CONNECTICUT SEA GRANT PROJECT REPORT

Please complete this progress or final report form and return by the date indicated in the emailed progress report request from the Connecticut Sea Grant College Program. Fill in the requested information using your word processor (i.e., Microsoft Word), and e-mail the completed form to Dr. Syma Ebbin syma.ebbin@uconn.edu, Research Coordinator, Connecticut Sea Grant College Program. Do NOT mail or fax hard copies. Please try to address the specific sections below. If applicable, you can attach files of electronic publications when you return the form. If you have questions, please call Syma Ebbin at (860) 405-9278.

Please fill out all of the following that apply to your specific research or development project. Pay particular attention to goals, accomplishments, benefits, impacts and publications, where applicable.

Project #: __R/CE-34-CTNY__ Check one: [ ] Progress Report [x] Final report

Duration (dates) of entire project, including extensions: From [March 1, 2013] to [August 28, 2015].

Project Title or Topic: Comparative analysis and model development for determining the susceptibility to eutrophication of Long Island Sound embayment.

Principal Investigator(s) and Affiliation(s):

1. Jamie Vaudrey, Department of Marine Sciences, University of Connecticut

2. Charles Yarish, Department of Ecology & Evolutionary Biology, Department of Marine Sciences, University of Connecticut

3. Jang Kyun Kim, Department of Marine Sciences, University of Connecticut

4. Christopher Pickerell, Marine Program, Cornell Cooperative Extension of Suffolk County

5. Lorne Brousseau, Marine Program, Cornell Cooperative Extension of Suffolk County

A. <u>COLLABORATORS AND PARTNERS</u>: *(List any additional organizations or partners involved in the project.)*

Justin Eddings, Marine Program, Cornell Cooperative Extension of Suffolk County
Michael Sautkulis, Cornell Cooperative Extension of Suffolk County
Veronica Ortiz, University of Connecticut
Jeniam Foundation (Tripp Killin, Exec. Dir.) provided additional support to replace malfunctioning equipment.
Save the Sound and The Nature Conservancy have offered help to advertise and disseminate the N-Load tool. Both have funding to support this activity.

B. PROJECT GOALS AND OBJECTIVES:

The overall intent of this project is to develop a statistically based model which employs land-use data coupled with embayment characteristics to identify the Long Island Sound (LIS) embayments at greatest risk for exhibiting symptoms of eutrophication and to identify the main sources of nitrogen (N) to these embayments. This statistical model will yield the relationship between the nitrogen load (N load), estuarine freshwater flushing time, and eutrophic status. If this simple approach does not yield significant results, additional forcing factors will be included. The specific objectives include:

1. QAPP development.
2. Calculate N load estimates for a minimum of 50 embayments using a published model which relates land-use in the watershed to the total N load for the embayment.
3. Calculate estimates of the freshwater flushing time for a minimum of 50 embayments using two methods: (1) a modified tidal prism method and (2) a simplified method developed in embayments which relates estuarine length and surface area to freshwater flushing time.
4. Using the output from Objectives 2 & 3, a published model will be used to estimate the dissolved inorganic nitrogen (DIN) concentration in the embayments. This value will be used to quantify the error of the model outputs predicting N load.
5. Field-based evaluation of ten embayments in New York (NY) and Connecticut (CT) for susceptibility to hypoxia and primary producer community composition.
6. Apply field data to indices developed to identify the trophic status of estuaries. We will use two methods: one developed by the EPA and one developed by NOAA.
7. Develop a statistical model using multivariate analysis techniques to relate the calculated N load (#2), fresh water flushing time (#3), and estuarine trophic status (#6). Develop predictions as to which of the unsampled LIS embayments are most likely to experience symptoms of eutrophication.
8. Using the predictions of eutrophication risk for 50 embayments (#7), develop “report cards” for each embayment detailing potential environmental issues and the likeliest causes. These report cards will be presented to the LISS STAC, community groups and other groups who provided data, NY Sea Grant, CT Sea Grant, Citizen’s Campaign for the Environment (CT and NY) and Save the Sound / CT Fund for the Environment.

C. PROGRESS: (*Summarize progress relative to project goals and objectives. Highlight outstanding accomplishments, outreach and education efforts; describe problems encountered and explain any delays.)*

Progress is described based on objectives presented in section B.:

1. QAPP Development. The QAPP was approved on 11/7/2013. Progress on the approval of the QAPP was originally hindered by the government shut down. However, preliminary approval to proceed with the summer 2013 field work and time critical lab analyses (macrophyte processing for biomass, total suspended solids, chlorophyll analysis) was received on 7/19/2013.

2. Calculate N load to embayments. Work is complete. The results have been presented in a number of different venues, as listed under the presentations section of this report..

3. Calculate flushing times. Work is complete. Flushing time is a crude approximation. While it was useful, we do not consider the results accurate enough to be applied beyond the work presented in this report.

4. Calculate predicted dissolved inorganic nitrogen in the embayments, for comparing to field data. Work is complete. Results were less than satisfactory, work beyond the scope of this project is required to better quantify in-estuarine nitrogen cycling specific to each embayment.
5. Field work in 10 embayments. Work is complete.
6. Identify trophic status of embayments where field sampling occurred. Work is complete.
7. Develop a statistical model linking N load and trophic status. Work is complete. The results are tenuous, as most sites scored the same for eutrophic status - highly impacted. We have provided alternate methods for estimating trophic status from N load.
8. Develop report cards for embayments. Results of this task will be available in the technical report. However, we have change the name to “embayment portfolios” as they are not true report cards. Also, Long Island Sound has a report card process underway and we did not want the two efforts to be confused.

D. PROJECT PUBLICATIONS, PRODUCTS AND PATENTS: *(Include published materials with complete references, as well as those which have been submitted but not yet published and those in press. Please attach electronic versions of any journal articles not previously provided.)*

Journal Articles:

Basso G, Vaudrey JMP, O'Brien K, Barrett J (in review) Landscape scale habitat assessment of the Long Island Sound Estuary, USA.

Conference Papers and Presentations:

Vaudrey, J.M.P. (2016) *Nitrogen Loads to Long Island Sound’s Coves and Embayments*. invited presentation. 2016 Advanced Master Gardener Coastal Certificate Program.

Vaudrey, J.M.P., C. Yarish, C. Pickerell, L. Brousseau, J. Eddings, J.K. Kim, M. Sautkulis (2016) *Embayment Nitrogen Loads for Long Island Sound – Utilizing the Excel Model Interface Workshop*. EPA Region 2 and Suffolk County New York, Cold Spring Harbor, NY.

Vaudrey, J.M.P. (2016) *Water Quality: From Ground to Sound*. panelist, Mystic Aquarium’s Conservation in Action Lecture Series, Mystic, CT. Co-panelists: David Prescott, Save the Bay; Chris Freeman, Clean Up Sound and Harbor.

Vaudrey, J.M.P., C. Yarish, C. Pickerell, L. Brousseau, J. Eddings, J.K. Kim, M. Sautkulis (2016) 3/2/16 “Embayment Nitrogen Loads for Long Island Sound.” EPA Region 2, New York City, NY. (with C. Yarish, C. Pickerell, L. Brousseau, J. Eddings, J.K. Kim, M. Sautkulis)

Vaudrey, J.M.P., C. Yarish, C. Pickerell, L. Brousseau, J. Eddings, J.K. Kim, M. Sautkulis (2016) 2/4/16 “Embayment Nitrogen Loads for Saugatuck River” invited presentation, Saugatuck Water Quality Symposium, hosted by The Nature Conservancy. (with C. Yarish, C. Pickerell, L. Brousseau, J. Eddings, J.K. Kim, M. Sautkulis)

Vaudrey, J.M.P., C. Yarish, C. Pickerell, L. Brousseau, J. Eddings, J.K. Kim, M. Sautkulis (2016) *Embayment Eutrophic Conditions in Long Island Sound*, invited presentation, Save the Sound and the Long Island Sound Report Card Initiative Workgroup.

Vaudrey, J.M.P., C. Yarish, C. Pickerell, L. Brousseau, J. Eddings, J.K. Kim, M. Sautkulis (2015) *Embayment Nitrogen Loads for Long Island Sound*, invited presentation, Long Island Sound Study's Management Committee, Housatonic Community College, CT.

Vaudrey, J.M.P., C. Yarish, C. Pickerell, L. Brousseau, J. Eddings, J.K. Kim, M. Sautkulis (2015) *Embayment Nitrogen Loads for Long Island Sound*, invited presentation, Long Island Sound Study's Citizen Advisory Committee, Housatonic Community College, CT.

Vaudrey, J.M.P. (2015) panelist for 15th Annual Connecticut League of Conservation Voters Environmental Summit. Hartford, CT.

Vaudrey, J.M.P., C. Yarish, C. Pickerell, L. Brousseau, J. Eddings, J.K. Kim (2015) *Nitrogen Loads to Long Island Sound's Coves and Embayments*. invited presentation. Long Island Sound Study Citizen Advisory Committee December Meeting.

Vaudrey, J.M.P. (2015) *Nitrogen Loads to Long Island Sound's Coves and Embayments*. invited presentation. 2015 Advanced Master Gardener Coastal Certificate Program.

Brousseau, L., J.M.P. Vaudrey, C. Yarish, C. Pickerell, J. Eddings, J.K. Kim (2015) *Embayment Nitrogen Loads*. invited presentation, New York State DEC Groundwater symposium.

Vaudrey, J.M.P., C. Yarish, C. Pickerell, L. Brousseau, J. Eddings, J.K. Kim (2015) *Embayment Nitrogen Loads for Long Island Sound*. invited presentation, Long Island Sound Funder's Collaborative.

Vaudrey, J.M.P., C. Yarish, C. Pickerell, L. Brousseau, J. Eddings, J.K. Kim (2015) *Embayment Nitrogen Loads*. invited presentation, joint meeting of the Long Island Sound Study's Science and Technical Advisory Committee and Long Island Sound Study's Citizen Advisory Committee.

Vaudrey, J.M.P., C. Yarish, C. Pickerell, L. Brousseau, J. Eddings, J.K. Kim (2015) *Embayment Rapid Assessment and Evaluation of Eutrophic Status*. invited presentation, New York State DEC and Save the Sound.

Krumholz, J. and J.M.P. Vaudrey, C. Yarish, C. Pickerell, L. Brousseau, J. Eddings, J.K. Kim (2015) *Embayment Nitrogen Loads*. invited presentation, Long Island Sound Study's Citizen Advisory Committee.

Vaudrey, J.M.P. (2015) *Dead Zones, Wetlands, Ocean Acidification and Wildlife: Nitrogen Pollution's Path of Destruction*. invited panelist at the Long Island Sound Citizen's Summit. Co-panelists: H. Baumann (UConn) & L. Suatoni (NRDC); J. Varekamp (Wesleyan U.) moderating.

Vaudrey, J.M.P. (2015) *Eutrophication in Long Island Sound Embayments: using troubled waters as a cross-disciplinary classroom*. invited presentation. UConn ECE Experience.

Dostie, A. and J.M.P. Vaudrey (2014) *Characterization Of The Extent And Source Of Nutrients Supporting A Massive Macroalgae Bloom In Little Narragansett Bay, CT*. New England Estuarine Research Society Fall Meeting.

Leamy, C and J.M.P. Vaudrey (2014) *Extent and Severity of Late Summertime Hypoxia in Connecticut And New York Embayments of Long Island Sound.* New England Estuarine Research Society Fall Meeting.

Vaudrey, J.M.P., C. Yarish, C. Pickerell, L. Brousseau, J. Eddings, J.K. Kim (2014) *Nitrogen Loads to Long Island Sound's Coves and Embayments*. invited presentation. 2014 Advanced Master Gardener Coastal Certificate Program.

Vaudrey, J.M.P., C. Yarish, C. Pickerell, L. Brousseau, J. Eddings, J.K. Kim (2014) *Embayment Nitrogen Loads*. invited presentation, LISS STAC.

Vaudrey, J.M.P., C. Yarish, C. Pickerell, L. Brousseau, J. Eddings, J.K. Kim (2014) *Eutrophic condition and habitat status in Connecticut and New York embayments of Long Island Sound.* invited presentation, CT DEEP's Niantic Nitrogen Work Group.

Vaudrey, J.M.P., C. Yarish, C. Pickerell, L. Brousseau, J. Eddings, J.K. Kim (2014) *Eutrophic condition and habitat status in Connecticut and New York embayments of Long Island Sound.* invited presentation, Southern Connecticut State University.

Vaudrey, J.M.P. (2014) *The Breathing of the Bays: a journey into green water.* invited presentation, Faulkners Light Brigade Lecture Series, Guilford, CT.

Vaudrey, J.M.P. and C. Yarish (2013) *Using Nitrogen Budgets as a Tool to More Effectively Manage Long Island Sound Embayments*. 2nd Workshop on Using Cultivated Seaweed and Shellfish for Nutrient Bioextraction in LIS and the Bronx River Estuary, Mamaroneck, NY.

Vaudrey, J.M.P. and C. Yarish (2013) *Nitrogen loading to embayments of Long Island Sound: method review and potential utility to management*. Presentation to the Long Island Funders Collaborative Meeting, New York City, NY. 01 Mar 2013.

Proceedings or book chapters:

Websites, Software, etc.:

LongIslandSound_NLoadingModel.xlsx - The nitrogen load model available for use by stakeholders to compare sites, investigate sources and trends, and run scenarios.

NLM.mat - The nitrogen lading model in a MatLab format, for academic research purposes.

GIS layers associated with the NLM

Technical Reports:

Vaudrey, J.M.P. for University of Connecticut and Cornell Cooperative Extension of Suffolk County. Comparative analysis and model development for determining the susceptibility to eutrophication of Long Island Sound embayments. QAPP Version 2 – September 9, 2013. EPA identifier RFA#: 13110.

Comparative analysis and model development for determining the susceptibility to eutrophication of Long Island Sound embayments - final technical report. Appendices include embayment portfolios.

Other Products (including popular articles):

Zaretsky, M. (8/4/13) *Low oxygen levels present even in bays in eastern estuary, UConn researchers find.* interview, article, and photos for the New Haven Register. (http://www.nhregister.com/general-news/20130804/low-oxygen-levels-present-even-in-bays-in-eastern-estuary-uconn-researchers-find; http://photos.newhavenregister.com/2013/08/01/photos-marine-researcher-studies-l-i-sound-oxygen/#1)

Publications planned / in progress:

- Eutrophic status in Long Island Sound embayments.
- Patterns of Nitrogen Loads to embayments – targeting NPS reductions
- Macrophyte C:N as an indicator of N-Load and eutrophic status
- Using N-Load and flushing time to predict eutrophic status in embayments and target management actions
- Embayments out of balance – regime shifts related to nitrogen loads

Patents: *(List those awarded or pending as a result of this project.)*

E. **FUNDS LEVERAGED**: *(If this Sea Grant funding facilitated the leveraging of additional funding for this or a related project, note the amount and source below.)*

$5,000 received by Marine Science Bachelor's of Science student, Amanda Dostie. Source: UConn IDEA Grant 2014. Project Title: Tracing the Nutrition Driving *Cladophora* sp. Dominance in Little Narragansett Bay

$1,000 received by Marine Science Master's Student, Rachel Perry. Source: Connecticut Association of Wetland Scientists. Project Title: Bioavailability of organic nitrogen entering small, shallow embayments: when, where, and how much?

F. **STUDENTS**: *(Document the number and type of students supported by this project.)*

*Note: **"Supported"** means supported by Sea Grant through financial or other means, such as Sea Grant federal, match, state and other leveraged funds. If a student volunteered time on this project, please note the number of volunteer hours below.*

Total number of **new*** K-12 students who worked with you: 0
Total number of **new** undergraduates who worked with you: 6
Total number of **new** Masters degree candidates who worked with you: 1
Total number of **new** Ph.D. candidates who worked with you: 0

Total number of **continuing**** K-12 students who worked with you: 0
Total number of **continuing** undergraduates who worked with you: 1
Total number of **continuing** Masters degree candidates who worked with you: 0
Total number of **continuing** Ph.D. candidates who worked with you: 0

Total number of volunteer hours: 0

(Note: * ***<u>New</u>*** *students are those who have <u>not</u> worked on this project previously.* ** ***<u>Continuing</u>*** *students are those who have worked on this project previously.)*

In the case of graduate students, please list student names, degree pursued, and thesis or dissertation titles related to this project.

