison.

Narrow TSS Range

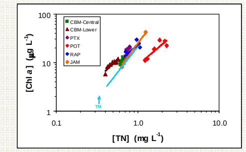

Figure 11. Data and regression lines for segments of river-dominated estuaries having narrow ranges of TSS. PTX designates the Patuxent River. Regression line for Tampa Bay is included for comparison.

Modeling

Nitrogen Box Model

Annual and spatial average concentrations of total nitrogen have been calculated for Narragansett Bay (RI), Boston Harbor (MA) before and after diversion of the outfall of the Boston sewage treatment plant, and Great Bay (NH) using the Estuary Nitrogen Model developed at AED (Dettmann, 2001). These applications used loading rates calculated by the USGS SPARROW model or monitoring data. Calculated and observed values are compared in Figure 12. This model is being used to calculate the sensitivity of Great Bay to nitrogen loading rates in support of the New Hampshire Department of Environmental Services' efforts to develop nitrogen standards for Great Bay.

Simulation Models

Hydrodynamics and related transport processes help determine nutrient and biotic distributions in estuaries. At a less detailed level of analysis, flushing time determines the sensitivity of nutrient concentrations in an estuary to loading from the watershed and determines export rates of plankton and nutrients from the estuary (Dettmann, 2001). We use the hydrodynamics and transport models RMA2 and RMA4 to simulate current patterns, hydrodynamic transport, and flushing time at the global (system-wide) and local scales in estuaries. This work supports other components of AED's Nutrient Effects Program. Simulation of local residence times is also expected to aid in estuary segmentation for management purposes, and supports AED's e-Estuary Program.

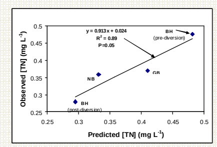

Figure 12. Predicted vs. measured average concentrations of TN in Narragansett Bay (NB), Boston Harbor (BH) before and after diversion of a large sewage outfall, and in Great Bay (GB).

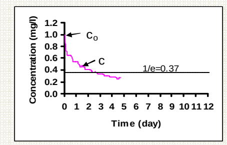

Figure 13. Global and local residence times are estimated as the simulated e-folding time of the concentration of a conservative tracer.

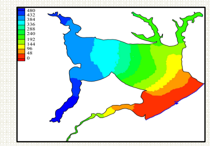

Figure 14. Simulated local residence times (hours) for Greenwich Bay, Rhode Island.

Conclusions:

The results of analysis of chlorophyll *a*:TN relationships have several implications for management of the ecological impacts of nitrogen loading to estuaries.

- Estuary response to nitrogen input is not uniform: there are spatial gradients of nitrogen and chlorophyll *a* concentrations.
- Regression analysis of spatial concentration trends permits development of chlorophyll *a*:nitrogen response relationships.
- Substantial year-to-year differences in response relationships indicate the need for data from multiple years.
- Year-to-year variability around average response must be considered in assessing potential extremes.
- Grouping of estuaries into classes is informative. Responses for the 10 systems differed between classes, within a class they showed strong similarities.
- Water clarity is an important key to understanding variability in responses. Water flow and temperature explain some of the year-to-year variability.
- Simulation techniques allow analysis of global and localized water residence times, and factors that influence them.

Impact and Outcomes:

Technical approaches and models we are developing support the Office of Water in its efforts to develop nutrient criteria for estuaries, and may be helpful to states in developing nutrient standards for these systems. We have provided additional support to USEPA by participation in the National Estuaries Experts Workgroup convened by the Office of Water, and have supported the New Hampshire Department of Environmental Services in development of nutrient standards for the Great Bay Estuary. Nutrient criteria will help ensure that estuarine water quality and ecosystems are protected from degradation as a result of anthropogenic nutrient inputs.

Future directions:

Future research efforts will be dictated by the need to extend and refine approaches currently employed and by the needs of the evolving Water Quality MYP. Further development of this research will require continuing interaction across NHEERL and ORD, and involvement by EPA's Program and Regional Offices to ensure that our research directions and approaches are compatible with their needs. Examples of further required research are:

- Complete analysis of chlorophyll *a*:TP relationships,
- Examine factors causing year-to-year variation in chlorophyll *a*:nutrient relationships,
- Extend analysis of chlorophyll *a*:nutrient relationships to additional estuary types, e.g. lagoons and fjords,
- Explore factors other than TSS that influence chlorophyll *a*:nutrient relationships,
- Explore application of local residence time and other factors to estuary segmentation.

References:

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Dettmann, E.H. and J.C. Kurtz. 2006. *Responses of Seagrass and Phytoplankton in Estuaries of the Eastern United States to Nutrients: Implications for Classification.* Vol. 1 of Final Report for APM #446, APG #2008.335, Proposed Classification Scheme for Coastal Receiving Waters Based on SAV and Food Web Sensitivity to Nutrients. Submitted to USEPA Office of Water, Office of Science and Technology.

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