Quality Assurance Project Plan: Data Synthesis and Modeling of Nitrogen Effects on Niantic River Estuary

QAPP – September 8, 2016

Funded by:

Millstone's Environmental Laboratory
located at Dominion's Millstone Power Station in Waterford, CT

Prepared for:

Niantic Nitrogen Work Group
and
Dominion, Millstone Environmental Laboratory

Prepared by:

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Section A – Project Management

A.1. Approval Page

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Jamie Vaudrey, Ph.D., Primary Investigator DATE
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Jason Krumholz, Ph.D., Project Partner DATE
Department of Marine Sciences, University of Connecticut

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Christopher Calabretta, Ph.D., Project Partner DATE
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Claudia Koerting, Ph.D., Project QA Officer DATE
Department of Marine Sciences, University of Connecticut

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Kelly Streich, Niantic Nitrogen Workgroup Project Manager DATE
CTDEEP, Bureau of Water Protection & Land Reuse

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Chris Bellucci, Quality Assurance Officer DATE
CTDEEP, Bureau of Water Protection & Land Reuse

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John Swenarton, Niantic Nitrogen Workgroup Grant Administrator DATE
Dominion, Millstone Environmental Laboratory

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A.2.Table of Contents

A.3. Distribution List

All documents will be provided in digital format; no hard copies will be provided. Thus, email is the main method of distribution.

Jamie Vaudrey, Principal Investigator
jamie.vaudrey@uconn.edu

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kelly.streich@ct.gov
Kelly Streich will distribute any project documents to the Niantic Nitrogen Workgroup and the Technical Advisory Committee.

Chris Bellucci, CTDEEP Quality Assurance Manager
christopher.bellucci@ct.gov

John Swenarton, Niantic Nitrogen Workgroup Grant Administrator
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TBD, EPA Quality Assurance Officer

Table 1: Acronyms and Abbreviations.

CCMP	Comprehensive Conservation and Management Plan
CT	Connecticut
DIN	dissolved inorganic nitrogen
DIP	dissolved inorganic phosphate
DON	dissolved organic nitrogen
DPSIR	drivers, pressures, states, impacts, responses
DQI	Data Quality Indicator
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System
LCS	laboratory control samples
LIS	Long Island Sound
MDS	multi-dimensional scaling
MEP	Massachusetts Estuaries Program
N	nitrogen
N/A	not applicable
NRE	Niantic River Estuary
NWG	Nitrogen Workgroup
NRWC	Niantic River Watershed Commission
NYHOPS	New York Harbor Observing and Prediction System
PCA	principal components analysis
PI	principal investigator
QA/QC	quality assurance / quality control
QAPP	quality assurance project plan
QC	quality control
TAC	technical advisory committee
TBD	to be determined
UCONN	University of Connecticut
USGS	United States Geological Survey

A.4. Project Organization

Jamie Vaudrey, Ph.D.; Department of Marine Sciences, UCONN, Principal Investigator
Vaudrey will supervise all aspects of the project and coordinate work among the group. Vaudrey will act as the point of communication with the Niantic Nitrogen Workgroup, who will be advising on the project. Vaudrey will prepare the EPA Quality Assurance Project Plan, review all data, and prepare data for reports. Vaudrey will take the lead on constructing an ecosystem model examining effects of nitrogen loads on oxygen and seagrass dynamics in Niantic River Estuary.

Jason Krumholz, Ph.D.; Department of Marine Sciences, UCONN, Project Partner
Krumholz provides expertise with data analysis of large datasets and application of science to management. Krumholz was instrumental to the development of the Long Island Sound Comprehensive Conservation Management Plan released in 2015; one of the components of this project is relating the work to the LIS CCMP. Krumholz will advise and participate in data analysis and provide a review of application of results to the management community.

Christopher Calabretta, Ph.D.; Department of Marine Sciences, UCONN, Project Partner
Calabretta provides expertise with Geographical Information Systems (GIS) technology and application, as well as evaluating anthropogenic influences on benthic organisms. Calabretta will be responsible for GIS analysis and visualization of data.

Claudia Koerting, Ph.D.; Department of Marine Sciences, UCONN, Project Quality Assurance Officer
Responsible for ensuring that the approved QAPP is fully implemented. Claudia Koerting is independent from those generating project information.

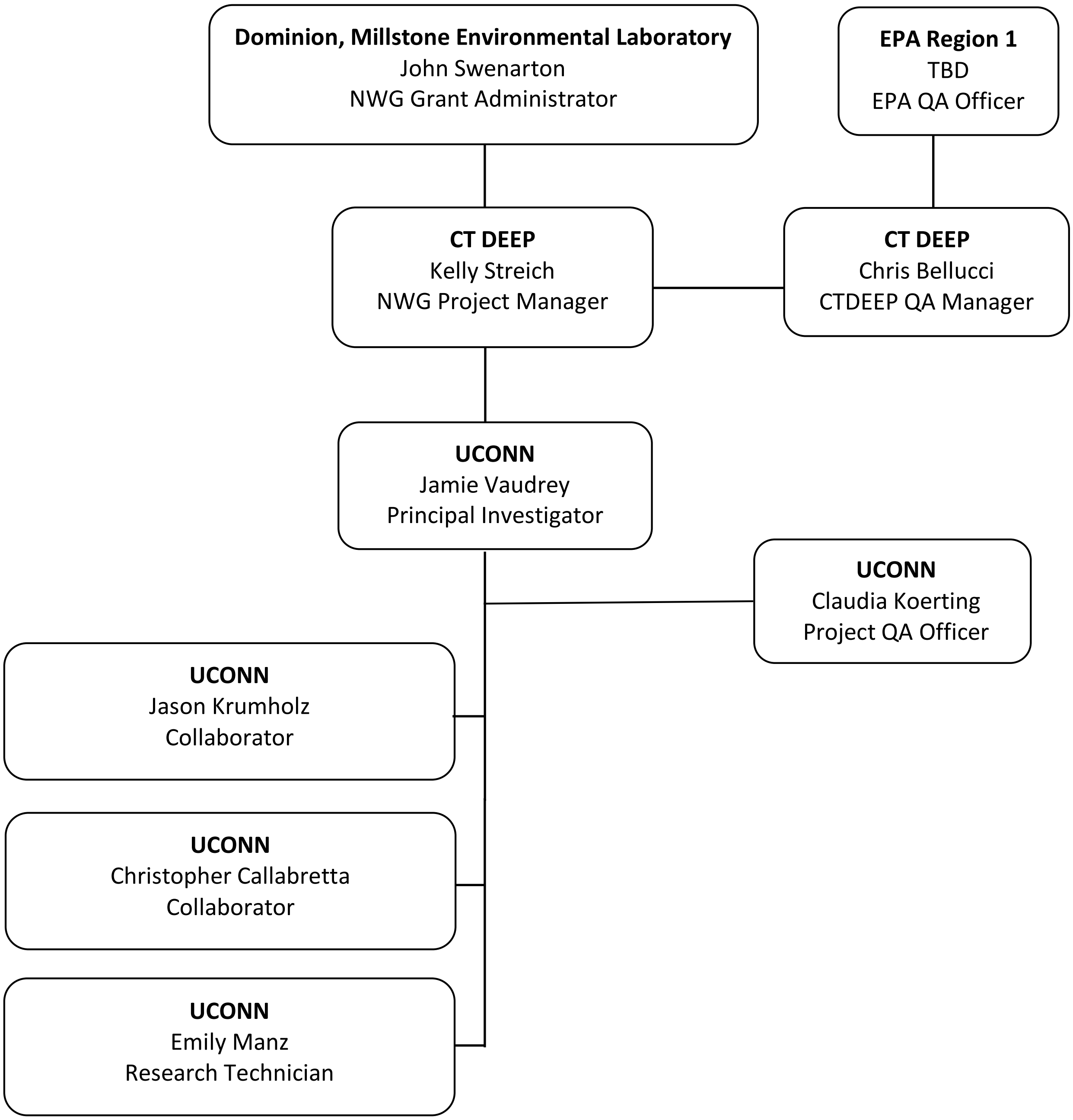
Kelly Streich, Niantic Nitrogen Workgroup Project Manager
Responsible for reviewing and approving the project work plan and QAPP, as well as reviewing progress and deliverables, including a final report.