Student Name: Rachel Perry
Degree Sought: Masters of Oceanography
Thesis or Dissertation Title: Nutrient Dynamics of Floating Seagrass Wracks in Greater Florida Bay
Date of thesis <u>completion:</u> August 2015
Expected date of graduation: August 2015

G. <u>PICTORIAL</u>: Please provide high resolution images/photos of personnel at work, in the field or laboratory, equipment being used, field sites, organism(s) of study. Attach images as separate files (do not embed). Include links to websites associated with the research project. Please include proper photo credits and a caption with date, location, names of people, and activity. These images are useful to document your project in future CTSG publications, websites and presentations.

H. <u>DATA MANAGEMENT PLANS:</u> Proposals funded in 2014-2016 and later cycles are required to have a data management plan in place. All environmental data and information collected and/or created must be made visible, accessible, and independently understandable to general users, free of charge or at minimal cost, in a timely manner (typically no later than two years after the data are collected or created). This is a reminder that your CTSG funded research data needs to be archived and accessible as outlined in the data management plan you submitted with your proposal. If there have been any modifications, adjustments or new information available regarding the location, timing, type, formatting and metadata standards, content, sharing, stewardship, archiving, accessibility, publication or security of the data produced please elaborate here.

Data will be made available as stated in our data management plan. As an additional outlet for data, we will be working with Save the Sound to incorporate embayment data and nutrient load model results into an online viewer, development of this viewer will be funded by Save the Sound. This work will be conducted starting December 2015.

<u>FOR FINAL REPORTS ONLY, PLEASE COMPLETE THIS SECTION:</u>

I. PROJECT OUTCOMES AND IMPACTS

RELEVANCE OF PROJECT: *(Describe briefly the issue/problem / identified need(s) that led to this work.)*

RESPONSE: *(Describe briefly what key elements were undertaken to address the issue, problem or need, and who is/are the target audience(s) for the work.)*

RESULTS: *(Summarize findings and significant achievements in terms of the research and any related education or outreach component; cite benefits, applications, and uses stemming from this project, including those expected in the future. Include qualitative and quantitative results.)*

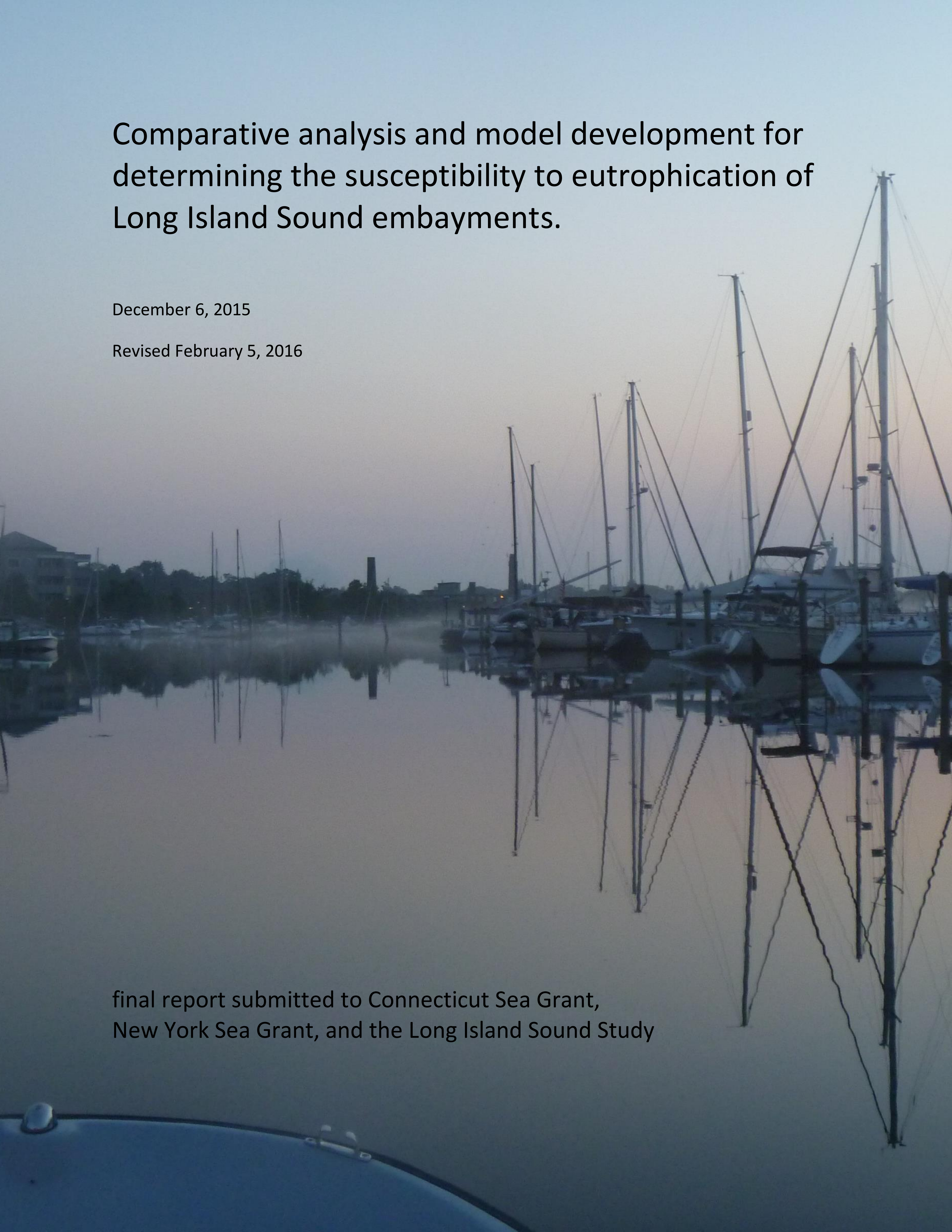
Consider the following as they apply to your research and any related outreach/education.

- What new tools, technologies, methods or information services were developed from this work? Have any been adopted / implemented for use and by whom?

- What are the environmental benefits of this work? Have policies been changed? How has conservation (of ecosystems, habitats or species) been improved?

- What are the social payoffs of this work? Who has benefited from this work? Have attitudes / behaviors of target audience changed? Elaborate. Have policies been changed?

- What are the economic implications / impacts of this work? (Where possible, please quantify.) Have new businesses been created /or existing businesses retained as a result of this research? Have new jobs been created or retained? Are new businesses or jobs anticipated?



Comparative analysis and model development for determining the susceptibility to eutrophication of Long Island Sound embayments.

December 6, 2015

Revised February 5, 2016

final report submitted to Connecticut Sea Grant,
New York Sea Grant, and the Long Island Sound Study

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Citation: Vaudrey, J.M.P, C. Yarish, J.K. Kim, C. Pickerell, L. Brousseau, J. Eddings, M. Sautkulis (2016) Connecticut Sea Grant Project Report: Comparative analysis and model development for determining the susceptibility to eutrophication of Long Island Sound embayments. Project number R/CE-34-CTNY. 46 p.

Embayment Overview

Long Island Sound, sometimes called the “Urban Sea,” is a body of water heavily impacted by the dense populations along it’s coastline. A comparison of the population among the 28 National Estuary Programs across the country places Long Island Sound as the third densest population; only the New York / New Jersey Harbor and San Juan Bay Estuary in Puerto Rico have a greater population density than Long Island Sound (Figure 1) (USEPA OW & USEPA ORD 2007; Basso et al. in review). A fact not captured by these data are the impact the New York / New Jersey Harbor has on Long Island Sound via the East River. A comparison of the total nitrogen load contributed to Long Island Sound from the embayments and the coastal portions of the four largest rivers indicates the East River accounts for 78% of the nitrogen load. Including the load from the whole watershed of each of these fours rivers would further increase their impact on the total load. Long Island Sound’s local load coupled with the influence of the East River arguably makes Long Island Sound the most urbanized of estuaries in the United States.

The embayments of Long Island Sound contribute roughly a fifth of the total load of nitrogen to the Sound, when compared to the coastal portions of the four major rivers; making these areas critical to efforts to reduce nutrient loads. An embayment is defined as a recess in a coastline or an indentation off a shoreline which forms a bay. In Long Island Sound, the names of embayments often include the words

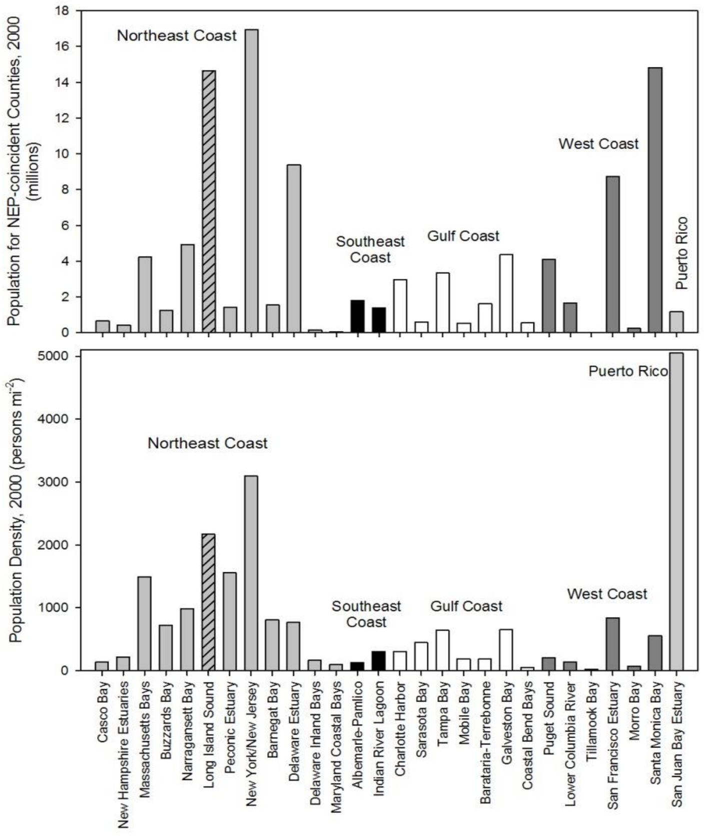


Figure 1: Total population and population density in NEP sites, as calculated from the 2000 census data (USEPA OW & USEPA ORD 2007).
Shading denotes the region of the estuary. LIS is identified by hatch marks. This figure is included in Basso et al. (Basso et al. in review)

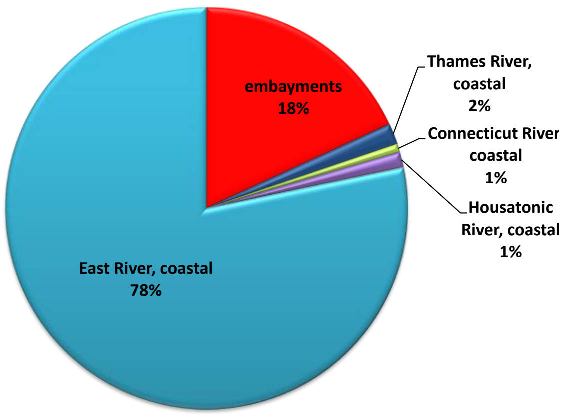


Figure 2: From this study, the fraction of the total nitrogen load attributed to various sources.
For the four major rivers draining to Long Island Sound, only the coastal portion of the watershed (as defined by the border of the HUC 12 units touching the Sound) were assessed.

Harbor (27%), River (23%), Cove (19%), Bay (10%), Creek (10%), and Pond (7%); with a few including the names Brook, Gut, Inlet, or Lake. These embayments are where people interact with Long Island Sound. They are the sites of our marinas and host our beaches and parks. People use embayments for kayaking, swimming, fishing, crabbing, and other recreational activities. These areas serve as nurseries and foraging ground for many commercially and recreationally important species of animals. Embayments are vital to an effective campaign for nutrient reduction to Long Island Sound because they are areas that incite people's passion and interest. While the embayment contribution to Long Island Sound's nitrogen load is relatively small (<20%), people are interested in the local effects of nitrogen on "their" embayment; and these effects can have a substantial impact on local embayment water quality. This local concern can be leveraged to generate actions to reduce loads to the embayments, and perhaps more importantly, to educate people on how and why nitrogen loading is impacting Long Island Sound overall. The environmental movement uses the phrase "Think Global, Act Local" to get people motivated to enact reform. But flipping this phrase to "Think Local, Act Global" is pertinent to the nitrogen load issues for Long Island Sound. By increasing awareness at a local level and encouraging local actions, we will develop a populace with a better understating of why reductions of nitrogen load are critical to creating the Long Island Sound that we want in our backyard.

Results from this study have identified the trophic status in 2011-2014 of fifteen embayments of Long Island Sound, estimated the nitrogen load and sources of nitrogen to all embayments of Long Island Sound, and established a list of embayments most likely to be experiencing the impacts of eutrophication. These results have been presented in a variety of forums beyond academia, including the Long Island Sound Study Estuary Program, New York and Connecticut government agencies, local citizen action groups, and advocacy organizations; as evidenced by the list of presentations provided in this report. The full details of the results will be provided in a technical report accompanied by a brief summary suitable for a general audience, which will be made publicly available through a permanent link via UConn's Digital Commons. The complete dataset of field data and an Excel-based tool for working with the nitrogen loading model will also be available through UConn's Digital Commons. These products will be available following a review by a group external to the project team, including reviewers from all sectors mentioned above in this paragraph. A brief summary of the major findings is provided below.

Nitrogen Loading Estimates

Nitrogen loads to the embayments were estimated using a model employing land use and population patterns to determine the amount of nitrogen reaching the edge of the embayment (Valiela et al. 1997). The model attenuation factors (nitrogen removal processes) and loading rates were modified to reflect local conditions.

Two land cover datasets were used for this analysis. The National Land Cover Dataset for the year 2011 (NLCD-2011) is a nationwide product created by the Multi-Resolution Land Characteristics (MRLC) Consortium (Homer et al. 2015). The Center for Land Use Education and Research (CLEAR) at the University of Connecticut created a land cover dataset for the

Connecticut and New York portions of Long Island Sound's watershed for the year 2010 (CLEAR-2010). With a national coverage, NLCD-2011 provides the ability to utilize a common dataset for other watersheds around the country. The CLEAR-2010 dataset provides greater accuracy in defining the land cover within Long Island Sound's watershed.

The number of houses and population within each zone of the watershed were determined from the 2010 U.S. Census data, which provides information on both population and housing. Watershed boundaries do not align with census block boundaries, thus census blocks were divided and apportioned to the correct watershed. Two methods were used to assign houses and population to the correct zone: a census block-based method and a dasymetric analysis. The census block method is easier to perform, but the dasymetric analysis is more accurate. From a research standpoint, we were interested in assessing the error of using the census block method. For the purposes of calculating the nitrogen loads, the dasymetric analysis is the preferred method. All results presented use the dasymetric analysis.

People within sewered and CSO areas were determined by analyzing the population within the defined sewer or CSO areas; available from CT, NY, and RI. Nitrogen loads from waste water treatment facilities (WWTFs) were determined from data obtained from CT DEEP (and RI DEM for Pawcatuck River), which track the reported loads for all major WWTFs in the Long Island Sound area. A four-year average (2011-2014) of the nitrogen load was used, except in cases where upgrades to the facility were completed during this time period. In cases where upgrades were completed, only data for the resulting lower contribution of N were included. All remaining people not on sewer were assumed to be utilizing traditional septic systems for areas not on Long Island. For Long Island, the vertical septic systems act more like a cesspool in terms of nitrogen reduction. Injection of waste water to a series of rings oriented vertically is designed to place the waste deeper into the ground. These vertical drain fields greatly reduce nitrogen attenuation in the vadose zone, where the greatest biological activity occurs. Thus while 53% of homes not on sewer on Long Island are estimated to use cesspools, all are treated as cesspools in the model.

Attenuation data (N removal) and loading rates were adjusted to reflect locally relevant information. For example, the original model uses a default attenuation of 35% in the aquifer, thus 65% of nitrogen reaching the aquifer travels to the embayment. However, more recent work evaluating the attenuation of nitrogen in the aquifer on the north shore of Long Island (Northport Bay area) indicated the attenuation factor of 35% (with 65% passing through to the embayment) was too high (Young et al. 2013). Young and colleagues (2013) attribute the lower rate of denitrification (and thus lower attenuation) to insufficient organic carbon available to support higher levels of denitrification mediated by heterotrophic bacteria. In addition to the low organic carbon levels, oxygen levels in the aquifer were observed to be high enough to inhibit the anaerobic denitrifying bacteria. The analysis of denitrification in the Northport area indicated an average attenuation of nitrogen in the aquifer of 15.6% with a range of 5.3% to 33.5%. The denitrification rate in the glacial aquifer of Connecticut and Westchester County, NY are also predicted to exhibit lower rates of N attenuation similar to the values found on Long Island, based on a number of studies conducted in Connecticut (Mullaney 2007; McMahon et al. 2008; Hinkle & Tesoriero 2014). Given that nitrogen load to groundwater has been increasing in the last few decades, a more conservative estimate of the denitrification capacity of the aquifers are in order, further supporting the use of a lower attenuation of N in aquifers in this model. Attenuation in the aquifers in both Connecticut and New York were set at 15.6%, with a range of 5.3% to 33.5%. As for loading rates, surveys of fertilizing practices in the Long Island Sound area (Stony Brook University Center for Survey Research 2006; Guillard & Fitzpatrick 2011) and precipitation patterns and nitrogen concentrations in rain (Luo et al. 2002; PRISM Climate Group 2015) were used to modify loading rates to reflect local practices.

