Final Report Summary

Marked similarities in the along-sound gradients in measurements of primary production (Goebel et al. 2006), the frequency of hypoxia in the bottom waters (CT-DEP), and external loads and internal concentrations of nitrogen (NY-DEC & CT-DEP 2000) of Long Island Sound (LIS) support the idea that nitrogen driven increases in primary production result in the major source of organic matter that leads to summer hypoxic events in this estuarine system. Comprehensive management plans are currently in place to reduce nitrogen inputs to LIS, with the aim to reduce observed hypoxic events. Such managerial decisions call for an accurate, predictive model of LIS that is practicable for the management of this highly eutrophic, seasonally hypoxic system. Recent attempts to numerically model production in LIS (HydroQual 1996; HydroQual 1999) however, provide examples of complex, uncorroborated models that require tuning of a high number of parameters in order to obtain the desired output. Furthermore, support for these models relies on predictions of stocks (e.g. phytoplankton biomass) without confirmation of the underlying rates critical for an accurate, predictive model of processes (e.g primary production) that lead to reduced bottom water oxygen concentrations.

We have formulated an alternative model to the complex, highly parameterized models currently used to assess the reduction in nitrogen loads necessary to alleviate hypoxia in LIS. The model is simplified by reducing the number of state variables and parameters necessary to adequately describe the system, and the values and numbers of free parameters constrained with the use of consistent semi-empirical relationships to model the keystone processes thought to influence oxygen dynamics in LIS. Reduction in the complexity of our modeling approach allows for improved investigation and understanding of the complex relationship between oxygen production and consumption processes and low oxygen concentrations in LIS, that is often masked by a high number of poorly-constrained parameters. Furthermore, such a simplistic model bolsters its utility as a management tool for evaluating present efforts to reduce nitrogen loads, hence hypoxia, in LIS.

This research has built upon the output of a previously EPA-funded study of Long Island Sound (LIS) "Water Column and Oxygen Production and Consumption: Measurement and Modeling (EPA Cooperative Agreement X-98164401)". In the previous study, a comprehensive set of measured rates of oxygen production and consumption throughout central and western LIS on 15 cruises during 2002 and 2003 enabled (1) characterization of temporal and spatial variations in primary production and community respiration and relationships to phytoplankton stocks and physico-chemical environmental variables (Goebel & Kremer In Press), and (2) annual measurements of primary production and the formulation of a primary production model specific to LIS (Goebel et al. 2006). This sub-model for primary production was then incorporated into a two-layer, time varying (0-dimensional) ecological model that also included export from the photic zone (upper layer) to the aphotic zone and benthos (lower layer), heterotrophic consumption in the water column and benthos, and benthic remineralization.

The primary objectives of the present study were to (1) implement this 0-d, two-layer ecological model in a 1-d vertically structured water column that varies with time, (2) refine, improve and test the consistency of this 1-d physical-ecosystem model, (3) assess the eco-physical model in a comparison of model output to measured concentrations of phytoplankton biomass (as chlorophyll), and rates of oxygen production (i.e. primary production) and consumption (i.e. respiration) in LIS, as well as published relationships between nitrogen loads and phytoplankton biomass and production (4) utilize the model to address management issues of hypoxia in the bottom waters of Long Island Sound by exploring the connection of nitrogen source loading with hypoxic events.

In a series of model runs that test the effects of increased external nitrogen loads to phytoplankton production and stocks (as chlorophyll) in LIS, we were able to demonstrate the consistency between modeled output of rates and stocks with and the cross-system relationship of increased chlorophyll stocks and rates of primary productivity with inputs of nitrogen (Nixon 1992). The cross-system comparison of Nixon's (1992) is independent of the formulation used to model primary production in our ecological physical model, hence comparison of our model output with this independent relationship serves as an independent corroboration of the accuracy of the formulation for primary production (and phytoplankton stocks) implemented in our model.

We also tested a modification of another semi-empirical formulation in our ecological-physical model, which predicts the average annual deposition of organic matter, hence oxygen demand (Borsuk et al. 2001) in LIS. In our model, we assumed that the primary source of carbon/oxygen demand, was from autochthonous (primary) production. Comparison of modeled daily rates of respiration in the aphotic portion of the water column over a series of model runs to measurements of water column respiration throughout LIS yielded a large inconsistency in the physical-ecological model. Measurements of oxygen consumption in LIS were 2-10 times larger than that calculated by the model. This discrepancy lead to further investigation of measured and modeled rates of oxygen consumption in LIS.

We determined that this disagreement between modeled outputs and measurements was not due to the accuracy of our field observations. Several comparisons of our observed data with the literature and other measured proxies for oxygen consumption in LIS indicate that our measurements are not only reasonable, but are also representative of the microbial community specific to the LIS ecosystem. Hence we felt confident that our comprehensive set of community respiration observations, as well as our detailed calculations of GPP (Goebel et al., 2006), in LIS are reasonable and representative of this highly productive system.

In a comparison of measured rates of community respiration (Rcint) and gross primary production (GPPint) integrated over the depth of the water column, the majority of stations sampled (~85%) demonstrated an excess Rcint over GPPint (Goebel et al., In Prep.). These measurements span central and western LIS and the majority of the annual cycle, though they under sample the important winter-spring period. A sound-wide balance demonstrated a similar conclusion. Hence the excess of Rcint over GPPint over nearly all sampled stations and dates clearly challenges the conventional assumption that LIS heterotrophic demand is driven by autochthonous carbon production. This observation suggests that previous assumptions of a predominantly autochthonous-driven system during summer, must also be driven by other source(s) of organic matter and/or oxygen sinks. Without identifying and incorporating such sources and sinks in our ecological-physical model, we cannot accurately model oxygen consumption in LIS.

In conclusion, we have demonstrated a proof of concept in our modeling approach, proposed as a useful alternative to modeling oxygen dynamics in LIS. In our new simplified modeling approach we successfully utilized semi-empirical relationships to replace numerous, unknown parameterized processes. The accuracy of the model thus far was demonstrated through corroborations of model outputs and observed measurements of phytoplankton stocks and production, however inconsistency between model outputs and oxygen consumption in LIS may be attributed to a missing carbon source and/or oxygen sink in our model that accurately represents the LIS system. Incorporation of these missing sources and/or sinks into our ecological-physical LIS model could lead to a simpler, more accurate and practical model for strategizing management of hypoxia in LIS.