Chris Bellucci, CTDEEP Quality Assurance Manager
Responsible for review and approval of the project QAPP.

John Swenarton, Niantic Nitrogen Workgroup Grant Administrator
Responsible for grant administration of this project upon the approval of deliverables by the NWG.

TBD, EPA Region 1 Quality Assurance Officer
Responsible for reviewing and approving the QAPP on behalf of the EPA Region 1 QA Unit.

Figure 1: Organizational Chart



A.5. Project Description and Background

The Niantic River Estuary (NRE) is a vibrant system, supporting a multitude of habitats including eelgrass beds, diverse macroalgae, sand flats, and fringing salt marshes. While water quality is better than many other embayments of Long Island Sound (LIS) as evidenced by the presence of eelgrass, the interannual fluctuations in eelgrass area and presence of nuisance macroalgae indicate this is a system nearing a tipping point. The reduction of eelgrass and increase of nutrient-loving macroalgae coupled with observed summertime hypoxia are symptoms of eutrophication, which is an increase in organic matter in a system, usually caused by human-sourced nutrient inputs[1]. Nitrogen inputs from sewage, fertilizer, and land use have been identified as the major human-induced cause of eutrophication in the NRE. The synergistic effects of high nutrient loads from the watershed and warming temperatures makes this system more susceptible to eutrophication.

Reversal of eutrophication and restoration of coastal habitats are critical objectives of the newly revised LIS Comprehensive Conservation and Management Plan (CCMP), released in 2015[2]. The preservation and augmentation of eelgrass falls within the auspices of both the “Clean Waters and Healthy Watersheds” and the “Thriving Habitats and Abundant Wildlife” themes of this document, and quantifiable ecosystem targets for nitrogen load, water clarity and eelgrass abundance are specified. Improving our understanding of the relationship between eelgrass health, water quality management efforts, and climate change is critical to continued effective stewardship of coastal marine resources. Eelgrass and water quality form a positive feedback loop; eelgrass requires good water quality, while healthy eelgrass beds help improve water quality by trapping sediment and pollutants and taking up nitrogen[3]. However, this can be a double edged sword, since while improvements to water quality can improve eelgrass, and consequently lead to further improvements in water quality, the converse is also true; that declines in water quality can result in eelgrass habitat loss, and further degradation of water quality.

The modeling effort in the proposed work involves application of an ecosystem model to define the in-estuary processes. The load of nitrogen from the watershed will be estimated using two methods: results of a watershed-based nitrogen loading model completed by Vaudrey and colleagues, and empirical estimates based on freshwater flow and nutrient concentrations at gaging stations completed by the USGS. Equations for in-estuary processes will be compared to a wealth of field data available for NRE. The end-use of the model results will be to inform regulatory practices in the watershed with the goal of improving water quality in NRE.

The NRE has a long history of monitoring of water quality, eelgrass metrics, and biota conducted by Millstone Environmental Lab and Save the River, Save the Hills. More recent work has been conducted by the Niantic River Watershed Commission, USGS, and a variety of academic researchers, including Vaudrey. Our proposed project involves three phases: (1) synthesis and integration of available data, (2) development of a model to investigate the relationship between nutrient inputs, physical flow, climatic

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[1] Nixon, S. W. (2009). Eutrophication and the macroscope. *Hydrobiologia, 629*, 5-19.
[2] Long Island Sound Study. (2015). Long Island Sound Comprehensive Conservation and Management Plan: Returning the Urban Sea to Abundance.: US Environmental Protection Agency, Long Island Sound Office, Stamford, CT.
[3] Burkholder, J. M., Tomasko, D. A., & Touchette, B. W. (2007). Seagrasses and eutrophication. *Journal of Experimental Marine Biology and Ecology, 350*(1-2), 46-72.

changes, and the response of the ecosystem (oxygen, eelgrass, macroalgae), and (3) application of the model and data synthesis towards management scenario analysis and development of recommendations.

With regards to the ecosystem model (biogeochemical model coupled to a physical mixing model) for in-estuary processes, two models will be evaluated: Vaudrey's work modeling Narragansett Bay[4,5,6,7] and the Massachusetts Estuary Project model[8]. in addition, sediment biogeochemistry components of these two models will be assessed and compared to the models reviewed in Wilson et al. (2013)[9]. The decision of which model is better for this application will be determined by examining the similarity of the other estuaries where the models were applied to the NRE, the number of model parameters versus the available field data for verification in the NRE, and the requirements associated with each model in terms of input data. Given that sampling programs in NRE were not designed with modeling in mind, it may be that one of the models may not have sufficient data to characterize the system. In this cases, a simpler model with greater uncertainty may be chosen over a more refined model with greater number of parameters which are poorly constrained for NRE. The issue is that poorly constrained parameters may be "over-tuned" to achieve a good match between field data and model results, but not be an accurate reflection of the reality of the system.

The ultimate goal of the project is to inform management decisions supportive of good water quality in NRE. The synthesis of existing data will be used to understand the dynamics of the system in relation to climate and nutrient loads. The model will be used to predict the level of nutrient loads supportive of eelgrass and shellfish (as indicators of good water quality) under a warming climatic regime. An analysis of the potential impact of nutrient mitigation strategies will guide prioritization of activities in the watershed, with the Niantic River Watershed Commission evaluating our suggestions and assessment of feasibility.