For each parameter, coefficient, and input into the model, a default value with a range of possible values are available. The model was run 10,000 times, allowing these values to vary within their range. This allowed for an assessment of the sensitivity of the model to the ranges of input factors. The 10,000 runs also yield an average best estimate of the total load with an associated range of estimates for each embayment. Details on this information are provided in the technical report, which will be available on the UConn Digital Commons website in early 2017. The model is especially sensitive to the attenuation rate in the aquifer, due in large part to the high range associated with this value.

Nitrogen load was determined for 115 embayments (Table 1). In some cases, sub embayments of a waterbody were delineated. For example, Williams Cove and Bebee Cove drain to the Mystic River. The nitrogen loads presented for Williams Cove and Bebee Cove are just for the watershed of those systems. However, in this report, the Mystic River includes the area in its' watershed plus the area for Williams Cove and Bebee Cove. The watersheds are delineated by different colors in figure 3.

Table 1: List of Embayments

Embayments are ordered starting in Rhode Island, moving west through Connecticut into New York, then eastward along Long Island. Included are symbols indicating connections among watersheds which are best understood by referring to the image of the watershed provided in the technical report. For example, Pawcatuck River (>-|) and Wequetequock Cove (>-|) both drain to Little Narragansett Bay (<---|). The symbol ">-" indicates water leaving that system. The symbol "|" indicates that you should follow that line down within the group of watersheds and find the receiving water body "<---|". The asterisks (*) indicate watersheds where only the coastal portion of the watershed were analyzed. Data in the column "area" were used for determining fertilization rates t home lawns, a survey of behaviors used these categories to assess fertilizer use (Stony Brook University Center for Survey Research 2006).

Site	RI - NY order	area	symbols indicate connections
Pawcatuck River, RI	1	Connecticut	>-|
Little Narragansett Bay, CT	2	Connecticut	<---|
Wequetequock Cove, CT	3	Connecticut	>-|
Quanaduck Cove, CT	4	Connecticut	
Stonington Harbor, CT	5	Connecticut	
Quiambog Cove, CT	6	Connecticut	

<table>
<tr><th>Site</th><th>RI - NY order</th><th>area</th><th>symbols indicate connections</th></tr>
<tr><td>Wilcox Cove, CT</td><td>7</td><td>Connecticut</td><td></td></tr>
<tr><td>Williams Cove, CT</td><td>8</td><td>Connecticut</td><td>>---|</td></tr>
<tr><td>Mystic River, CT</td><td>9</td><td>Connecticut</td><td>>---|</td></tr>
<tr><td>Bebee Cove, CT</td><td>10</td><td>Connecticut</td><td>>---|</td></tr>
<tr><td>West Cove, CT</td><td>11</td><td>Connecticut</td><td></td></tr>
<tr><td>Palmer Cove, CT</td><td>12</td><td>Connecticut</td><td></td></tr>
<tr><td>Venetian Harbor, CT</td><td>13</td><td>Connecticut</td><td></td></tr>
<tr><td>Mumford Cove, CT</td><td>14</td><td>Connecticut</td><td></td></tr>
<tr><td>Poquonock River, CT</td><td>15</td><td>Connecticut</td><td></td></tr>
<tr><td>Baker Cove, CT</td><td>16</td><td>Connecticut</td><td></td></tr>
<tr><td>* Thames River, CT</td><td>17</td><td>Connecticut</td><td></td></tr>
<tr><td>Alewife Cove, CT</td><td>18</td><td>Connecticut</td><td></td></tr>
<tr><td>Goshen Cove, CT</td><td>19</td><td>Connecticut</td><td></td></tr>
<tr><td>Jordan Cove, CT</td><td>20</td><td>Connecticut</td><td></td></tr>
<tr><td>Gardners Pond, CT</td><td>21</td><td>Connecticut</td><td></td></tr>
<tr><td>Niantic River, CT</td><td>22</td><td>Connecticut</td><td>>-|</td></tr>
<tr><td>Niantic Bay, CT</td><td>23</td><td>Connecticut</td><td><---|</td></tr>
<tr><td>Pattagansett River, CT</td><td>24</td><td>Connecticut</td><td></td></tr>
<tr><td>Bride Brook, CT</td><td>25</td><td>Connecticut</td><td></td></tr>
<tr><td>Four Mile River, CT</td><td>26</td><td>Connecticut</td><td></td></tr>
<tr><td>Threemile River, CT</td><td>27</td><td>Connecticut</td><td></td></tr>
<tr><td>Black Hall River, CT</td><td>28</td><td>Connecticut</td><td>>-|</td></tr>
<tr><td>* Connecticut River, CT</td><td>29</td><td>Connecticut</td><td><---|</td></tr>
<tr><td>South Cove, CT</td><td>30</td><td>Connecticut</td><td>>-|</td></tr>
<tr><td>Indiantown Harbor, CT</td><td>31</td><td>Connecticut</td><td>>---|</td></tr>
<tr><td>Oyster River, Old Saybrook, CT</td><td>32</td><td>Connecticut</td><td>>---|</td></tr>
<tr><td>Hagar Creek, CT</td><td>33</td><td>Connecticut</td><td></td></tr>
<tr><td>Patchogue River, CT</td><td>34</td><td>Connecticut</td><td>>---|</td></tr>
<tr><td>Menunkesucket River, CT</td><td>35</td><td>Connecticut</td><td>>---|</td></tr>
<tr><td>Clinton Harbor, CT</td><td>36</td><td>Connecticut</td><td></td></tr>
<tr><td>Toms Creek, CT</td><td>37</td><td>Connecticut</td><td></td></tr>
<tr><td>Fence Creek, CT</td><td>38</td><td>Connecticut</td><td></td></tr>
<tr><td>Guilford Harbor, CT</td><td>39</td><td>Connecticut</td><td></td></tr>
<tr><td>Indian Cove, CT</td><td>40</td><td>Connecticut</td><td></td></tr>
<tr><td>Sachem Head Harbor, CT</td><td>41</td><td>Connecticut</td><td></td></tr>
<tr><td>Joshua Cove, CT</td><td>42</td><td>Connecticut</td><td></td></tr>
<tr><td>Island Bay, CT</td><td>43</td><td>Connecticut</td><td></td></tr>
<tr><td>Little Harbor, CT</td><td>44</td><td>Connecticut</td><td></td></tr>
<tr><td>Branford Harbor, CT</td><td>45</td><td>Connecticut</td><td></td></tr>
<tr><td>Pages Cove, CT</td><td>46</td><td>Connecticut</td><td></td></tr>
<tr><td>Farm River, CT</td><td>47</td><td>Connecticut</td><td></td></tr>
<tr><td>New Haven Harbor, CT</td><td>48</td><td>Connecticut</td><td></td></tr>
<tr><td>Oyster River, Milford, CT</td><td>49</td><td>Connecticut</td><td></td></tr>
<tr><td>Calf Pen Meadow Creek, CT</td><td>50</td><td>Connecticut</td><td></td></tr>
<tr><td>Milford Harbor, CT</td><td>51</td><td>Connecticut</td><td></td></tr>
<tr><td>* Housatonic River, CT</td><td>52</td><td>Connecticut</td><td></td></tr>
</table>

Site	RI - NY order	area	symbols indicate connections
Lewis Gut, CT	53	Connecticut	>-|
Bridgeport Harbor, CT	54	Connecticut	<---|
Pequonnock River, CT	55	Connecticut	>-|
Black Rock Harbor, CT	56	Connecticut	
Ash Creek, CT	57	Connecticut	
Pine Creek, CT	58	Connecticut	
Mill River, CT	59	Connecticut	
Sasco Brook, CT	60	Connecticut	
Sherwood Millpond, CT	61	Connecticut	>-|
Compo Cove, CT	62	Connecticut	<---|
Saugatuck River, North, CT (Freshwater)	63	Connecticut	>-|
Saugatuck River, CT	64	Connecticut	<---|
Cockenoe Harbor, CT	65	Connecticut	
Norwalk Harbor, CT	66	Connecticut	
Sheffield Island Harbor, CT	67	Connecticut	
Five Mile River, CT	68	Connecticut	
Scotts Cove, CT	69	Connecticut	
Gorham Pond, CT	70	Connecticut	>-|
Darien River, CT	71	Connecticut	<---|
Holly Pond, CT	72	Connecticut	>-|
Cove Harbor, CT	73	Connecticut	<---|
Wescott Cove, CT	74	Connecticut	
Stamford Harbor, CT	75	Connecticut	
Greenwich Cove, CT	76	Connecticut	
Mianus River, CT	77	Connecticut	
Indian Harbor, CT	78	Connecticut	
Smith Cove, CT	79	Connecticut	
Greenwich Harbor, CT	80	Connecticut	
Captain Harbor, CT	81	Connecticut	
Byram River, CT	82	Connecticut	>---|
Kirby Pond, NY	83	Westchester Co.	>---|
Playland Lake, NY	84	Westchester Co.	>---|
Milton Harbor, NY	85	Westchester Co.	
Van Amringe Millpond, NY	86	Westchester Co.	
Mamaroneck River, NY	87	Westchester Co.	
Larchmont Harbor, NY	88	Westchester Co.	
Premium Millpond, NY	89	Westchester Co.	
Echo Bay, NY	90	Westchester Co.	
Hunter Island Bay, NY	91	Bronx / Queens	
Eastchester Bay, NY	92	Bronx / Queens	
Westchester Creek, NY	93	Bronx / Queens	>-|
Pugsley Creek, NY	94	Bronx / Queens	<---| -->|
* East River, NY	95	Bronx / Queens	<---|
Little Neck Bay, NY	96	Bronx / Queens	
Manhassett Bay, NY	97	Long Island	
Hempstead Harbor, NY	98	Long Island	
Dosoris Pond, NY	99	Long Island	

Site	RI - NY order	area	symbols indicate connections
Frost Creek, NY	100	Long Island	
Mill Neck Creek, NY	101	Long Island	>-|
Oyster Bay, NY	102	Long Island	<---| -->|
Cold Spring Harbor, NY	103	Long Island	<---|
Lloyd Harbor, NY	104	Long Island	
Huntington Harbor, NY	105	Long Island	> ------|
Centerport Harbor, NY	106	Long Island	>-|
Northport Harbor, NY	107	Long Island	>-|
Northport Bay, NY	108	Long Island	<---| -->|
Huntington Bay, NY	109	Long Island	<-------|
Nissequogue River, NY	110	Long Island	
Stony Brook Creek, NY	111	Long Island	
Conscience Bay, NY	112	Long Island	>-|
Port Jefferson Harbor, NY	113	Long Island	<---|
Mount Sinai Harbor, NY	114	Long Island	
Mattituck Creek, NY	115	Long Island	
Goldsmith's Inlet, NY	116	Long Island	

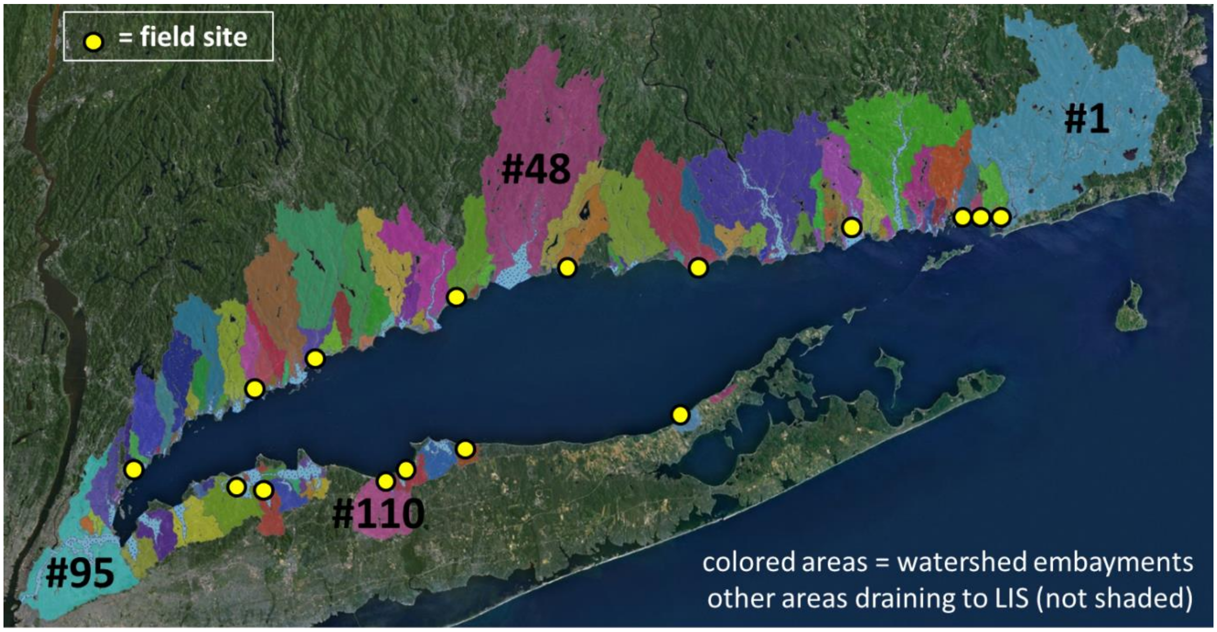


Figure 3: Map of embayment watersheds included in this study.
The numbers correspond to the "RI - NY order" identification number in table 1. Field sites included 15 embayments and some additional sampling conducted in Little Narragansett Bay, on the CT - RI border. Sites are numbered moving from Pawcatuck River in the east (#1), westward along the CT border to New York City and the East River (#95), then east along Long Island to Goldsmith's Inlet (#116). The Saugatuck River watershed is divided into a northern section (#63) which drains to the freshwater portion of the river and a southern section (#64) which drains to the estuarine portion of the embayment.

Nitrogen load estimates reveal higher loads to many embayments familiar for known issues with water quality, relative to other Long Island Sound embayments (Figure 4). Restrictions to tidal flow from bridges and natural barriers can increase the susceptibility of a system to nitrogen load by restricting flushing and dilution of the embayment's water by Long Island Sound. Thus, an embayment shaded yellow in Figure 4 may express a greater impact from nitrogen than a well-flushed system (shaded blue) with a similar nitrogen load. Due to differences in the size of embayments and in the degree of flushing, identifying a total load as high or low is less useful for predicting impact on embayment water quality than looking at the load normalized to the area of the embayment. However, the total load has implications for Long Island Sound, with higher total loads likely to deliver more nitrogen to the Sound. For example, focusing efforts on nitrogen reduction in New Haven Harbor will have an impact on the total load to Long Island Sound (though small compared to the four major rivers). In contrast, reductions to the load to Williams Cove (#8) are unlikely to impact Long Island Sound, but may have a substantial impact on the local embayment water quality.

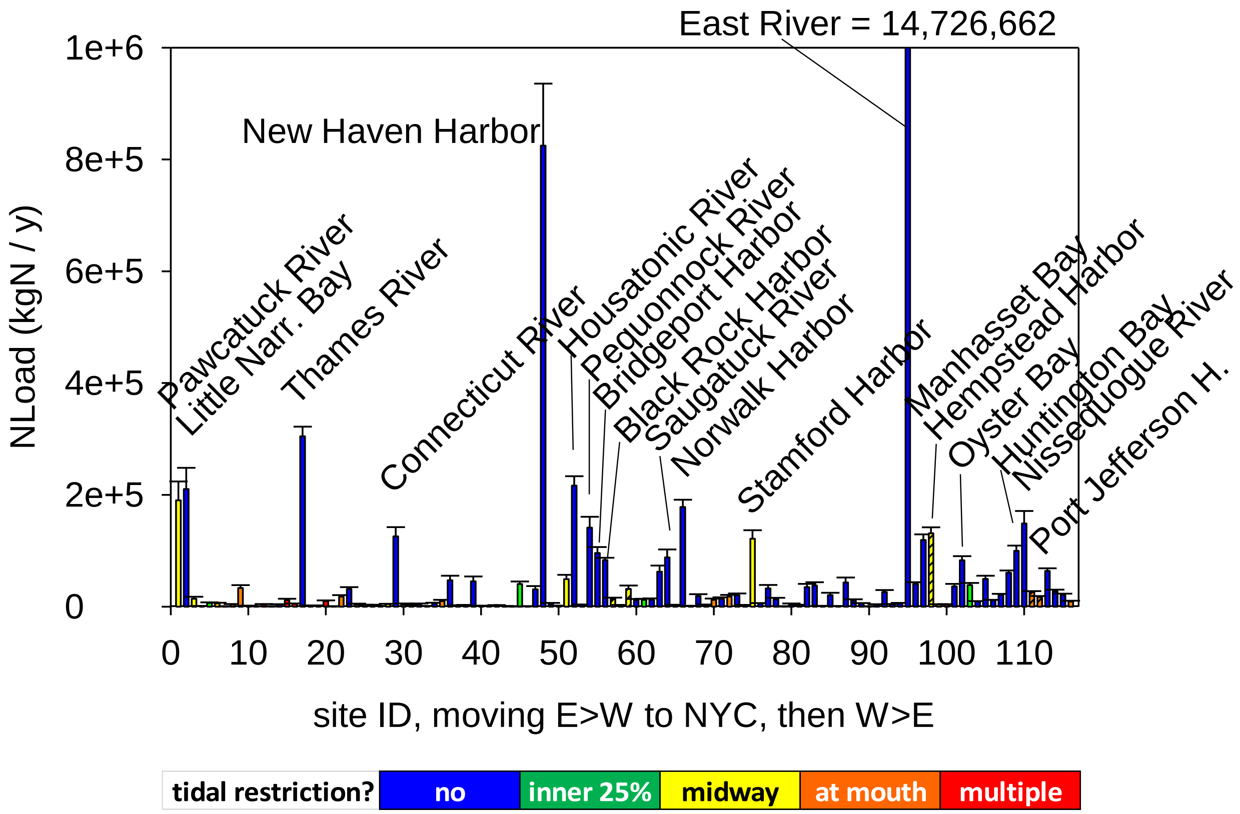


Figure 4: Total nitrogen load to the embayments.

Names are provided for sites with a high load or systems of interest. The numbers correspond to the "RI - NY order" identification number in table 1. Error bars are the standard deviation of the average estimate from 10,000 runs of the model, allowing all parameters to vary within their defined range. Colors of the bars indicate the degree of tidal restrictions present in the system. Note that only the coastal portions of the four major rivers are included in this estimate: Thames River, Connecticut River, Housatonic River, and East River.

While examining tidal restrictions can aid with identifying systems with the potential for a large impact from their nitrogen load, normalizing to the area of the receiving water seems to predict best which systems are at greatest risk of expressing symptoms of eutrophication (Figure 5). Ideally, the hydrodynamic interactions of the embayments with Long Island Sound would be used to inform predictions of the impact of nitrogen to the system. As a first step in this direction, freshwater flushing times for each embayment were estimated using two rough approaches. While the flushing times were used in calculating a prediction of effect of nitrogen load, the most straightforward approach (i.e. without too many assumptions) is to normalize the load to embayment area. Four sites listed as having a high total load (Figure 4) also have a high load per embayment area (Figure 5). These are: Pawcatuck River, Nissequogue River, Pequonnock River, and Black Rock Harbor. These four sites are likely to be expressing symptoms of eutrophication.

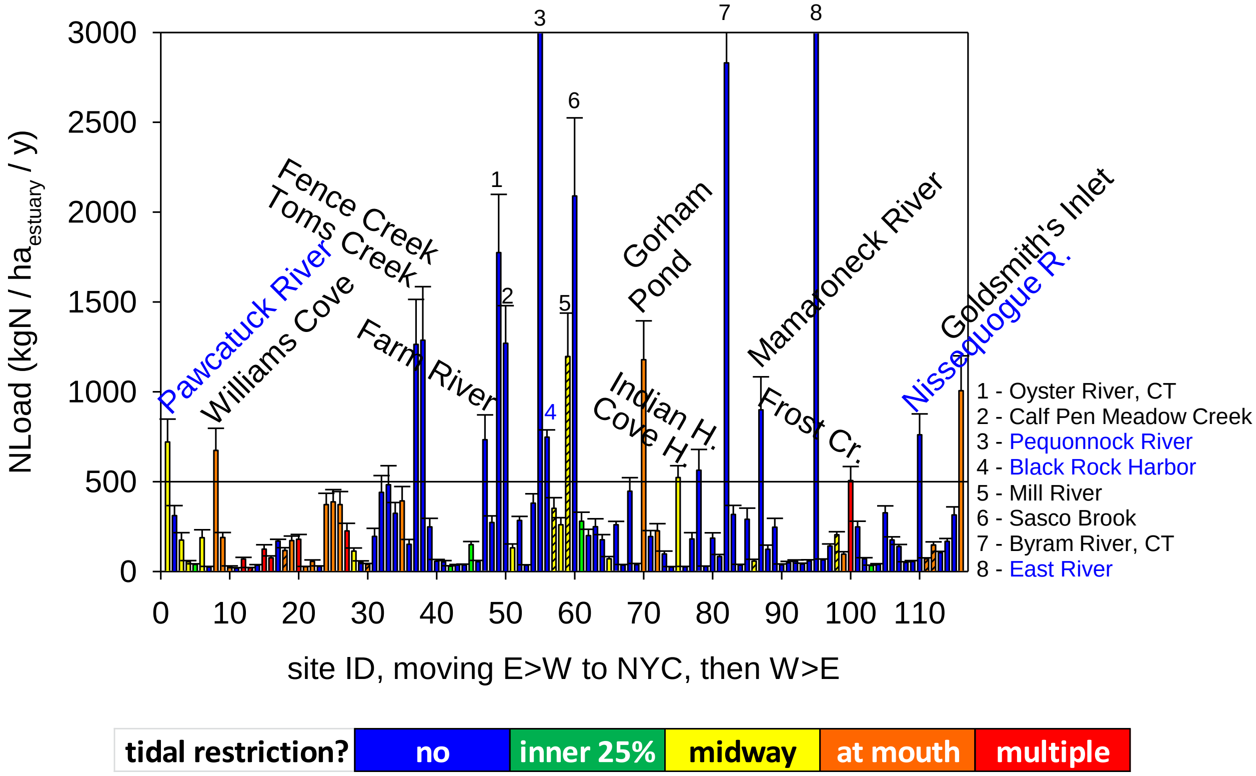


Figure 5: Nitrogen load normalized to the receiving embayment's area of water. Names are provided for sites with a high load or systems of interest. Names shaded blue are also listed in Figure 4 as having a high total load. The numbers correspond to the "RI - NY order" identification number in Table 1. Error bars are the standard deviation of the average estimate from 10,000 runs of the model, allowing all parameters to vary within their defined range. Colors of the bars indicate the degree of tidal restrictions present in the system. Note that only the coastal portions of the four major rivers are included in this estimate: Thames River, Connecticut River, Housatonic River, and East River. The twenty highest loads are visually indicated by a line at 500 Kg N / ha$_{estuary}$ / y.

Fourteen embayments are listed in Figure 5 as having a high per embayment area load, but prioritizing these sites must also take into account other factors. For example, total nitrogen load (Figure 4), area of the watershed, watershed population, area of the embayment, and level of use of the embayment are appropriate as a first pass for setting priorities for developing nitrogen reduction plans. Availability of data could also be used as a metric for prioritizing sites designated for action; additional data will likely be required to develop a nitrogen reduction plan. Other factors to consider are the involvement of the local community and their willingness to take action to preserve their local system. If a group is primed to improve their embayment's water and habitat quality, that site may be prioritized over a similar embayment with little community-based support. Given the number of embayments in Long Island Sound, it is prudent to prioritize based on the ability to achieve action, as well as using the load to indicate potential for impairment. In order to assess actual (versus predicted) impairment, further evaluation of the field conditions in a particular embayment are required.

Eelgrass (*Zostera marina*) is a submerged aquatic plant requiring excellent water quality to thrive (Vaudrey 2008b; Vaudrey 2008a). Eelgrass has been identified as a desirable end goal for Long Island Sound, in other words, its presence indicates we have attained the level of water quality we would like to achieve (http://longislandsoundstudy.net/2010/07/eelgrass-abundance/). Latimer and Charpentier (2010) conducted an assessment of nitrogen loads using the NLM in 74 embayments throughout Southern New England. This work was used to derive a relationship between N load and eelgrass extent (Latimer & Rego 2010). Latimer and Rego concluded that below a N load rate of 50 kg / $ha_{estuary}$ / y, the presence of eelgrass is determined by other factors (e.g. temperature, water clarity, bathymetry, sediment quality, current speed, physical disturbance, etc.). Between 50 and 100 kg / $ha_{estuary}$ / y, eelgrass presence was impacted by the N load and may be present if other factors were favorable. Above 100 kg / $ha_{estuary}$ / y, the nitrogen load results in community changes which are unfavorable to eelgrass (e.g. increase in benthic macroalgae and epiphytes on eelgrass, changes to sediment biogeochemistry, reduction in water clarity, etc.). Of the 110 embayments, 23 had N load levels below 50 kg / $ha_{estuary}$ / y and 19 has N loads between 50 and 100 kg / $ha_{estuary}$ / y (Table 2). Eelgrass has been mapped in three Connecticut embayments of Long Island Sound: Stonington Harbor, Mumford Cove, and Niantic River (Tiner et al. 2010; Tiner et al. 2013). Niantic Bay also has eelgrass and the N load has been calculated for this area; however, Niantic Bay is more influenced by Long Island Sound than a typical embayment. Please note that in the eelgrass aerial survey reports, some areas with eelgrass have the same names as embayments but refer to areas outside these embayments, in Long Island Sound. Mumford Cove (35 ± 4 kg / $ha_{estuary}$ / y) and Stonington Harbor (39 ± 4 kg / $ha_{estuary}$ / y) are well below the 50 kg / $ha_{estuary}$ / y limit identified by Latimer and Rego (2010). Both of these sites host eelgrass beds which are stable interannually (Tiner et al. 2003; Tiner et al. 2007; Tiner et al. 2010; Vaudrey et al. 2010; Tiner et al. 2013). Niantic River, with a N load of 57 ± 8 kg / $ha_{estuary}$ / y, falls in the range identified by Latimer and Rego (2010) as likely to exhibit some loss. The Niantic River bed shows a high degree of interannual variability, doing well when other conditions are favorable and disappearing when conditions are bad (e.g. high temperatures in 2012 lead to the loss of the bed, with moderate recovery in subsequent years). The N load rates of the embayments shown in Table 2 indicate eelgrass could exist in other embayments of Long Island Sound. On-site review of these sites might reveal they are suitable candidates for restoration efforts.

Table 2: Total N Load normalized to the embayment area for sites with loads supportive of eelgrass. Left column includes sites with loads less than 50 kg N / ha$_{estuary}$ / y, a level with the potential to support eelgrass. At these loading levels, eelgrass presence is controlled by factors other than nutrient loads. Loads between 50 and 100 kg N / ha$_{estuary}$ / y are shown in the right column. These sites have loads which could potentially support eelgrass if other conditions are favorable. Loads above 100 kg N / ha$_{estuary}$ / y do not generally support eelgrass. Sites in bold italic currently contain eelgrass within the embayment. Sites in the left column are generally stable beds, interannually. The Niantic River site in the right column has an eelgrass population which fluctuates interannually, with recent years exhibiting complete loss followed by moderate recovery in subsequent years.

Embayment	ID#	Total N Load ± Std Dev (kg N / ha$_{estuary}$ / y)
Stonington Harbor, CT	5	39 ± 4
Wilcox Cove, CT	7	25 ± 3
Bebee Cove, CT	10	28 ± 3
West Cove, CT	11	19 ± 2
Venetian Harbor, CT	13	20 ± 2
Mumford Cove, CT	14	35 ± 4
Gardners Pond, CT	21	26 ± 2
Niantic Bay, CT	23	28 ± 3
South Cove, CT	30	39 ± 6
Joshua Cove, CT	42	29 ± 3
Island Bay, CT	43	35 ± 4
Little Harbor, CT	44	37 ± 4
Lewis Gut, CT	53	35 ± 3
Sheffield Island Harbor, CT	67	35 ± 4
Scotts Cove, CT	69	39 ± 6
Wescott Cove, CT	74	24 ± 3
Greenwich Cove, CT	76	26 ± 3
Smith Cove, CT	79	28 ± 2
Playland Lake, NY	84	35 ± 4
Echo Bay, NY	90	38 ± 4
Westchester Creek, NY	93	42 ± 4
Cold Spring Harbor, NY	103	33 ± 3
Lloyd Harbor, NY	104	39 ± 4

Embayment	ID#	Total N Load ± Std Dev (kg N / ha$_{estuary}$ / y)
Quanaduck Cove, CT	4	54 ± 7
Palmer Cove, CT	12	69 ± 10
Baker Cove, CT	16	76 ± 11
Niantic River, CT	22	57 ± 8
Connecticut River, CT	29	52 ± 7
Indian Cove, CT	40	57 ± 10
Sachem Head Harbor, CT	41	54 ± 7
Pages Cove, CT	46	55 ± 7
Cockenoe Harbor, CT	65	71 ± 12
Captain Harbor, CT	81	83 ± 12
Van Amringe Millpond, NY	86	58 ± 9
Hunter Island Bay, NY	91	48 ± 8
Eastchester Bay, NY	92	57 ± 7
Pugsley Creek, NY	94	58 ± 7
Little Neck Bay, NY	96	64 ± 5
Oyster Bay, NY	102	69 ± 6
Northport Bay, NY	108	50 ± 4
Huntington Bay, NY	109	55 ± 5
Stony Brook Harbor, NY	111	70 ± 5

An estimate of the dissolved inorganic nitrogen in the water column of the embayment was estimated using the Estuarine Loading Model (ELM), which incorporates an estimate of freshwater flushing time (Figure 6) and the cycling of nitrogen in the embayment (Valiela et al. 2004). The ELM has many assumptions and parameters were not adjusted for these embayments. Freshwater flushing times were estimated using two crude approaches: tidal prism method and a statistical relationship (Abdelrhman 2005). These are very rough approximations; application of a well-resolved hydrodynamic model is suggested (e.g. ROMS, FVCOM).

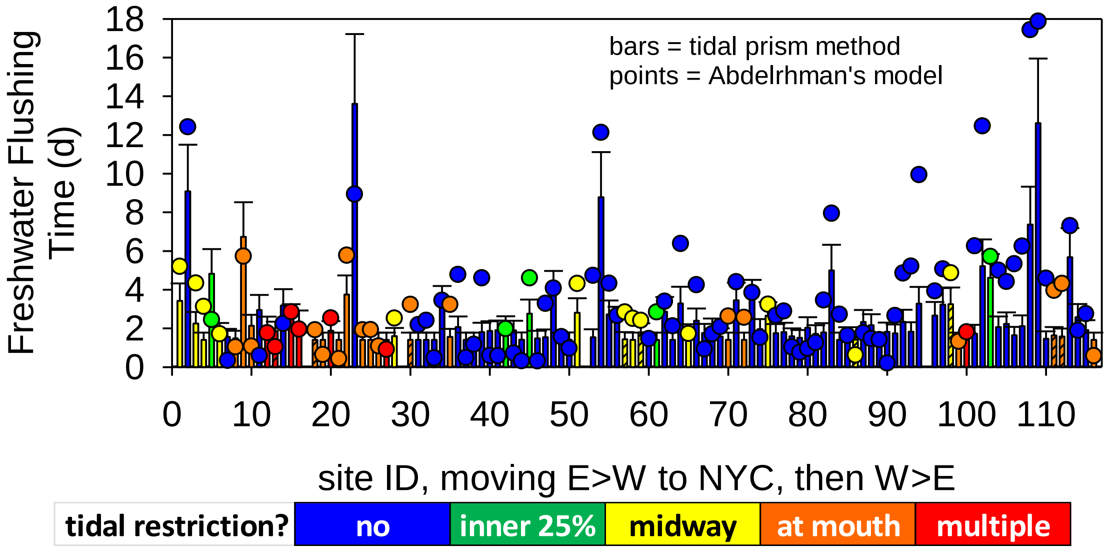


Figure 6: Freshwater flushing time estimates.
The bars indicate the tidal prism method, with error bars representing variability due to estimates of water depth in the embayment. The points represent the estimate based on a statistical model (Abdelrhman 2005). Colors of the bars indicate the degree of tidal restrictions present in the system. These tidal restrictions were not factored in when calculating freshwater flushing time. Note that flushing times of the four major rivers were not estimated: Thames River, Connecticut River, Housatonic River, and East River.