A.6. Project / Task Description

Our team is uniquely qualified to conduct this synthetic research of the large dataset available for the NRE. Our project scope touches on four of the five categories of methods reviewed by Kemp et al. (2012)[10]. Our project scope includes an analysis of time-series data as part of the data synthesis. The

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[4] Brush, M. J. (2002). *Development of a numerical model for shallow marine ecosystems with application to Greenwich Bay, RI.* Ph.D. Doctoral Dissertation, Univeristy of Rhode Island, Narragansett, RI.
[5] Brush, M. J., & Nixon, S. W. (2010). Modeling the role of macroalgae in a shallow sub-estuary of Narragansett Bay, RI (USA). *Ecological Modelling, 221*, 1065–1079.
[6] Kremer, J. N., Vaudrey, J. M. P., Ullman, D., Bergondo, D. L., Nasota, N., Kincaid, C., Codiga, D. L., & Brush, M. J. (2010). Simulating property exchange in estuarine ecosystem models at ecologically appropriate scales. *Ecological Modelling, 221*, 1080-1088.
[7] Vaudrey, J. M. P. (2014). 2014 working report on the Narragansett Bay EcoGEM model (pp. 68): University of Connecticut.
[8] Howes, B. L., Ramsey, J. S., & Kelley, S. W. (2001). Nitrogen Modeling to Support Watershed Management: Comparison of Approaches and Sensitivity Analysis: prepared for: Massachusetts Department of Environmental Protection Bureau of Resource Protection and U.S. Environmental Protection Agency Region I.Project #00-06/104.
[9] Wilson, R. F., Fennel, K., & Mattern, P. (2013). Simulating sediment-water exchange of nutrients and oxygen: A comparative assessment of models against mesocosm observations. *Continental Shelf Research, 63*, 69-84.
[10] Kemp, W. M., & Boynton, W. R. (2012). Synthesis in estuarine and coastal ecological research: what is it, why is it important, and how do we teach it? *Estuaries and Coasts, 35*(1), 1-22. doi: 10.1007/s12237-011-9464-9

balance of cross-system boundary fluxes is fundamental to developing recommendations for a target nitrogen loading rate, an important component for the management of NRE. We will incorporate both system-specific simulation and general systems modeling via incorporation of a watershed nitrogen loading model to assess mitigation strategies and the development of an ecosystem model (linking hydrodynamics to a biogeochemical model) to assess controls and responses within the system.

Vaudrey has experience evaluating eutrophication, hypoxia, and seagrass dynamics; including the synthesis of data with information and theories from the scientific literature, as well as development of GIS-based and dynamic ecosystem models[11,12,13,14,15,16,17,18,19,20]. Krumholz brings experience in nutrient mass balance, time series analysis, and nearshore restoration ecology[21,22,23,24]. In addition, as the lead author of the "Clean Waters and Healthy Watersheds" theme of the Long Island Sound Study CCMP and

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[11] Ganju, N. K., Brush, M. J., Rashleigh, B., Aretxabaleta, A. L., del Barrio, P., Grear, J. S., Harris, L. A., Lake, S. J., McCardell, G., O'Donnell, J., Ralston, D. K., Signell, R., Testa, J. M., & Vaudrey, J. M. P. (2015). Progress and Challenges in Coupled Hydrodynamic-Ecological Estuarine Modeling. *Estuaries and Coasts*, 1-22. doi: 10.1007/s12237-015-0011-y

[12] Kremer, J. N., Vaudrey, J. M. P., Ullman, D., Bergondo, D. L., Nasota, N., Kincaid, C., Codiga, D. L., & Brush, M. J. (2010). Simulating property exchange in estuarine ecosystem models at ecologically appropriate scales. *Ecological Modelling, 221*, 1080-1088.

[13] Short, F. T., Klein, A. S., Burdick, D. M., Moore, G. E., Granger, S., Pickerell, C., Vaudrey, J., Bayley, H., & Evans, N. T. (2012). The eelgrass resource of Southern New England and New York: science in support of management and restoration success: Final Report submitted to The Nature Conservancy, 122 p.

[14] Vaudrey, J. M. P. (2007). *Estimating total ecosystem metabolism (TEM) from the oxygen rate of change: a comparison of two Connecticut estuaries.* Ph.D. Doctoral Dissertation, University of Connecticut, Groton.

[15] Vaudrey, J. M. P. (2008a). Establishing restoration objectives for eelgrass in Long Island Sound - Part I: review of the seagrass literature relevant to Long Island Sound (pp. 58). Groton, CT: Final Grant Report to the Connecticut Department of Environmental Protection, Bureau of Water Protection and Land Reuse and the U.S. Environmental Protection Agency. http://www.lisrc.uconn.edu/eelgrass/index.html (select Literature Reviews > Seagrass Literature Survey Report).

[16] Vaudrey, J. M. P. (2008b). Establishing restoration objectives for eelgrass in Long Island Sound - Part II: case studies (pp. 64). Groton, CT: Final Grant Report to the Connecticut Department of Environmental Protection, Bureau of Water Protection and Land Reuse and the U.S. Environmental Protection Agency. http://www.lisrc.uconn.edu/eelgrass/index.html (select Literature Reviews > Case Study Report).

[17] Vaudrey, J. M. P., Eddings, J., Pickerell, C., Brousseau., L., & Yarish., C. (2013). Development and application of a GIS-based Long Island Sound Eelgrass Habitat Suitability Index Model: Final report submitted to the New England Interstate Water Pollution Control Commission and the Long Island Sound Study. 171 p. + appendices.

[18] Vaudrey, J. M. P., Kim, J. K., Yarish, C., Brousseau, L., Pickerell, C., & Eddings, J. (2013). Comparative analysis and model development for determining the susceptibility to eutrophication of Long Island Sound embayments: University of Connecticut and Cornell Cooperative Extension of Suffolk County.

[19] Vaudrey, J. M. P., & Kremer, J. N. (2010). 2010 working report on the Narragansett Bay EcoGEM model (pp. 68): University of Connecticut.

[20] Vaudrey, J. M. P., Kremer, J. N., Branco, B. F., & Short, F. T. (2010). Eelgrass recovery after nutrient enrichment reversal. *Aquatic Botany, 93*, 237-243. doi: http://dx.doi.org/10.1016/j.aquabot.2010.08.005

[21] Cummings, C., Zuke, A., DeStasio, B., & Krumholz, J. (2015). Coral growth assessment of an established artificial reef in Antigua. *Ecological Restoration, 33*(1), 90-95. doi: 10.3368/er.33.1.90

[22] Forrester, G. E., O'Connell-Rodwell, C., Bailey, P., Forrester, L. M., Giovannini, S., Harmon, L., Karis, R., Krumholz, J., Rodwell, T., & Jarecki., L. (2011). Evaluating Methods for Transplanting Endangered Elkhorn Corals in the Virgin Islands. *Restoration Ecology, 19*(3), 299-306. doi: 10.1111/j.1526-100X.2010.00664.x

[23] Krumholz, J. (2012). *Spatial and Temporal Patterns in Nutrient Standing Stock and Mass-Balance in Response to Load Reductions in a Temperate Estuary.* University of Rhode Island, Graduate School of Oceanography. Retrieved from Open Access Dissertations. Paper 79. http://digitalcommons.uri.edu/oa_diss/79Open (Open Access Dissertations. Paper 79. http://digitalcommons.uri.edu/oa_diss/79Open)

[24] Krumholz, J. S., & Jadot, C. (2009). Demonstration of a new technology for restoration of Red Mangrove (*Rhizophora mangle*) in high-energy environments. *Marine Technology Society Journal 43*(1), 64-72. doi: 10.4031/MTSJ.43.1.10

the CCMP ecosystem targets appendix[25], Krumholz is intimately familiar with the ecology of Long Island Sound and has published several papers on the translation of scientific data into sound management policies[26,27,28]. Calabretta is skilled in the geospatial analysis and interpretation of data from numerous sources to relate trends in environmental condition to physical and biological stressors. Calabretta also has extensive practical experience with multivariate ecological statistics, forensic chemistry, and the development and management of large environmental databases.