Estimated dissolved inorganic nitrogen concentrations in the embayments were compared to field data collected as part of this project to assess the accuracy of ELM (Figure 7). The ELM over-predicts the nitrogen concentration by a factor of 4.3, though it does capture the relative trend among sites (R^2 = 0.83). This large overestimation may reflect the extent of macroalgae in many of these embayments. The ELM does not include the impact macroalgae can have as a sink for nitrogen in an embayment; the macroalgae pulls nitrogen from the water column and stores it as biomass. In order to predict the dissolved inorganic nitrogen concentration in the embayments and to accurately gauge the impact of nitrogen load on the system, application of an estuary model using locally relevant data for each embayment is suggested. The Massachusetts Estuary Project provides an excellent model for this type of assessment (http://www.oceanscience.net/estuaries/). The nitrogen loads estimated as part of this project are only half of the story; an understanding of in-estuarine processes is strongly recommended in order to develop nutrient load reduction plans specific to an embayment.

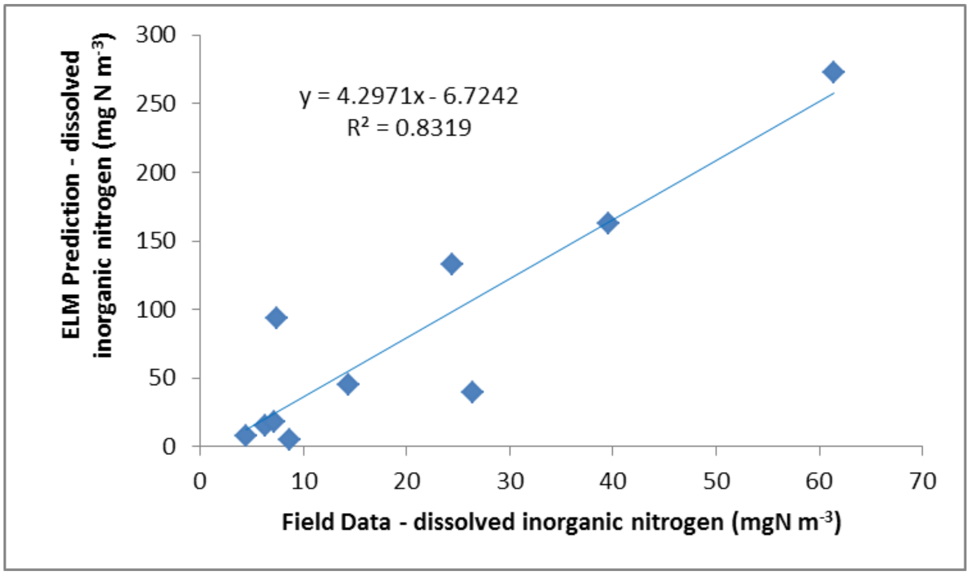


Figure 7: Modeled dissolved inorganic nitrogen versus field data.

Although ELM does not yield an accurate prediction of nitrogen in the water column, the fact that it captures the relative trends among sites is promising. The predicted dissolved inorganic nitrogen from ELM was divided by the slope shown in Figure 7 (4.2971) to better approximate the actual concentration of DIN in the water column. Many of the sites with high nitrogen loads per embayment area are also predicted to have high DIN in the water column (Figure 8). Taking the top twenty sites most likely to be impacted based on the per embayment area nitrogen load and the ELM predicted DIN in the water column, we see that 13 of the 20 sites are identified in both lists (Table 3). The sites listed in Table 3 are the sites most likely to be experiencing the heaviest symptoms of eutrophication.

The N loads to each embayment can be apportioned into the source of the nitrogen (Figure 9). While figure 9 shows only five categories (atmospheric deposition to land, atmospheric deposition to the embayment, fertilizer, septic, sewer), these sources can be further identified utilizing the portfolio of information provided for each embayment in the technical report.

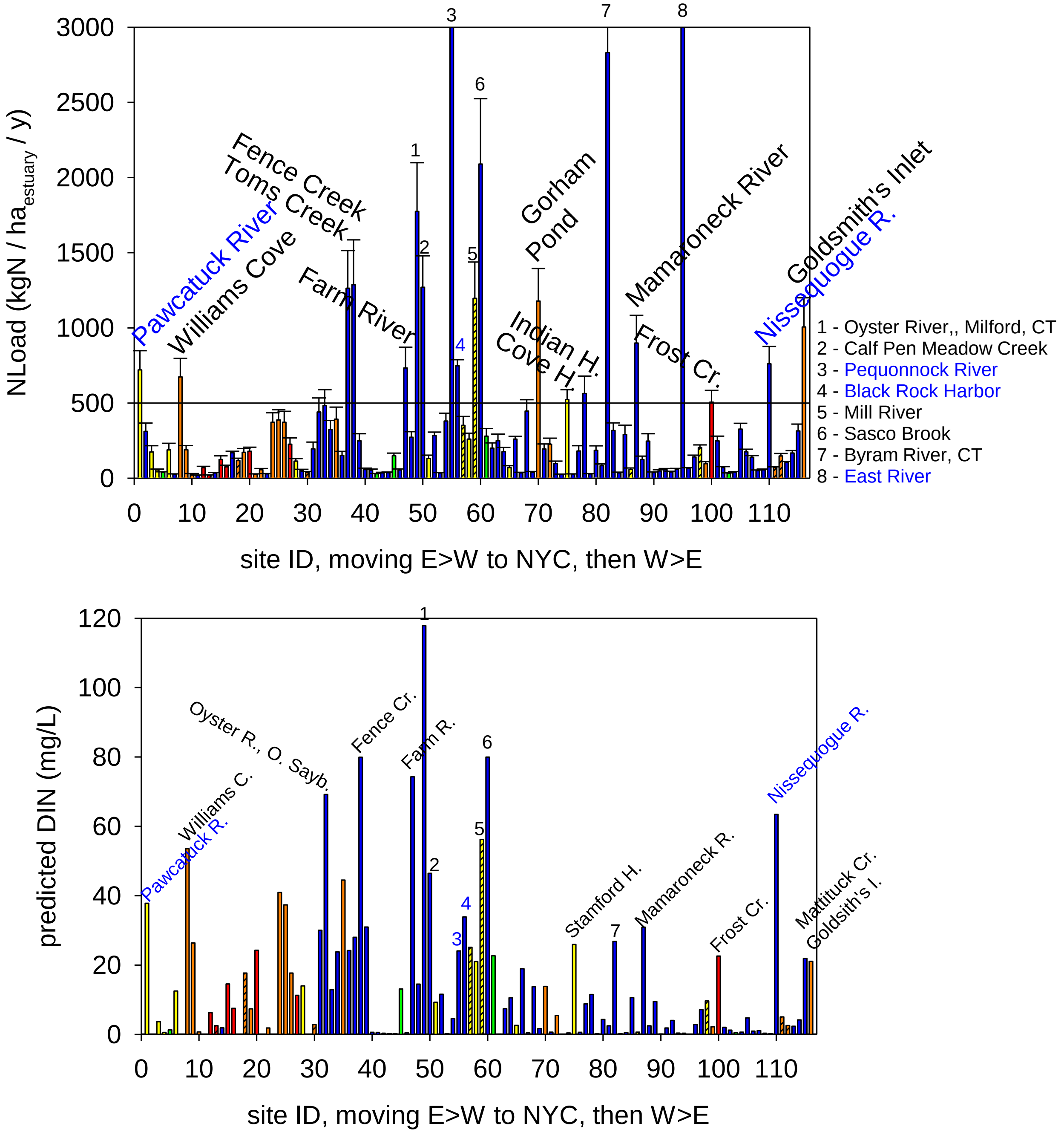


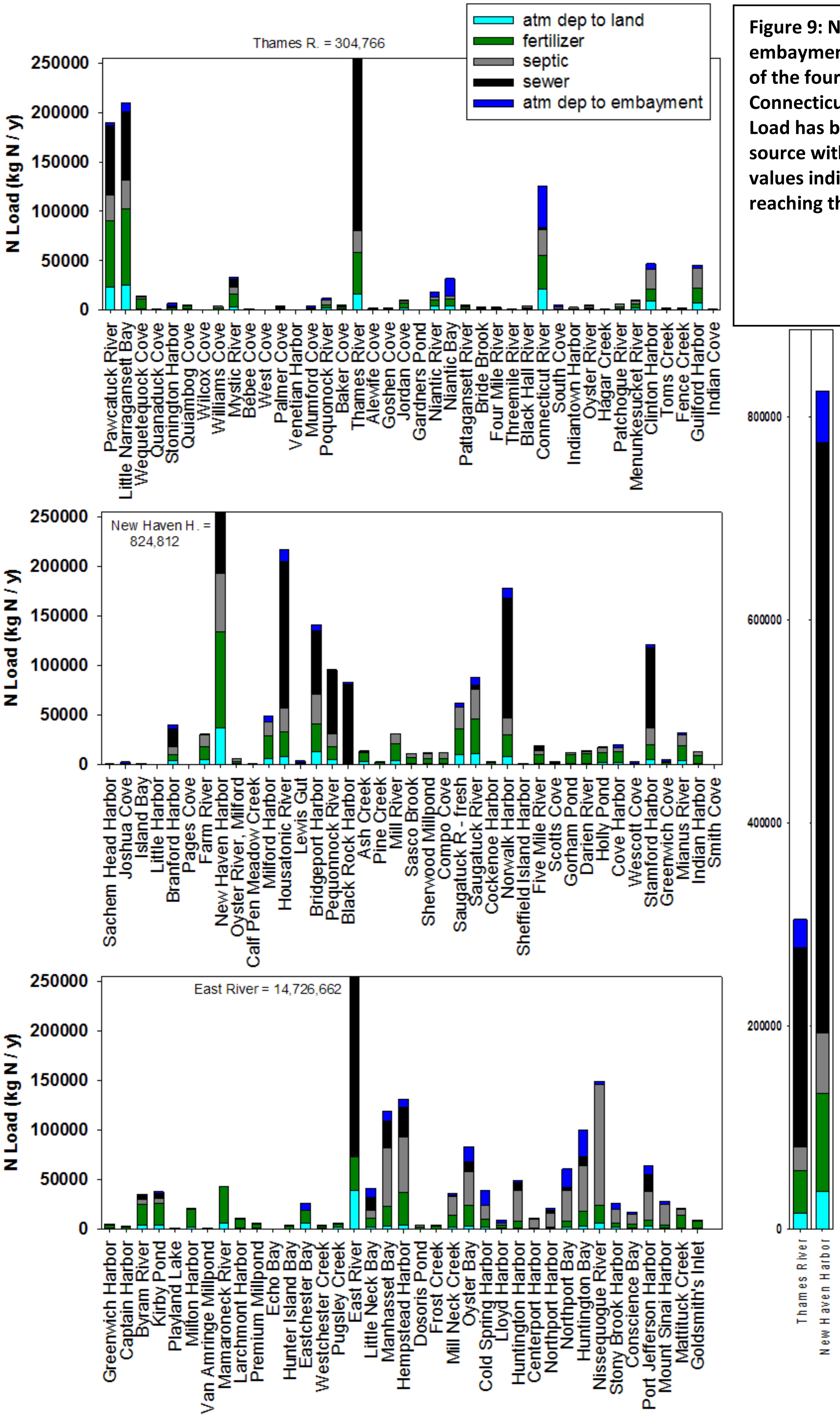
Figure 8: Predicting potential symptoms of eutrophication.

The top panel shows the nitrogen load normalized to the embayment area, as shown in Figure 5. The twenty highest loads are visually indicated by a line at 500 Kg N / ha$_{embayment}$ / y. The bottom panel shows the ELM predicted nitrogen concentration in the water of the embayments. These ELM predictions have been divided by the slope shown in Figure 7 (4.2971) to better approximate the actual concentration of DIN in the water column. Note that both panels identify almost the same embayments with high values, predicting a high impact of nitrogen loads on these systems. Given the many assumptions involved with the ELM model (bottom panel), the nitrogen loads normalized to the embayment is considered a better predictor of potential for eutrophication (top panel).

Table 3: Comparison of Priority Embayments Predicted Using Two Methods.
Top 20 sites with the highest nitrogen loads per embayment area versus the top 20 sites with the highest predicted water column DIN in the embayment. Bold text indicates sites in the top 20 for both categories.

Site ID #	High Nitrogen Load Per Area of Embayment	High Predicted DIN in Embayment Water Column
1	**Pawcatuck River, RI**	**Pawcatuck River, RI**
8	**Williams Cove, CT**	**Williams Cove, CT**
9		Mystic River, CT
24		Pattagansett River, CT
25		Bride Brook, CT
31		Indiantown Harbor, CT
32		Oyster River, Old Saybrook, CT
33	Hagar Creek, CT	
35		Menunkesucket River, CT
37	**Toms Creek, CT**	**Toms Creek, CT**
38	**Fence Creek, CT**	**Fence Creek, CT**
39		Guilford Harbor, CT
47	**Farm River, CT**	**Farm River, CT**
49	**Oyster River, Milford, CT**	**Oyster River, Milford, CT**
50	**Calf Pen Meadow Creek, CT**	**Calf Pen Meadow Creek, CT**
55	Pequonnock River, CT	
56	**Black Rock Harbor, CT**	**Black Rock Harbor, CT**
59	**Mill River, CT**	**Mill River, CT**
60	**Sasco Brook, CT**	**Sasco Brook, CT**
70	Gorham Pond, CT	
75	Stamford Harbor, CT	
78	Indian Harbor, CT	
82	**Byram River, CT**	**Byram River, CT**
87	**Mamaroneck River, NY**	**Mamaroneck River, NY**
100	Frost Creek, NY	
110	**Nissequogue River, NY**	**Nissequogue River, NY**
116	Goldsmith's Inlet, NY	

Figure 9: N Load results for each embayment and the coastal portions of the four major rivers (Thames, Connecticut, Housatonic, East). Load has been apportioned to the source within the watershed, with values indicating the amount of N reaching the embayment.



Fertilizer contributes more to the embayment loads than has been portrayed in recent estimates for LIS using this same model (Lloyd 2014; Woods Hole Group 2014). This difference is attributable to better refining of estimates for fertilizer application to lawns, parks, recreational fields and golf courses. In this application of the NLM model, golf courses were hand delineated, as GIS layers do not adequately capture golf course areas for the Long Island Sound area. In embayment watersheds where almost all of the population is on sewer and the WWTF outfall is not in the embayment, fertilizer is the major contributor to the nitrogen load (e.g. Greenwich Cove through Pugsley Creek, Figure 9). It is interesting to note that these highly populated systems (Greenwich Harbor through Pugsley Creek, Figure 9) without sewer or septic contributions still have a total nitrogen load greater than many other systems, largely attributed to fertilizer application.

> *"The Connecticut Department of Energy and Environmental Protection (CTDEEP) and New York State Department of Environmental Conservation (NYSDEC) developed a Total Maximum Daily Load (TMDL) for Dissolved Oxygen. The TMDL, which EPA approved in 2001, outlined nitrogen reductions necessary to meet water quality standards in the Sound by 2014. These reductions include a 58.5% reduction in nitrogen loading from sources in CT and NY, a 25% reduction from point sources and a 10% reduction in nonpoint sources in the upper basin states (MA, NH, VT), and an 18% reduction in nitrogen from atmospheric deposition* [through implementation of the Clean Air Act].*" (NEIWPCC 2014)*

Over the past 15 years, implementation of the Long Island Sound TMDL has resulted in significant reductions to the nitrogen load to Long Island Sound. The annual discharge of nitrogen from wastewater treatment facilities has been reduced by 40 million pounds, attaining 94% of the TMDL reduction requirements, with full attainment of the goal expected by 2017. Controls on discharge of nitrogen to the atmosphere have reduced nitrogen from atmospheric deposition by an average of 25% for total nitrogen and 50% for nitrate (NEIWPCC 2014). While great strides have been made in nutrient reduction from WWTFs, septic and sewer are still major contributors to the total nitrogen load to embayments (Figures 9 and 10). Targeting these sources for nutrient reductions is, in many respects, more straight forward than targeting fertilizer application. The exception is when the fertilizer application loads are due to applications to golf courses and municipal fields, as is the case for many Western Sound communities. Educational campaigns targeted at homeowners could be quite effective at mitigating nitrogen loads from fertilizer application to turf, a large component of many watersheds. Areas on septic are candidates for sewering, which has the potential to remove more nitrogen than a septic system close to the embayment. Upgrades and proper maintenance of septic systems are another way of reducing this source. In all cases, consideration of costs versus benefits are critical. The portfolio developed for each embayment can assist with making these decisions at a local level.

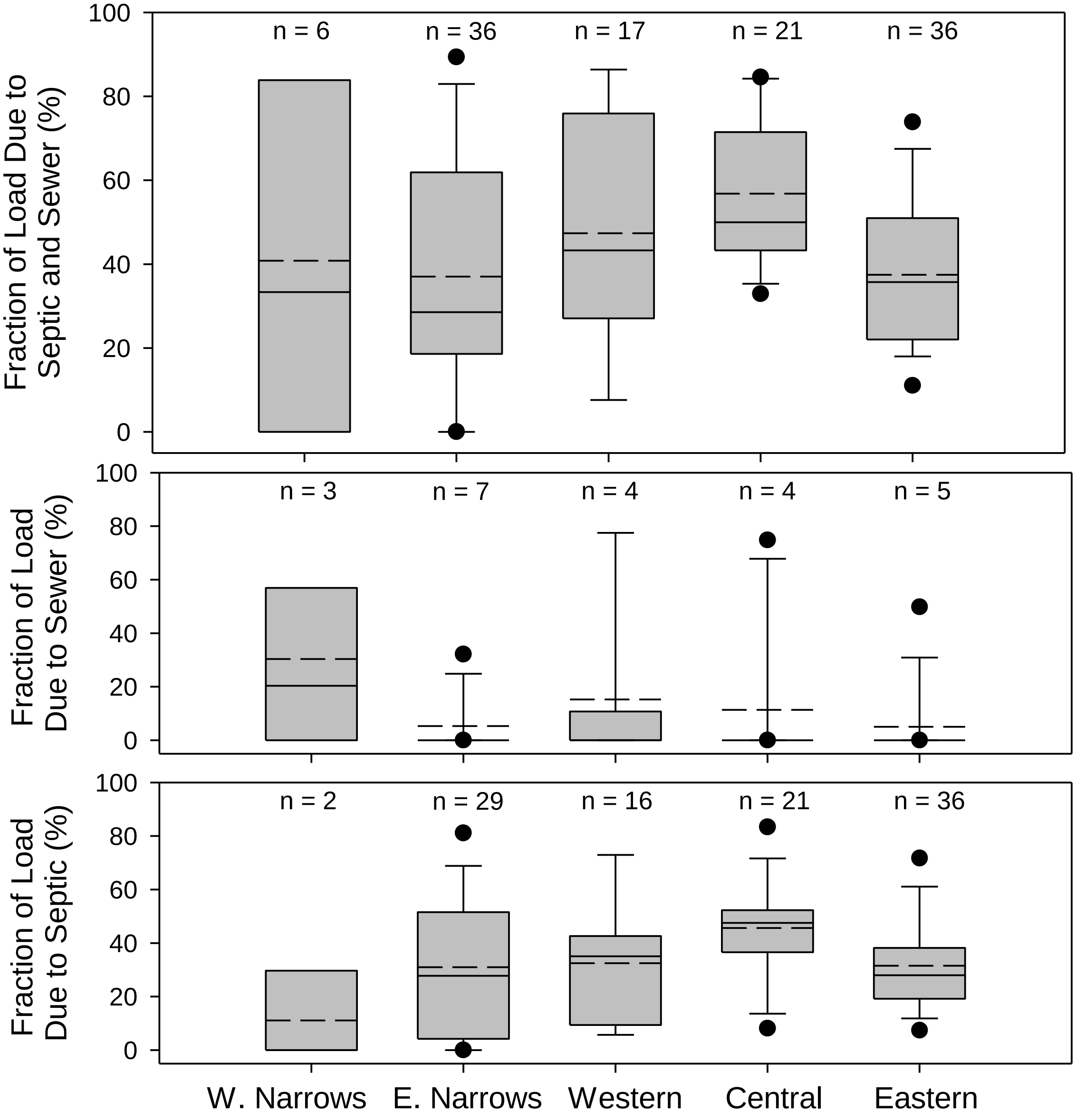


Figure 10: Fraction of the total load due to septic and sewer, grouped by basin of Long Island Sound. Solid line in the bar is the median, dashed line is the mean. Whiskers represent the 25th and 75th percentiles, points indicate the 5th and 95th percentile. The number of embayments included in each basin is shown above the bars. In the W. Narrows, E. Narrows, and Western basin, many watersheds are fully sewered with the outfall located outside of the embayment. Thus they appear to have a low contribution from wastewater.

Eutrophic Status of Embayments

Eutrophication has been defined as an increase in the rate of supply of organic matter to a system (Nixon 1995; Nixon 2009). For systems influenced by dense human populations, this increase in the rate of supply of organic matter is often fueled by nutrient inputs. Nutrients support the growth of primary producers, and under increasing nutrient loads, the primary producer community is dominated by nutrient-loving nuisance species (harmful algal blooms, nuisance macroalgae). While these primary producers generate oxygen during the daytime via photosynthesis, they respire oxygen during the night, resulting in a lowering of water column dissolved oxygen values. When excess nutrient loads support large amounts of primary producers, the large biomass of algae can rapidly cause hypoxic and anoxic conditions at night. Some draw down of oxygen is expected in shallow systems dominated by benthic processes (seaweed sitting on the bottom and microalgae on the sediment). However, large swings in the oxygen levels, ranging from anoxia to supersaturation within a 24-hour period, indicate a problem. For shallow embayments, expressions of eutrophication may include large blooms of macroalgae, high chlorophyll levels, low dissolved oxygen values, and large diel swings in dissolved oxygen (from anoxia to supersaturation). Water column nutrient levels are often low in these systems because the primary producer are effective at stripping the water of nutrients to fuel their growth.

The field work for this project built off a 2011-2012 assessment of eutrophic symptoms expressed by eight embayments of Long Island Sound (Figure 11). A surprising result of this previous study was the discovery of dawn hypoxia in the inner portions of many embayments, including those in the Eastern Basin of Long Island Sound. A second finding was that systems which were shallow (Stony Brook Harbor) or with unrestricted flow due to an absence of small openings under bridges (Branford Harbor, Clinton Harbor) had lower expressions of eutrophic symptoms. This led to an investigation in this project of freshwater flushing time and restrictions to flow and their impact on expressions of eutrophication.

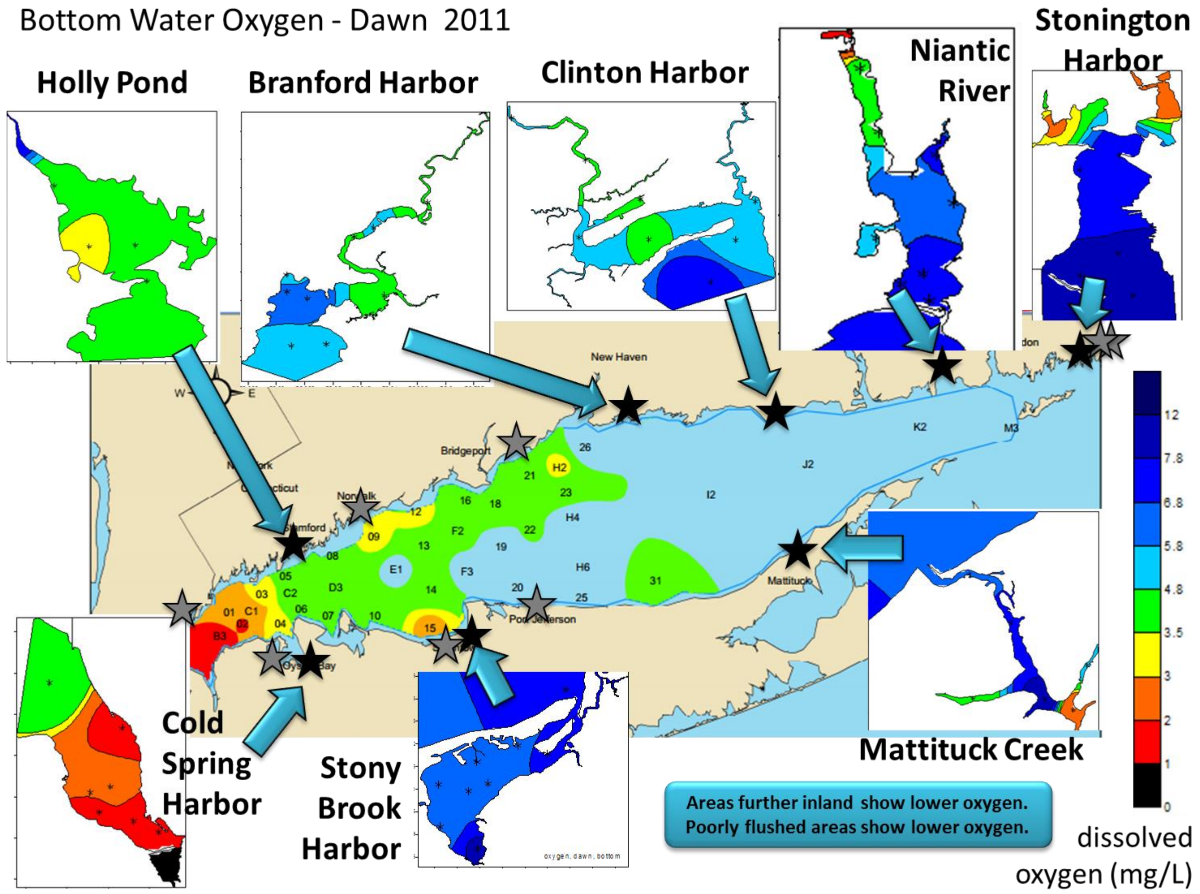


Figure 11: Dawn oxygen records from late summer 2011.
The central figure is the CT DEEP survey of hypoxic conditions in Long Island Sound, conducted in August of 2011. Black stars on the CT DEEP map indicate the location of the embayments shown, sampled in 2011-2012. Grey stars are embayments sampled as part of this study in 2013-2014, Niantic River and Mattituck Creek were sampled during all four years. The CT DEEP map in the center uses the color scale shown, but the pale blue includes all oxygen values greater than 4.8 mg/L. The embayments use an expanded scale to allow for differentiation of oxygen values greater than 4.8 mg/L. All other colors used are on the same scale for all figures shown.

While spatial surveys at dawn can provide an understanding of the area of hypoxia in these embayments and were included in this study (figures not shown), temporal resolution of the timing of hypoxia over longer deployments was considered essential to understanding the dynamics in these very shallow systems. Oxygen sensors (Onset HOBO U26 Dissolved Oxygen Data Loggers) were deployed in five sites along the north shore of Long Island Sound in 2013 (Connecticut and Westchester County, NY), and in 2014 sensors were deployed in those five sites plus three sites on Long Island. Due to budgetary limitations, only one sensor was bought per each of the targeted eight embayments. Sensors were deployed at a single location in each embayment in an area predicted to experience hypoxia. As shown by the maps in Figure 11, not all areas in an embayment will experience hypoxia. The sensor was deployed 10 to 20 cm off the bottom for a deployment of two weeks in 2013 and six weeks in 2014. After the 2013 deployment, we found that sensors in some embayments were heavily fouled following the month long deployment. Thus, only the first two weeks of data were used for 2013. In 2014, sensors were cleaned every 7 to 10 days, yielding a six week deployment without problems from fouling organisms.

Records indicate embayments experience broad swings in oxygen levels, going from anoxic at night to supersaturated during the day (Figure 12). These swings are due to the shallowness of these systems and the resulting sunlight supplied to the benthos. The sunlight fuels primary production by macroalgae and benthic microalgae, causing intense oxygen production in some systems during the day and large amounts of respiration at night. Chlorophyll concentration, an indicator of phytoplankton biomass, was low in most systems, indicating benthic organisms were the main contributors to these swings. Timing of sampling is critical, as single samples collected at 9 a.m. are likely to miss hypoxia.

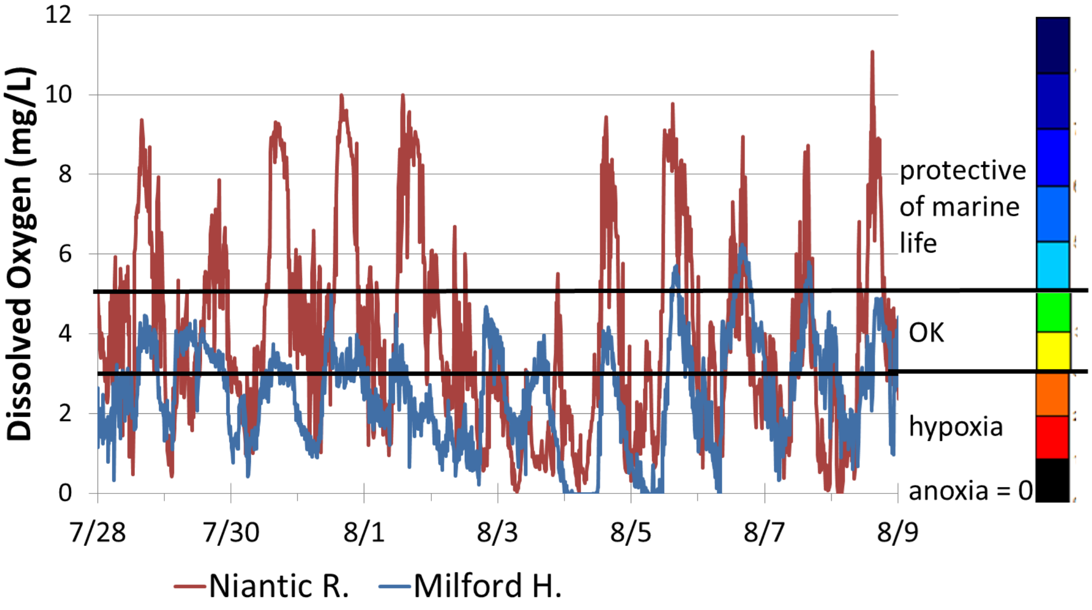


Figure 12: Diel oxygen records - two sites.
Oxygen sensors were deployed 20 cm off bottom in one location in each of eight embayments (Figure 13) in 2014. The location was chosen as the most likely area within the embayment to go hypoxic. As shown in Figure 11, not all areas of an embayment will be hypoxic. Only a portion of the record from two embayments are shown.

The oxygen data collected at 15 minute intervals over a multi-week deployment illustrate the need to assess embayments using a different set of criteria from the main stem of Long Island Sound. Using only hypoxia and anoxia as an indicator can be misleading as to the extent of eutrophication in these systems. Based on an assessment of the frequency of hypoxia in the eight sampled embayments, the Long Island embayments sampled appear to exhibit fewer effects of eutrophication (Figure 13). However, many of these systems are dominated by nuisance macroalgae (data not shown). This macroalgae results in supersaturation during the day, when sunlight drives increases in oxygen resulting from photosynthesis. While the Long Island sites look better in terms of hypoxia, they experience supersaturation more frequently than most of the other sites. For shallow systems, the extremes in dissolved oxygen concentration, whether high or low, should be assessed to evaluate the degree of eutrophication.

Figure 13 illustrates a way to look at the oxygen record in embayments to determine the degree of eutrophication. While many of the embayments assessed are considered highly eutrophied (description of this assessment included in the next section), the oxygen temporal record provides a way to compare among systems. The distance between the two black bars represents the time an embayment's oxygen levels remain at levels which are supportive of marine life without becoming supersaturated. While supersaturation is fine in terms of available oxygen to support life, it is an indication that a large biomass of primary producers, likely fertilized by excess nutrients, is dominating the system. Mamaroneck River appears to be the least eutrophied of all the embayments presented in Figure 13. It has a low incidence of hypoxia and relatively little supersaturation. Oyster Bay also falls into this category, likely in part due to it being a deeper embayment, which reduces the impact of nitrogen loads on the system via dilution and the greater depth limits light available for the macroalgae growth.