A.6.1. OBJECTIVES

Task 1: Data Synthesis
Synthesize data and use statistical techniques to evaluate the relationship between environmental state (eelgrass extent, phenology of eelgrass, hypoxia, macroalgae) and anthropogenically influenced drivers and pressures (e.g. drivers: land use changes, nutrient inputs, climate change; pressures: river flow, temperature, sunlight).

Task 2: Model Development
Utilize existing data to develop an ecosystem model (biogeochemical model coupled to a physical mixing model). Two models will be evaluated, including Vaudrey's work modeling Narragansett Bay[29,30,31,32] and the Massachusetts Estuary Project model[33]. Additionally, the sediment biogeochemistry models reviewed in Wilson et al. (2013)[34] will be assessed for use in NRE.

Task 3: Target N Load Recommendations
Develop recommendations for a target nitrogen load from the watershed which is supportive of CCMP targets for eelgrass and ecosystem integrity, taking into account the predicted changes in climate (e.g. rising temperatures and sea levels).

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[25] Long Island Sound Study. (2015). Long Island Sound Comprehensive Conservation and Management Plan: Returning the Urban Sea to Abundance.: US Environmental Protection Agency, Long Island Sound Office, Stamford, CT.
[26] Krumholz, J. (2011). Quantifying and Monitoring Ecological Response to No-Take Marine Reserves. *Journal of Ecology and Environment, 2(1)*, E3. doi: 10.5296/jee.v2i1.696
[27] Krumholz, J., Barber, T., & Jadot, C. (2010). Avoiding "Band-Aid" Solutions in Ecosystem Restorations. *Ecological Restoration, 28*(1), 17-19. doi: 10.3368/er.28.1.17
[28] Krumholz, J. S., & Brennan, M. L. (2015). Fishing for common ground: Investigations of the impact of trawling on ancient shipwreck sites uncovers a potential for management synergy. *Marine Policy, 61*, 127-133. doi: 10.1016/j.marpol.2015.07.009
[29] Brush, M. J. (2002). *Development of a numerical model for shallow marine ecosystems with application to Greenwich Bay, RI.* Ph.D. Doctoral Dissertation, Univeristy of Rhode Island, Narragansett, RI.
[30] Brush, M. J., & Nixon, S. W. (2010). Modeling the role of macroalgae in a shallow sub-estuary of Narragansett Bay, RI (USA). *Ecological Modelling, 221*, 1065–1079.
[31] Kremer, J. N., Vaudrey, J. M. P., Ullman, D., Bergondo, D. L., Nasota, N., Kincaid, C., Codiga, D. L., & Brush, M. J. (2010). Simulating property exchange in estuarine ecosystem models at ecologically appropriate scales. *Ecological Modelling, 221*, 1080-1088.
[32] Vaudrey, J. M. P. (2014). 2014 working report on the Narragansett Bay EcoGEM model (pp. 68): University of Connecticut.
[33] Howes, B. L., Ramsey, J. S., & Kelley, S. W. (2001). Nitrogen Modeling to Support Watershed Management: Comparison of Approaches and Sensitivity Analysis: prepared for: Massachusetts Department of Environmental Protection Bureau of Resource Protection and U.S. Environmental Protection Agency Region I.Project #00-06/104.
[34] Wilson, R. F., Fennel, K., & Mattern, P. (2013). Simulating sediment-water exchange of nutrients and oxygen: A comparative assessment of models against mesocosm observations. *Continental Shelf Research, 63*, 69-84.

Task 4: Evaluate N Mitigation Strategies
Utilize a land-use based nitrogen loading model recently developed by Vaudrey for many embayments, including Niantic River, to evaluate nitrogen mitigation strategies.

Task 5: Assess Transferability
Assess the applicability of this study to other embayments of Long Island Sound by suggesting approach and data requirements for various assessments.

Task 6: Identify Data Gaps
Identify any data gaps and suggest monitoring protocol to fill these gaps.

A.6.2. PROJECT TASKS AND TIMELINE

Task 1: Data Synthesis

Collate Data

Project Timeline (month)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
collate data		x	x															
assign DQI		x	x															

Exiting data on water quality and biological parameters in Niantic River Estuary will be collected to statistically evaluate changes over time and how various factors affect the current and potential success of eelgrass in the estuary. Data evaluated will include:

- water column nutrients (nitrate, nitrite, ammonium, phosphate, total dissolved nitrogen, particulate nitrogen)
- water column isotopic nitrogen ($\delta^{15}N$)
- temperature
- dissolved oxygen
- salinity
- meteorological conditions
- fish and invertebrate species composition and abundance
- eelgrass abundance and distribution
- water quality impairment data for developing CWA 303d biennial reports
- stream gauge data, including flow, water quality, nutrient, chemistry, and bacteria
- groundwater nutrient loads
- sediment characteristics (organic content, grain size)
- sediment biogeochemistry, denitrification, and ANAMMOX
- modeled nitrogen loads
- hydrodynamic dye studies
- NYHOPS model of hydrodynamics

Statistical Analyses

Project Timeline (month)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
statistical analyses			x	x		x	x											
interim report due					x													
revision, reporting, synthesis - final report											x	x	x	x	x	x	x	x

For terminology when discussing the ecosystem and societal interactions, we will employ the DPSIR framework (drivers, pressures, states, impacts, responses). An overview of the definitions of each term and the interactions among the terms is presented in Figure 2. Figure 3 presents an example of the application of the DPSIR framework to Greenwich Bay, an embayment of Narragansett Bay, RI[35].

The relationship between environmental state (eelgrass extent, phenology of eelgrass, hypoxia, macroalgae) and a suite of naturally variable and/or anthropogenically influenced drivers and pressures (e.g. drivers: land use changes, nutrient inputs, climate change; pressures: river flow, temperature, sunlight, siltation, mortality, smothering) will be assessed using multivariate statistical approaches to identify the key drivers on the system and evaluate how these drivers may have changed over time. Climate data (temperature, wind speed, cloud cover, precipitation) and river flow (USGS gauging stations) will be assessed as pressures on state variables such as eelgrass extent[36,37,38,39]. We will also assess the impact of anthropogenic drivers like nutrient load and concentration. Building off of the Eelgrass Habitat Suitability Index model, we will investigate the effect of drivers on eelgrass distribution over time and assess the factors most important to eelgrass success[40]. If the data allow, we will also examine the temporal changes in fish and macroalgae abundance from trawl data collected by Millstone Environmental Lab, as additional indicators of the state of ecosystem health.