At the other end of the spectrum, Wequetequock Cove exhibits long periods of both hypoxia and supersaturation (Figure 13). This is attributable to a massive bloom of a fine green alga, *Cladophora* sp. (Figure 14). In Wequetequock Cove, the algae mat was 2 mm to 10 mm thick. The algae reached a meter in depth at the mouth of the Pawcatuck River. A similarly large bloom of an invasive *Gracilaria* sp. (red macroalgae) was observed in Holly Pond, CT in 2011 and 2012. Milford Harbor and Mamaroneck River had stations with large biomass of the green sea lettuce (*Ulva* sp.), but it was confined to a much smaller percent of the embayment area relative to Wequetequock Cove and Holly Pond.

In these shallow systems, the presence of large blooms of macroalgae are good indicators of problems resulting from nutrient loads. Monitoring of both diel oxygen swings and macroalgae biomass are more effective for determining eutrophic status than the parameters typically employed for the deeper main stem of Long Island Sound. Chlorophyll levels are also useful, especially in deeper systems. Nutrient levels in the water column are often low in systems with intense primary production by macroalgae or phytoplankton. The primary producers rapidly deplete the stock of nutrients in the water column to fuel photosynthesis and growth.

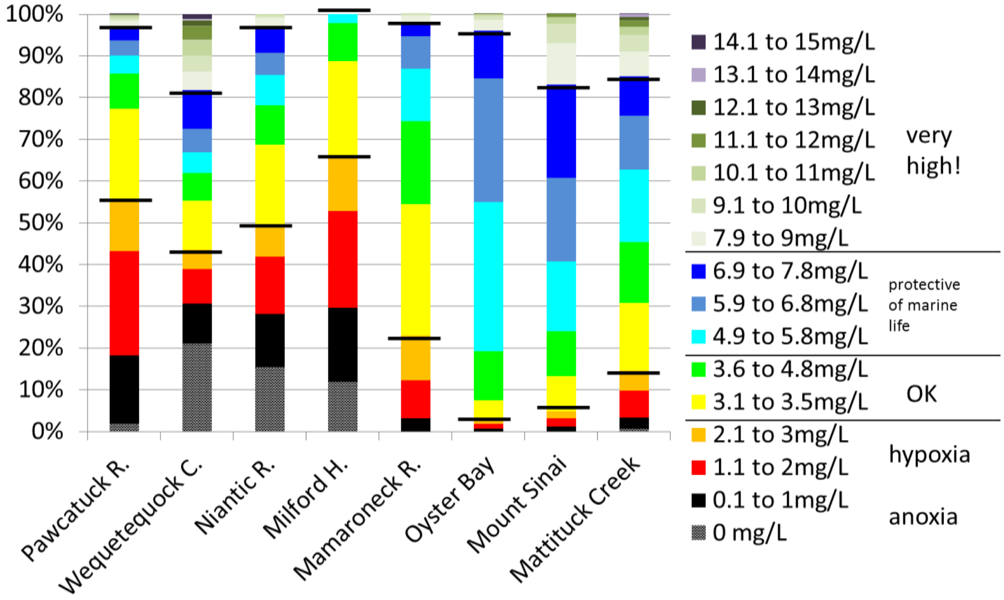


Figure 13: Diel oxygen records - all sites.
Percent of time bottom water was within the defined ranges for oxygen data from July 25 through August 30, 2014. The two black lines overlain on each bar mark the low and high point of acceptable oxygen levels. A larger space between these lines indicates a system experiencing fewer symptoms of eutrophication.

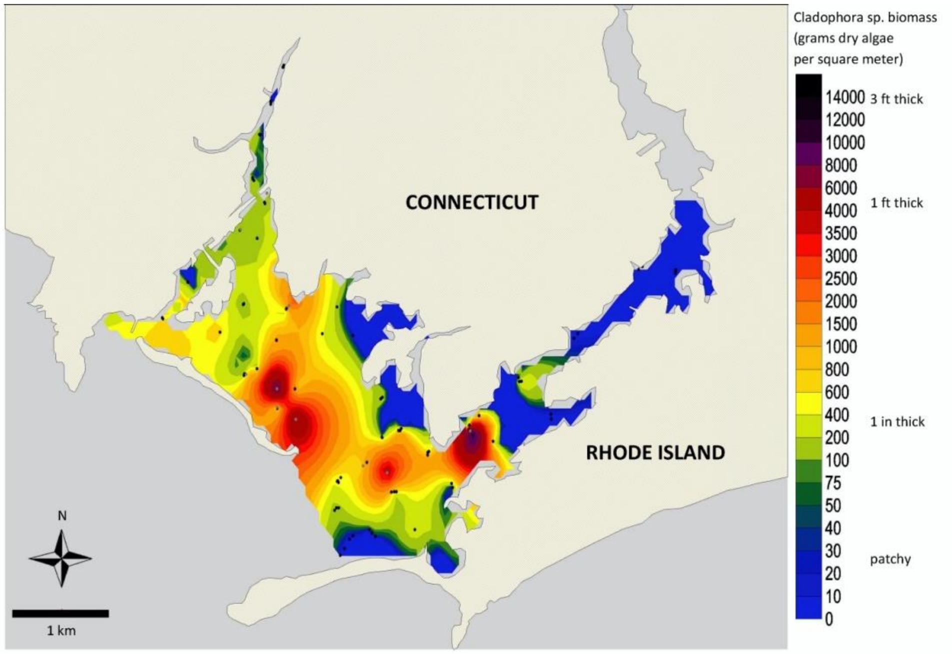


Figure 14: Biomass survey of the green algae, *Cladophora* sp.
Surveys conducted in Wequetequock Cove, Little Narragansett Bay, and the Pawcatuck River, summer 2014. This work was funded by a UConn IDEA Grant awarded to undergraduate UConn Marine Sciences student, Amanda Dostie. Black and grey points are sample locations. Black points were sampled by grab, grey by snorkeler as the algae was too thick for the grab.

Eutrophic status in the embayments was assessed using two standardized metrics used nationwide, one developed by EPA and the other by NOAA. Our approach utilized a combination of methods developed for coastal assessment programs and builds on previous work conducted in LIS. The field sampling design followed the EPA's National Coastal Assessment (NCA) protocols and provided data for use in NOAA's Assessment of Eutrophication Trophic Status (ASSETS).

NOAA's National Estuarine Eutrophication Assessment (NEEA) approach for the Assessment of Eutrophication Trophic Status (ASSETS) provides a framework for evaluating the overall eutrophic condition of a system (Bricker et al. 2007; Ferreira et al. 2007; Bricker et al. 2008). A site is assessed based on the level of expression of five symptoms: chlorophyll *a*, macroalgae, low dissolved oxygen, loss of submerged aquatic vegetation, and the occurrence of harmful algal blooms. Nitrogen and phosphorus are the external forcing conditions in the model. Primary symptoms of chlorophyll *a* and macroalgae growth reflect a decreased light availability, increased organic decomposition and changes in the dominant algae reflecting eutrophication. Secondary symptoms include loss of eelgrass, low dissolved oxygen, and harmful algal bloom. LIS was evaluated using this method in 1991 and was considered at "high" risk for overall eutrophic condition. By 2002, water quality in the Sound had improved, resulting in a "moderate" risk designation (http://eutro.org/syslist.aspx). The NOAA approach includes benthic indicators. This metric ideally relies on sampling throughout the year. Our sampling was conducted in only the summer. While results will not be comparable to the nationwide results for the NOAA assessment, the creators of the assessment agreed that it would work for a comparison among sites sampled over the same time frame and using the same techniques.

EPA's National Coastal Assessment sampling protocol uses data similar to that applied to the ASSETS approach, but focuses on water quality issues at one particular time of year (Diaz-Ramos et al. 1996; EPA 2001). The NCA approach requires participants to sample a range of parameters. Five of these are used in a water quality index to assess the condition of the estuary: nitrogen, phosphorus, chlorophyll *a*, water clarity and dissolved oxygen. Different water clarity criteria are associated with systems where submerged aquatic vegetation (eelgrass, for Long Island Sound) is predicted. The EPA assessment uses summer time data, but is a completely water quality based assessment. Thus, the contribution of the benthic community of primary producers, which is important in shallow systems, is not included.

The presence of submerged aquatic vegetation is included in both models assessing eutrophic status. Eelgrass, *Zostera marina*, was once found commonly throughout Long Island Sound (Rozsa 1994; Yarish et al. 2006). The EPA NCA uses eelgrass indirectly to apply a different criterion to water clarity, but does not utilize eelgrass directly. The NOAA ASSETS approach includes eelgrass directly as an indicator in the metric. For this assessment, eelgrass was assumed to have been present historically in the Long Island Sound portion of the study area. While it is likely that eelgrass was present in the estuarine portions of the embayments, some embayments may have had hydrographic restrictions to eelgrass. Due to the lack of historical data throughout all of the field sites, the historical presence of eelgrass was entered as “unknown” for the model except in those sites where eelgrass is present today. This lack of eelgrass resulted in higher eutrophic scores for many embayments in the NOAA ASSETS results.

Differences in the ranking of eutrophic status of sites between the two assessment metrics highlight the need for a benthic component and reveal interesting impacts on water quality. The following summary of results highlights the utility of these metrics.

The NOAA ASSETS metric first ranks the pressure on the system based on their susceptibility and level of nutrient loading (Figure 15). The field sites all show high susceptibility, with varying nitrogen loads. It is important to note that this nutrient loading is not the result of the nutrient loading model used in the rest of this study. It is based on watershed area and embayment characteristics, but does not “see” the land use or population data. The ASSETS program then goes on to assign eutrophic status based on field data collected from the embayment (Figure 15). Stonington Harbor ranked best in terms of having the lowest eutrophic status. Niantic River also ranked comparatively low. Both of these embayments still host eelgrass. Nissequogue River, Saugatuck River, and Milford Harbor scored a “moderate high risk” for at least one year, but were scored as “high risk” during the other year they were sampled. Stony Brook Harbor was scored at “high risk”, but the primary symptoms were moderate, suggesting it is less at risk than systems with high primary symptoms. The remaining systems all scored “high risk” for all years sampled, with high primary symptoms (alphabetically: Branford Harbor, Clinton Harbor, Cold Spring Harbor, Holly Pond, Mamaroneck River, Mattituck Creek, Mount Sinai Harbor, Oyster Bay, Pawcatuck River, Wequetequock Cove).

The EPA NCA metric assigns a rank of “good,” “fair,” or “poor” to a site. All sites received an overall score of either “fair” or “poor.” Looking at ranking of stations within a field site yields a better understanding of the eutrophic status and the limitations of this assessment in shallow systems dominated by benthic processes. The number of stations per embayment varied with the overall size of the embayment (Table 4). Larger sites had more stations, smaller sites had fewer stations. However, the minimum number of stations in a site was four, regardless of the size. The score for each station is shown as a percentage of total stations. In Figure 16, the embayments have been sorted based on their NOAA ASSETS score (Figure 15), but the EPA NCA results are shown. Stonington Harbor and Niantic River are at the top of the list, as they had the lowest eutrophic status according to the NOAA ASSETS results. Both of these systems show a number of stations receiving a “good” ranking from EPA NCA, with no stations receiving a “poor.” Saugatuck River through Stony Brook received a solid “fair”, with no “good” or “poor” stations. For the remaining sites, which received the rank of “high risk” from the NOAA ASSETS metric, we see some embayments with “poor” ranking of the EPA NCA, and some with solid “fair” rankings. However, we see a number of stations with a “good” ranking in Pawcatuck River and Wequetequock Cove. Clinton Harbor, Mattituck Creek, and Mount Sinai also have at least one station with a score of “good.” These sites illustrate the breakdown of this metric when applied to shallow systems. The EPA NCA does not include an estimate of benthic processes, only water column quality. Pawcatuck River and Wequetequock Cove are overrun with a nuisance green macroalgae (Figure 14). This macroalgae immediately utilizes any nutrient in the water column for growth, thus cleaning the water column of nutrients. This in turn reduces chlorophyll *a* in the water column, as the phytoplankton lose the competition for nutrients when faced with the enormous biomass of macroalgae. Mattituck Creek, Mount Sinai, and Clinton Harbor have similar situations, but the macroalgae in these sites are not nearly as widespread or abundant.

Table 4: Stations Per Site

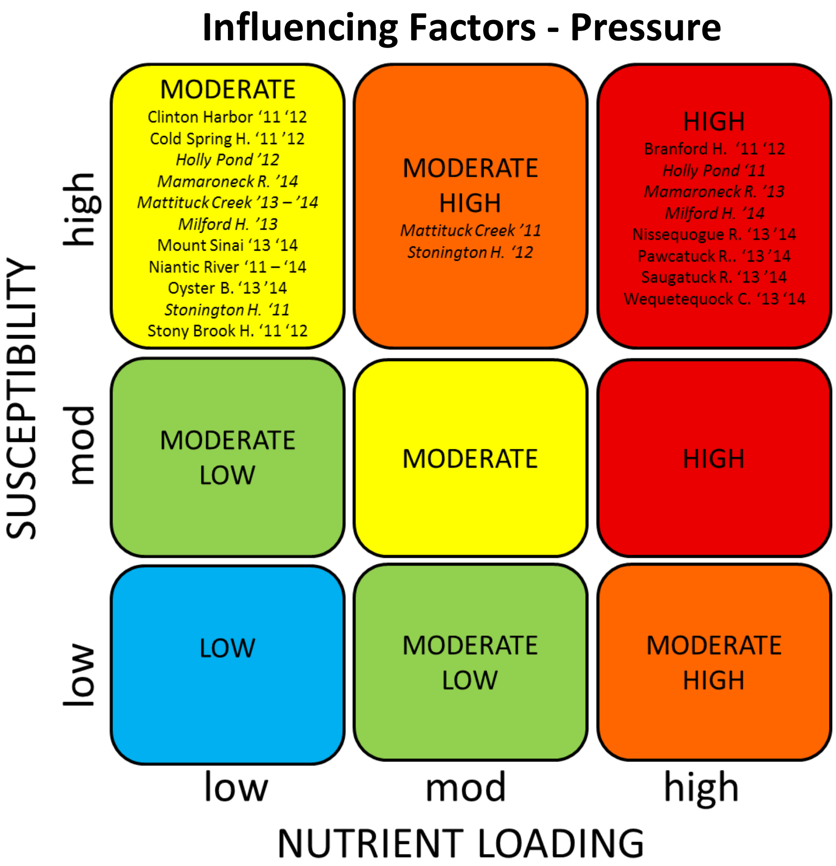
The number of stations sampled within each of the study sites was determined based on the size of the area of interest. A minimum of four stations were sampled per site. A guideline for determining the number of stations was based on the extensive knowledge of community composition in Niantic River, CT. To adequately capture the range of conditions, six stations are advisable. Based on the area of Niantic River, this yields 1 station per 0.42 km^2. The maximum number of stations that could be sampled by boat giving the timing criteria was 9. In each embayment, sampling occurred in three salinity zones: tidal fresh (< 0.5 psu), mixing zone (0.5 – 25 psu), and LIS zone (> 25 psu). Land stations were used to sample freshwater tidal areas and were sampled throughout the year. Boat stations were sampled only in late summer. For the Long Island embayments, 3 of the boat stations were sampled throughout the year.

	approximate area (km^2)	recommended # of stations for 1 station per 0.42 km^2	actual # of stations
Pawcatuck River, CT	3.4	9	9 boat, 4 land
Wequetequock Cove, CT	0.9	3	4 boat, 4 land
Niantic River, CT	2.5	6	7 boat, 3 land
Milford Harbor, CT	0.3	1	4 boat, 3 land
Saugatuck River, CT	2.8	7	7 boat, 3 land
Mamaroneck River, NY	5.9	15	5 boat, 4 land
Oyster Bay Harbor, NY	10.3	25	9 boat
Nissequogue River, NY	0.8	2	6 boat
Mt. Sinai Harbor, NY	1	3	6 boat
Mattituck Creek, NY	0.5	2	6 boat

These comparisons of the two metrics illustrate that a eutrophic indicator for a shallow system must include an assessment of the benthic primary producer community, specifically macroalgae. For deeper systems like Oyster Bay and Cold Spring Harbor, the EPA NCA metric is probably accurate. It also seems to work for systems with lower eutrophic conditions. However, once benthic processes, specifically macroalgae, begin to dominate the nitrogen cycle activity, the EPA NCA is no longer useful. The NOAA NEAA ASSETS approach seems to do a much better job of defining the eutrophic status, when compared to our first-hand knowledge of these systems.

Moving forward, our suggestions for monitoring eutrophic status in embayments include:

- monitor diel cycles of oxygen during late summer
- monitor macroalgae biomass
- monitor chlorophyll concentration as an indicator of phytoplankton biomass
- utilize the NOAA NEAA ASSETS approach to assessing eutrophic status, which requires:
  - annual nutrient concentration in fresh water and Long Island Sound (sampled a minimum of 4 times / y)
  - annual mean salinity in embayment and in Long Island Sound at mouth of embayment
  - Waste water treatment facility nitrogen load (annual load)
  - River flow (annual volume total)
  - chlorophyll *a*, macroalgae, low dissolved oxygen, loss of submerged aquatic vegetation, and the occurrence of harmful algal blooms - field data collected in summer, ideally collected multiple times throughout the year
- explore ways to monitor harmful algal blooms


Influencing Factors - Pressure

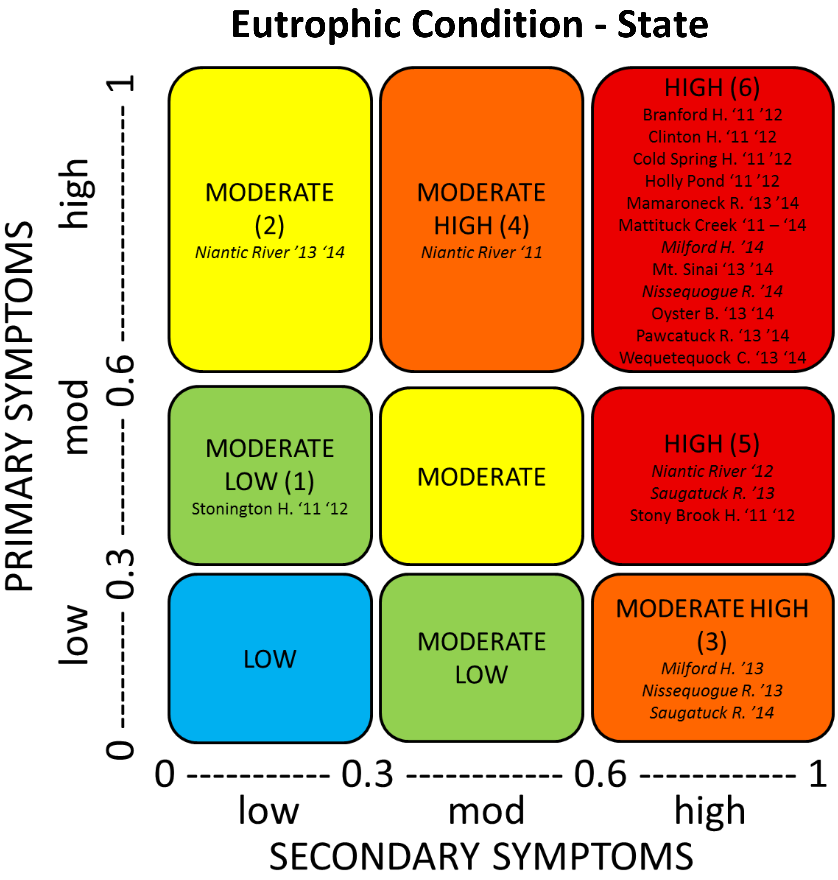

Eutrophic Condition - State

Figure 15: NOAA NEAA ASSETS Results. Top panel: Results for assessment of the NOAA NEAA ASSETS assessment of the influencing factors or pressure on embayment's trophic status. Susceptibility reflects the physical characteristics of the embayment, the embayment area, volume, and tidal range; watershed area; and assessment of a degree of mixing based on salinity within the embayment. Nutrient loading is based on the watershed size, it does not include information on the land use or population characteristics of the embayment. Site names are followed by the year they were sampled (e.g.: ’11 ’12 indicates 2011 and 2012). Sites in italics indicate that site had a different score during a different year. Bottom panel: Results for assessment of the NOAA NEAA ASSETS assessment of the eutrophic condition. Site names are followed by the year they were sampled (e.g.: ’11 ’12 indicates 2011 and 2012). Sites in italics indicate that site had a different score during a different year.

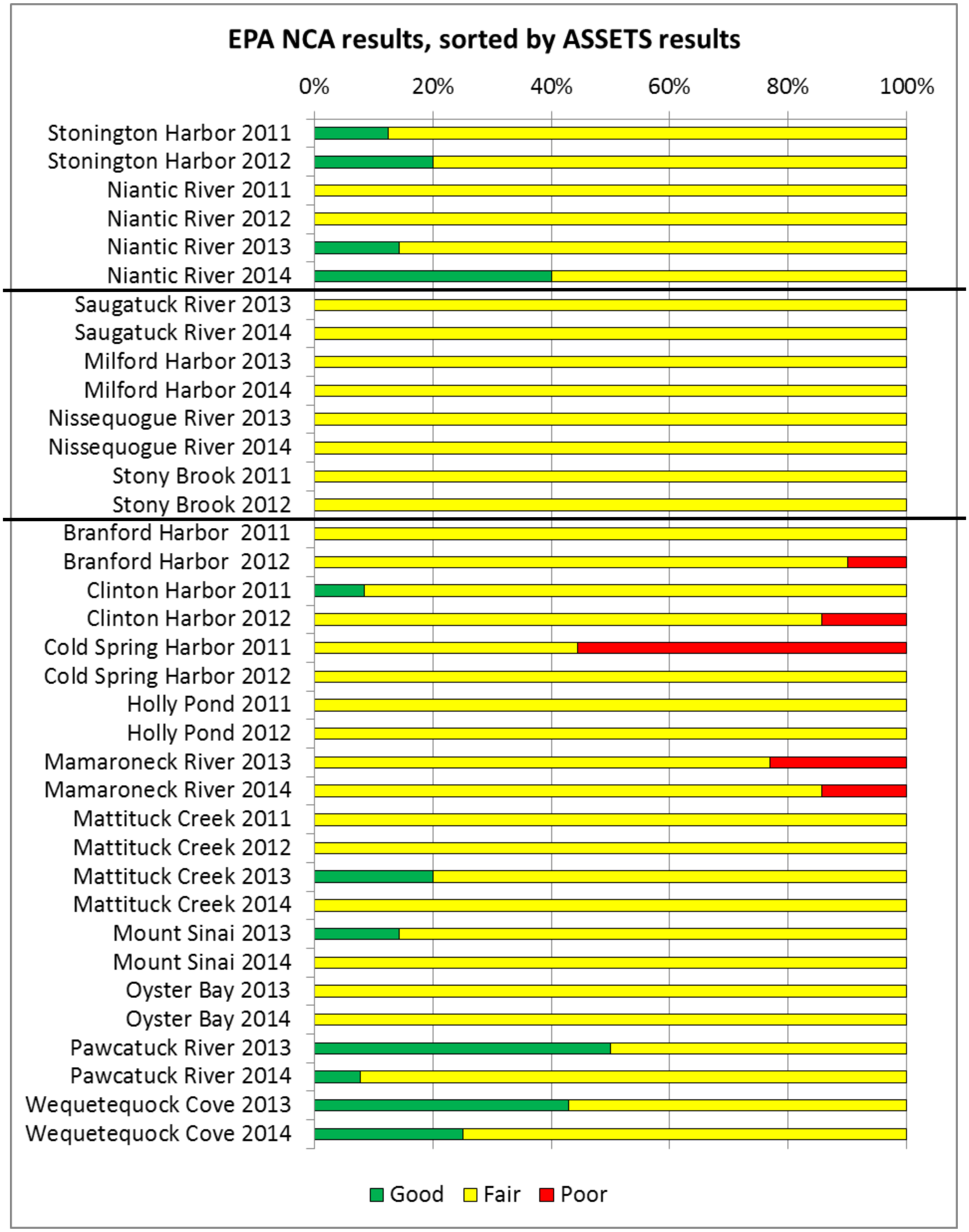


Figure 16: EPA National Coastal Assessment Results.
Results of applying the EPA National Coastal Assessment metric to summer field data. The sites have been sorted based on the NOAA ranking of eutrophic status presented in Figure 15, then alphabetically within each category. The y-axis indicates the site name and year of sampling.

Prioritizing Embayments of Concern

Prioritizing embayments of concern requires consideration of factors beyond the nitrogen load. An example of prioritizing embayments is provided here, but ranking of all sites using criteria discussed below and presented in table 5 are recommended. The key is that this process must include stakeholders and the priority given to different aspects of how the ranking is conducted will reflect the priorities of the people doing the ranking. While we typically think of priority embayments as those with the greatest nitrogen load, other factors may be considered more important. For example, if reducing nitrogen load to Long Island Sound is the priority, the East River should be the top priority. If reducing nitrogen load to heavily impacted embayments is the priority, Pawcatuck River is a likely candidate. If preserving existing eelgrass beds is a priority, Niantic River and Stonington Harbor will top the list. The example below illustrates how these data can be used to prioritize embayments, but the criteria for prioritizing will vary by the group setting the priorities. Other factors, such as expected improvements to ecosystem services and resources and willingness of stakeholders in the watershed to enact change should also be considered, but were not assessed in this study.

To make this example more manageable, the embayments identified in Table 3 as most likely to be exhibiting symptoms of eutrophication are compared (Table 5). In this example, the goal is to identify those embayments with the highest loads and biggest impacts on Long Island Sound populations of people. Thus, additional factors to consider are the population of the watershed, the size of the embayment, the size of the watershed, the total nitrogen load, the nitrogen load normalized to the area of the embayment, and the nitrogen load normalized to the area of the watershed. Table 5 has been sorted by population, working under the assumption that we would want to prioritize embayments with the largest impact on the most people. For sites with the largest populations, Pequonnock River has a high total load and the highest per embayment load, but a small embayment size. Pawcatuck River has the highest total load, but the large size of the watershed and embayment potentially reduce the relative impact. Stamford Harbor and Nissequogue River, with the two highest populations, are also ranking fairly high in most categories. These sites constitute areas which need more attention.

Another step in prioritizing sites is considering the source of the nitrogen and the likelihood of controlling that source. It may be prudent to first approach those systems with the potential for a big impact and where controlling the nitrogen inputs is easier to achieve. Referring back to Figure 9, we see that Pequonnock River and Stamford Harbor are dominated by sewer; greater nitrogen removal from the WWTF would reduce the nitrogen loads. Pawcatuck is dominated by fertilizer application and sewer inputs. Improving nitrogen removal in the WWTF would lower the load, and some outreach to reduce fertilizer input could also be helpful. Nissequogue River is dominated by septic inputs. Given the large population in the Nissequogue River watershed, sewering of more densely populated areas is suggested.

While the embayments listed in Table 5 are a good list to start attacking the nitrogen pollution in Long Island Sound embayments, interested stakeholders could use the results of this project to set their own priorities for embayments of concern.

Table 5: Embayments of concern.
The following embayments were listed in Table 3 as likely to exhibit symptoms of eutrophication. The sites in bold text were identified by both a high per embayment area nitrogen load and a high predicted dissolved inorganic nitrogen concentration in the embayment. Sites in regular text were identified by only a high per embayment area nitrogen load. Sites in italicized text were identified by only a high predicted dissolved inorganic nitrogen concentration in the embayment. Additional factors to consider are included. Conditional formatting has been applied to each column such that high levels are red and low levels are green. These may be interpreted as high priorities (red) for nutrient reduction efforts and lower priorities (green). Data are sorted by population.

Site ID #	Site Names	Embayment Area (ha)	Watershed Area (ha)	Total Load, including atmospheric deposition to the embayment (kg N / y)	Total Load, including atmospheric deposition to the embayment (kg N / ha-estuary / y)	Total Load, not including atmospheric deposition to the embayment (kg N / ha-watershed / y)	Population (# of people)
75	Stamford Harbor, CT	232	7,895	130,171	561	16.0	93,582
110	**Nissequogue River, NY**	195	9,745	281,098	1,440	28.5	91,441
55	Pequonnock River, CT	20	8,682	100,959	5,002	11.6	86,997
87	**Mamaroneck River, NY**	48	6,647	120,725	2,507	18.1	73,062
1	**Pawcatuck River, RI**	264	67,456	228,213	865	3.3	56,361
82	**Byram River, CT**	12	7,026	36,372	2,952	5.1	43,191
59	**Mill River, CT**	26	8,707	35,297	1,338	4.0	27,301
47	**Farm River, CT**	42	6,739	35,229	836	5.1	26,600
39	*Guilford Harbor, CT*	182	13,070	54,517	299	3.9	23,893
56	**Black Rock Harbor, CT**	111	512	83,506	752	159.7	20,355
9	*Mystic River, CT*	117	6,722	29,514	252	4.2	12,416
49	**Oyster River, Milford, CT**	3	982	7,209	2,246	7.3	9,895
78	Indian Harbor, CT	23	2,232	13,876	595	6.1	8,931
70	Gorham Pond, CT	10	1,698	12,989	1,247	7.6	8,882
60	**Sasco Brook, CT**	5	2,452	12,515	2,296	5.1	7,781
24	*Pattagansett River, CT*	12	2,320	5,452	437	2.3	6,488
35	*Menunkesucket River, CT*	25	4,544	11,922	468	2.5	5,317
50	**Calf Pen Meadow Creek, CT**	1	268	1,731	1,540	6.4	3,944
25	*Bride Brook, CT*	7	1,098	3,127	434	2.7	3,870
32	*Oyster River, Old Saybrook, CT*	11	1,682	5,880	550	3.4	3,098
8	**Williams Cove, CT**	6	626	4,648	809	7.3	1,776
38	**Fence Creek, CT**	2	374	3,043	1,632	8.0	1,653
31	*Indiantown Harbor, CT*	14	318	3,692	257	10.9	1,577
37	**Toms Creek, CT**	2	309	2,526	1,608	8.1	911
33	Hagar Creek, CT	2	135	1,179	625	8.5	483
116	Goldsmith's Inlet, NY	9	559	8,811	994	15.6	464
100	Frost Creek, NY	7	426	3,793	511	8.7	447

Next Steps

Understanding the impact of nutrient loads on embayments is critical to targeting nutrient reductions to have the greatest impact. In order to better understand problems, assessment of embayments with the potential to be experiencing eutrophication is recommended. The list of sites provided in Table 5 also reflects those embayment s which should be assessed for problems.

In order to assess the eutrophic status in embayments, the following activities are suggested:

- monitor diel cycles of oxygen during late summer
- monitor macroalgae biomass
- monitor chlorophyll concentration as an indicator of phytoplankton biomass
- utilize the NOAA NEAA ASSETS approach to assessing eutrophic status, which requires:
    - annual nutrient concentration in fresh water and Long Island Sound (sampled a minimum of 4 times / y)
    - mean salinity in embayment and in Long Island Sound at mouth of embayment
    - Waste water treatment facility nitrogen load (annual load)
    - River flow (annual volume total)
    - chlorophyll *a*, macroalgae, low dissolved oxygen, loss of submerged aquatic vegetation relative to historic distribution and potential habitat, and the occurrence of harmful algal blooms - field data collected in summer, ideally collected multiple times throughout the year
- explore ways to monitor harmful algal blooms

The next logical application of the results of this project are to work with stakeholders to prioritize sites and identify strategies for reducing nitrogen inputs into the embayments. Embayments may serve as a tool for educating the populace and gaining support for nitrogen mitigation strategies that benefit Long Island Sound. By using an embayment familiar to the people in the watershed, familiarity with the importance of reducing nutrient inputs to coastal waters can be increased and applied to the larger system of Long Island Sound.

While the nitrogen load from watersheds is highly useful on its own, further study regarding in-estuary processes would help to improve our understanding regarding impact of the nitrogen load on embayments. One such example of this is the Massachusetts Estuary Project (MEP), led by Brian Howes (SMAST), Roland Samimy (SMAST), and Brian Dudley (MA DEP); the MEP illustrates the integration of watershed-based nitrogen loads with an understanding of in-estuarine processes (http://www.oceanscience.net/estuaries/about.htm). These assessments include a finely reolved hydrodynamic model which allow for a characterization of what is being exported from and imported to an embayment from the neighboring ocean. Such an approach is recommended for better understanding the impact of embayments on Long Island Sound, and vice versa. It must be emphasized that while this additional work is of interest and importance, we understand these nitrogen sources and relative impacts well enough to start making changes now.

Data Quality and Availability

All work was conducted under an EPA QAPP. Details of the adherence to QAPP standards are provided in the technical report. Field data, GIS layers, and an Excel-based tool with the nitrogen loading model will be made available in a permanent and stable database through UConn's Digital Commons within the coming year. Contact Jamie Vaudrey (jamie.vaudrey@uconn.edu) for details if you are unable to find the data files by searching the UConn Digital Commons.

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