The exact statistical methods that are employed will depend on the type, quantity and quality of the observations in the database and the degree to which the underlying assumptions for a particular statistical technique have been met (e.g. normal distribution, independence, etc.). When possible, we will investigate spatial and temporal patterns in environmental state variables with exploratory techniques such as hierarchical clustering (e.g. Cormack, 1971)[41], principal components analysis (PCA,

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[35] Shumchenia, E. J., Pelletier, M. C., Cicchetti, G., Davies, S., Pesch, C. E., Deacutis, C. F., & Pryor, M. (2015). A biological condition gradient model for historical assessment of estuarine habitat structure. *Environmental Management*.
[36] Kleinschmidt Associates. (2006). Niantic River Watershed Protection Plan (pp. 263): Connecticut Department of Environmental Protection, Office of Long Island Sound Programs, http://www.ct.gov/dep/cwp/view.asp?a=2719&q=379296&depNav_GID=1654.
[37] Latimer, J. S., & Charpentier, M. (2010). Nitrogen inputs to seventy-four southern New England estuaries: application of a watershed nitrogen loading model. *Estuarine, Coastal and Shelf Science, 89*, 125-136.
[38] Mullaney, J. R. (2013). Nutrient concentrations and loads and Escherichia coli densities in tributaries of the Niantic River estuary, southeastern Connecticut, 2005 and 2008–2011: U.S. Geological Survey Scientific Investigations Report 2013–5008, 27 p.
[39] Mullaney, J. R. (2015). Evaluation of the effects of sewering on nitrogen loads to the Niantic River, southeastern Connecticut, 2005–11: U.S. Geological Survey Scientific Investigations Report 2015–5011, 30 p.
[40] Vaudrey, J. M. P., Eddings, J., Pickerell, C., Brousseau., L., & Yarish., C. (2013). Development and application of a GIS-based Long Island Sound Eelgrass Habitat Suitability Index Model: Final report submitted to the New England Interstate Water Pollution Control Commission and the Long Island Sound Study. 171 p. + appendices.
[41] Cormack, R. M. (1971). A review of classification. *Journal of the Royal Statistical Society: Series A, 134*, 321-367.

e.g. Chatfield & Collins, 1980)[42] and/or multi-dimensional scaling (MDS, e.g. Kruskal & Wish, 1978)[43]. Ecological state tendencies generated by environmental drivers will be evaluated with routines available in the PRIMER 6 (Plymouth Routines in Multivariate Ecological Research) software package[44,45,46].

Spatial data and related information will also be organized into data layers and imported into a geographic information system (GIS) for visualization and geostatistical analysis of spatial trends.

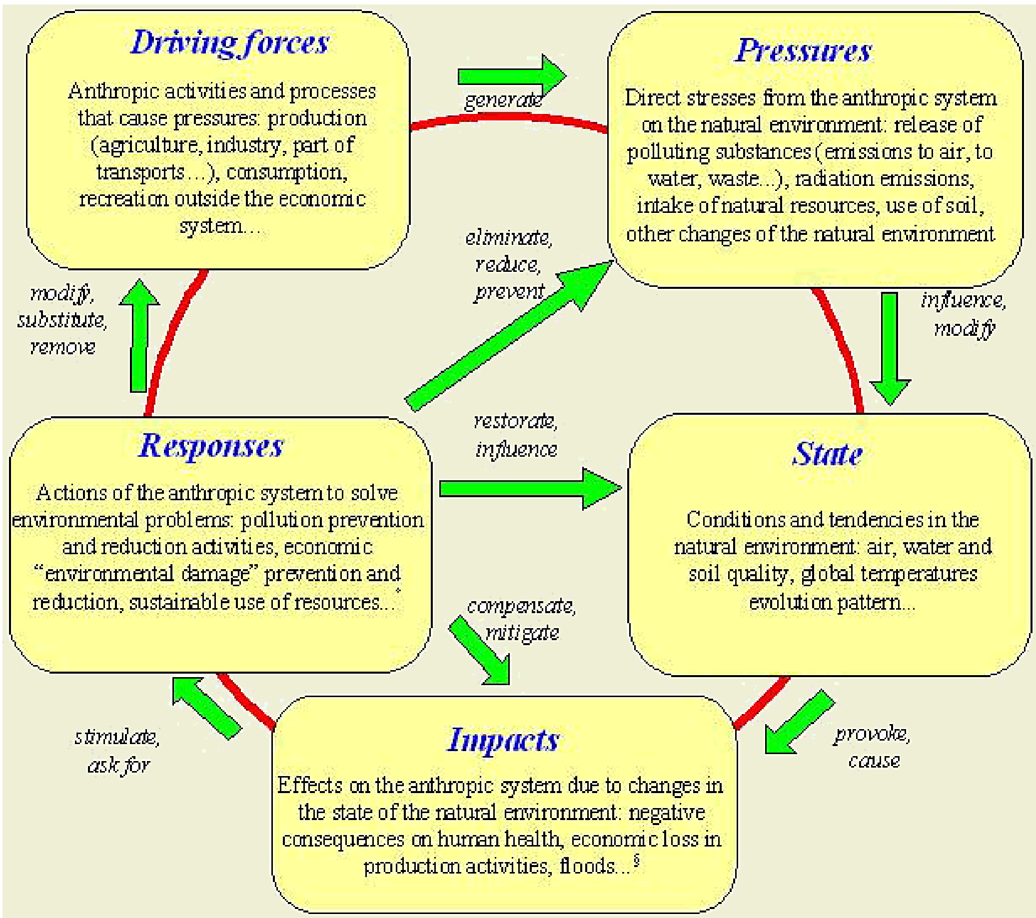

Figure 2: Explanation of the terminology employed in the DPSIR framework. copied from: <u>http://www.uni-kiel.de/ecology/users/fmueller/salzau2006/studentpages/Human_Environmental_Interactions/index.html</u>; modified from "ISTAT, C. Costantino, F. Falcitelli, A. Femia, A. Tuolini, OECD-Workshop, Paris, May 14–16, 2003"

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42 Chatfield, C., & Collins, A. J. (1980). *Introduction to multivariate analysis*. London: Chapman and Hall.
43 Kruskal, J. B., & Wish, M. (1978). *Multidimensional scaling*. Beverley Hills, California: Sage Publications.
44 Anderson, M. J., Gorley, R. N., & Clarke, K. R. (2008). *PERMANOVA+ for PRIMER: Guide to software and statistical methods.* Plymouth, UK.: PRIMER-E Ltd.
45 Clarke, K. R. (1993). Non-parametric multivariate analysis of changes in community structure. *Australian Journal of Ecology, 18*, 117-143.
46 Clarke, K. R., & Warwick, R. M. (2001). *Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition*. Plymouth, U.K.: PRIMER-E Ltd.

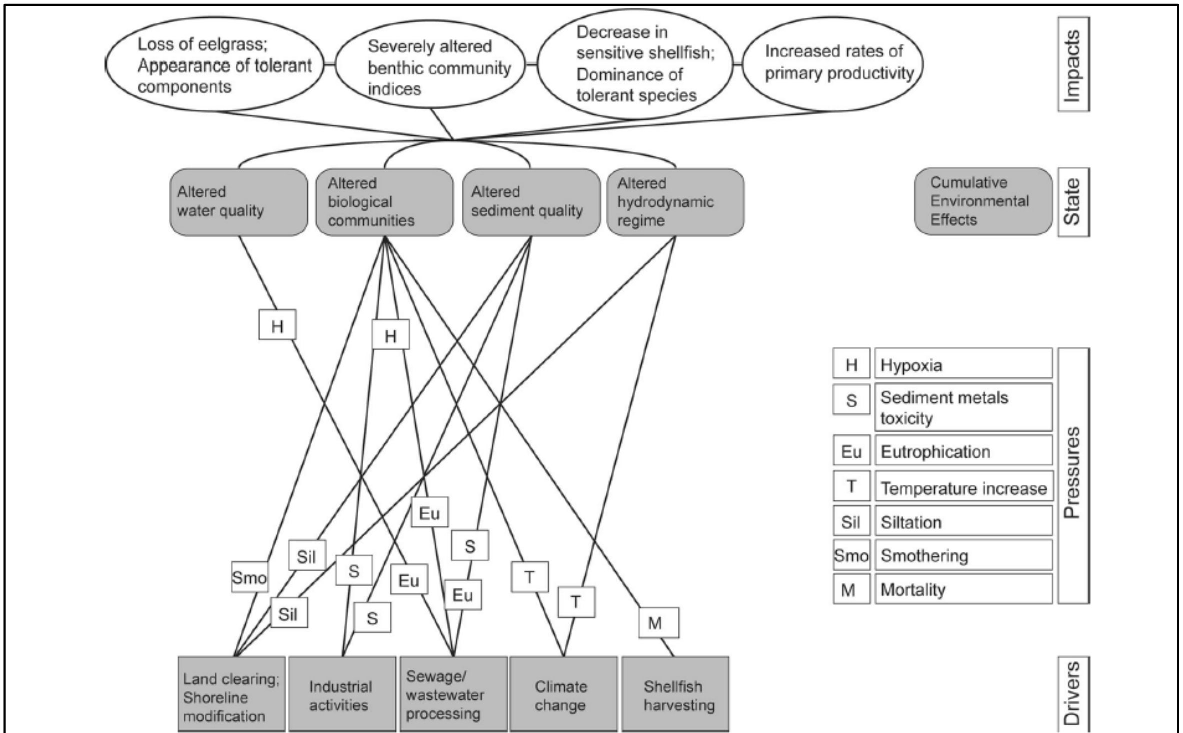

Fig. 3 The DPSIR model for the Greenwich Bay ecosystem. The *gray boxes* below represent the human Drivers that apply Pressures (in *white boxes*) that alter the State of the ecosystem (*rounded corners gray boxes*). Cumulatively, the alterations to ecosystem State cause Impacts to each of the biological indicators examined for this BCG (*ovals at top*)

Figure 3: Example of the DPSIR framework as applied to Greenwich Bay, an embayment of Narragansett Bay, RI (copied from Shumchenia, et al., 2015).

Task 2: Model Development

Evaluate Choice of Model

Project Timeline (month)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
review other models				x														
write-up model justification for TAC review				x														

To investigate the impacts on NRE from nutrient loads and climatically controlled pressures (light, temperature, etc.), an ecosystem model will be developed. This model will combine a physical mixing model with a biogeochemical model (Figure 1)[47,48,49,50,51]. Vaudrey has worked with a team of researchers in Narragansett Bay, including Krumholz, to develop an ecological model which simulates the impact of nutrient inputs on an estuarine system. This model has been applied to a number of estuaries. NRE is a good candidate for the Narragansett Bay Model, given the similarity in factors considered important in biogeochemical cycling. This model has been applied by Dr. Mark Brush (VIMS) to a number of smaller systems (http://www.vims.edu/research/departments/bio/programs/semp/models/index.php). The model will be modified with the addition of eelgrass and macroalgae compartments to specifically address the questions posed by this project. We will also investigate different sediment biogeochemistry models, using the work of Dr. Craig Tobias' lab group to determine which equations best describe the sediment interactions.

We will investigate the potential to use the Linked Model employed in the Massachusetts Estuaries Project[52]. However, this model uses a finely resolved hydrodynamic model (SMS, which costs ~$9,000 at the academic reduced price). We will examine the model components to determine if they are transferrable to our box model approach. We will also look into the Buzzards Bay Project Nitrogen Loading Methodology and the Cape Cod Commission Nitrogen Loading/Critical Loads Methodology. We should have the data available to apply these methodologies to NRE. These comparisons will also inform choices of models for other Long Island Sound embayments.

<u>Develop the Physical Mixing Model</u>

Project Timeline (month)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
request modeled salinity data	x																	
apply Officer box model					x													
compare model results to existing field data and flow studies					x	x												

[47] Brush, M. J. (2002). *Development of a numerical model for shallow marine ecosystems with application to Greenwich Bay, RI.* Ph.D. Doctoral Dissertation, Univeristy of Rhode Island, Narragansett, RI.
[48] Brush, M. J., & Nixon, S. W. (2010). Modeling the role of macroalgae in a shallow sub-estuary of Narragansett Bay, RI (USA). *Ecological Modelling, 221*, 1065–1079.
[49] Officer, C. B. (1980). Box models revisited. In P. Hamilton & R. B. McDonald (Eds.), *Estuarine and Wetland Processes with Emphasis on Modeling* (Vol. 11, pp. 65-114). New York: Plenum Press.
[50] Officer, C. B., & Kester, D. R. (1991). On estimating the non-advective tidal exchanges and advective gravitational circulation exchanges in an estuary. *Estuarine, Coastal and Shelf Science, 32*(1), 99-103. doi: 10.1016/0272-7714(91)90031-6
[51] Vaudrey, J. M. P. (2014). 2014 working report on the Narragansett Bay EcoGEM model (pp. 68): University of Connecticut.
[52] Howes, B. L., Ramsey, J. S., & Kelley, S. W. (2001). Nitrogen Modeling to Support Watershed Management: Comparison of Approaches and Sensitivity Analysis: prepared for: Massachusetts Department of Environmental Protection Bureau of Resource Protection and U.S. Environmental Protection Agency Region I.Project #00-06/104.

The physical mixing will be modelled using the Officer box model approach and available data for salinity and freshwater flow[53,54]. This approach estimates physical exchanges between adjacent elements using data on freshwater inputs to the estuary and the corresponding salinity within the estuary and at the ocean boundary. Existing salinity data will be evaluated for use.

Additional salinity data may be required to accurately parameterize the mixing component of the model. These data will be collected by Vaudrey's team and/or by working in coordination with the Millstone Environmental Lab; quality objectives and criteria for this is included in Section A.7.1. (page 28). Vaudrey currently has seven Star-Oddi conductivity sensors which could be deployed in the embayment. In their housing, these loggers are 4 inches long by 1 inch diameter in size. They can be deployed for months at a time and can be affixed to existing structures (floating markers, docks, etc.).

As a final method of obtaining additional salinity data, Vaudrey has requested modeled salinity from Dr. Nickitas Georgas at Stevens Institute of Technology and will also ask Dr. Michael Whitney at UCONN to see if he has modeled salinity results he is willing to share. Both of these researchers have used fine-scale hydrodynamic models in the area of Niantic River. The benefit of modeled salinity would be a long term record responsive to changes in river flow and other seasonal patterns.

Dr. Georgas uses a model called NYHOPS (New York Harbor Observing and Prediction System) for hindcasting salinity (as well as other parameters) in the Long Island Sound area. Access to model results is available at http://hudson.dl.stevens-tech.edu/maritimeforecast/maincontrol.shtml (on the right hand side, under Region, select Long Island Sound). Dr. Georgas states, "The contributing watershed name in NYHOPS is "Southeast Shoreline 17, CT." It covers 42.54 square miles. Flow is estimated by watershed-area-adjusting the Shetucket near Willimantic gaged USGS daily flow (404 miles). The freshwater yield (discharge in the model) is split into three NYHOPS receiving water cells," within the Niantic River Estuary. One at the very head of the River (where Latimer Brook enters NRE), one at the adjacent cell to the south (where Stony Brook comes in), and one just west of Niantic Bay's mouth from several tributaries. River water temperature is assigned from the nearby Connecticut River at Essex gage. Niantic River has two model boxes, with three boxes in Niantic Bay (Figure 4). Unfortunately, the NYHOPS model does not include the restriction at the south end of Niantic created by the road and train bridge. Comparison of model predictions with salinity data will be used to evaluate the impact of this missing restriction. If the NYHOPS modeled salinity accurately captures the major trends in salinity in Niantic River and Bay, the 35 year model predictions would be of great use to hindcasting the ecological model to explore the pressures impacting the state variables within the system (Figure 5).

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[53] Officer, C. B. (1980). Box models revisited. In P. Hamilton & R. B. McDonald (Eds.), *Estuarine and Wetland Processes with Emphasis on Modeling* (Vol. 11, pp. 65-114). New York: Plenum Press.
[54] Officer, C. B., & Kester, D. R. (1991). On estimating the non-advective tidal exchanges and advective gravitational circulation exchanges in an estuary. *Estuarine, Coastal and Shelf Science, 32*(1), 99-103. doi: 10.1016/0272-7714(91)90031-6

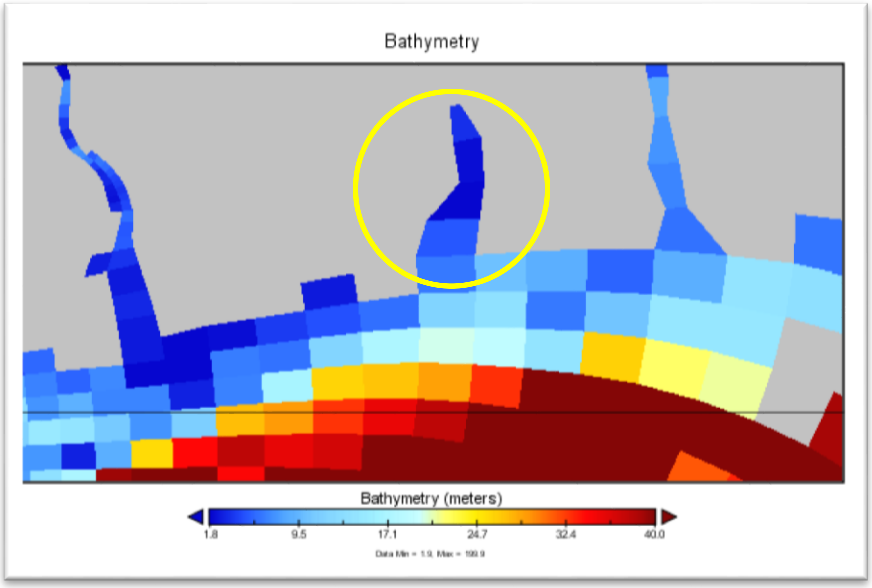

Figure 4: Bathymetry from the NYHOPS model, provided by Dr. Nickitas Georgas, Stevens Institute of Technology. Niantic River and Bay are identified by the yellow oval. (Image courtesy of Dr. Georgas.)

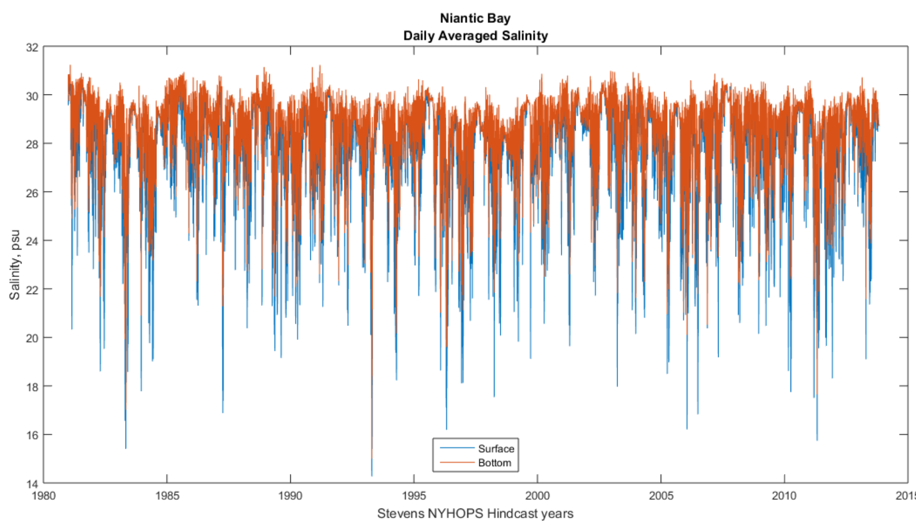

Figure 5: NYHOPS modeled salinity for 1980 to 2014 in Niantic Bay, provided by Dr. Nickitas Georgas, Stevens Institute of Technology. (Image courtesy of Dr. Georgas.)

Develop the Biogeochemical Model

Project Timeline (month)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
incorporate seagrass and macroalgae into model					x													
assess locally relevant values for constants and coefficients					x													
provide write-up of model to TAC for input						x												
compare model results to partial data sets						x	x											
assess skill of model using naïve data sets							x	x										
conduct scenario runs of the model							x	x										
interim report due									x									
revision, reporting, synthesis - final report											x	x	x	x	x	x	x	x

The parameters and equations included in the ecological model will be determined following the evaluations of other models (Task 2 reviewed on page 18). Figure 6 provides an overview of the processes that any model will need to include.

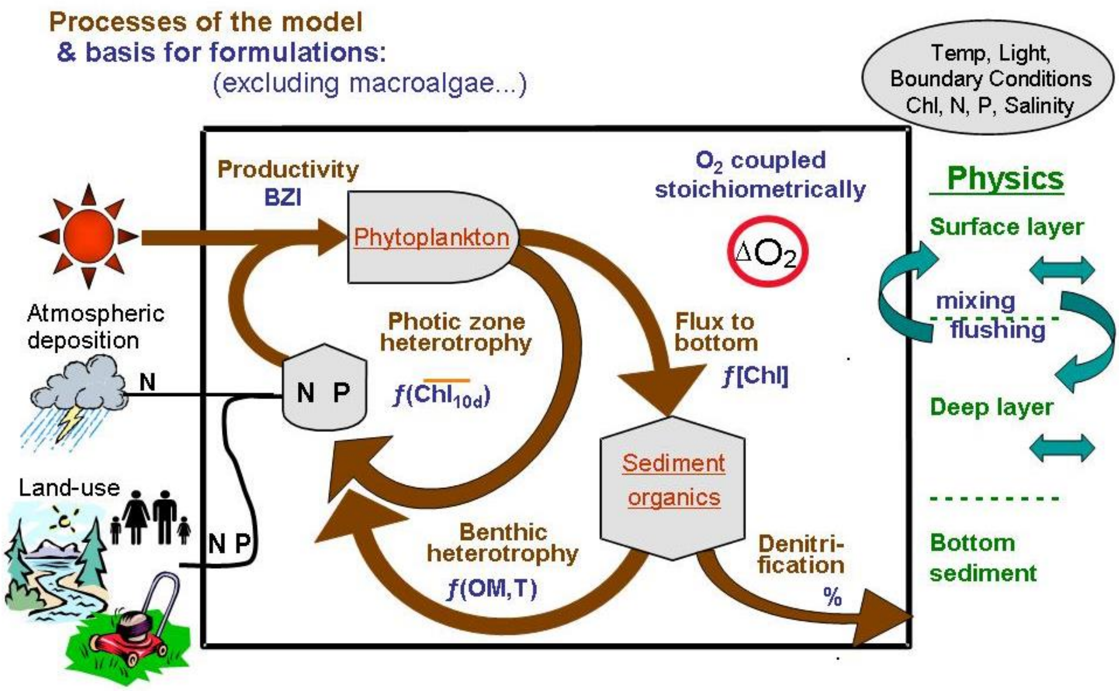

Figure 6: Overview of model processes from the existing Narragansett Bay simulation. This proposal seeks to add eelgrass and macroalgae compartments as well as specifically tune the existing model to fit the NRE. Brown text and arrows indicate model processes. The blue text indicates the basis for the formulation of the relationship. For example, productivity of the phytoplankton is determined from a "BZI" relationship which takes into account the biomass of the phytoplankton (B), depth of the photic zone (Z) and incident irradiance (I). Production is controlled by the available light (sun symbol) and the available nutrients in the water column (N, P). Some phytoplankton are consumed (photic zone heterotrophy) and some die and settle to the bottom (flux to bottom). For phytoplankton consumed, some of the nutrients are recycled to the water column. For phytoplankton sinking to the bottom, a fraction is respired with recycled nutrient returning to the water column or leaving the system via denitrification. Physical mixing can move all of these constituents within NRE and remove them to LIS. Oxygen is coupled to the system stoichiometrically using an understanding of oxygen demand and production during respiratory and production processes. Macroalgae and seagrass will be added to the model for NRE, following the methods developed by Dr. Mark Brush (Brush 2002; Brush and Nixon 2010).

Task 3: Target N Load Recommendations

Project Timeline (month)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
develop target N recommendations							x	x	x									
interim report due										x								
revision, reporting, synthesis - final report											x	x	x	x	x	x	x	x

The relationship between nitrogen inputs and eelgrass survival has been established in a number of systems, though the range of nitrogen loads at which eelgrass is threatened and eventually lost is large (50 - 100 kg N / ha of estuary / y)[55,56]. We will use the ecosystem model to assess the impact of nitrogen load on the system. Utilizing the model means that we are able to account for in-estuarine processing of nutrient loads versus export (or import) of N to Long Island Sound. The tidal study of nutrient fluxes conducted by the Millstone Environmental Lab will be useful to this analysis. Temperature is predicted to have an impact on eelgrass survival in NRE and elsewhere. Higher temperature results in greater respiratory demand on the eelgrass plants, placing additional stress on the plants[57]. To keep pace with this potentially increasing pressure, a reduction in impact from N would be required. Furthermore, as sea levels increase, water clarity will need to improve, or seagrass beds may experience a decline in areas where shoreward migration is not possible due to development. We will assess the results of the data synthesis and the model outcomes to determine a recommended nutrient input protective of eelgrass. We will highlight how this approach can be applied to other estuaries of Long Island Sound and beyond.

As part of this process, we will review and evaluate the approaches to determining a nitrogen loading target from a number of different programs. While this list is likely to expand, we will include:

- The Nature Conservancy's efforts at assessing eelgrass success in Southern New England[58] and linking that eelgrass status to nitrogen loads[59].
- The EPA NHEERL (Dr. James Latimer's) assessment of nutrient loads[60] and the impact on eelgrass[61].

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[55] Latimer, J. S., & Rego, S. A. (2010). Empirical relationship between eelgrass extent and predicted watershed-derived nitrogen loading for shallow New England estuaries. *Estuarine, Coastal and Shelf Science, 90*(4), 231-240.
[56] Vaudrey, J. M. P., Kremer, J. N., Branco, B. F., & Short, F. T. (2010). Eelgrass recovery after nutrient enrichment reversal. *Aquatic Botany, 93*, 237-243. doi: http://dx.doi.org/10.1016/j.aquabot.2010.08.005
[57] Vaudrey, J. M. P. (2008a). Establishing restoration objectives for eelgrass in Long Island Sound - Part I: review of the seagrass literature relevant to Long Island Sound (pp. 58). Groton, CT: Final Grant Report to the Connecticut Department of Environmental Protection, Bureau of Water Protection and Land Reuse and the U.S. Environmental Protection Agency. http://www.lisrc.uconn.edu/eelgrass/index.html (select Literature Reviews > Seagrass Literature Survey Report).
[58] Short, F. T., Klein, A. S., Burdick, D. M., Moore, G. E., Granger, S., Pickerell, C., Vaudrey, J., Bayley, H., & Evans, N. T. (2012). The eelgrass resource of Southern New England and New York: science in support of management and restoration success: Final Report submitted to The Nature Conservancy, 122 p.
[59] Woods Hole Group. (2014). Southern New England and New York Seagrass Research Towards Restoration – Phase II: prepared for The Nature Conservancy, Cold Spring Harbor, NY. 133 pages, with appendices.
[60] Latimer, J. S., & Charpentier, M. (2010). Nitrogen inputs to seventy-four southern New England estuaries: application of a watershed nitrogen loading model. *Estuarine, Coastal and Shelf Science, 89*, 125-136.
[61] Latimer, J. S., & Rego, S. A. (2010). Empirical relationship between eelgrass extent and predicted watershed-derived nitrogen loading for shallow New England estuaries. *Estuarine, Coastal and Shelf Science, 90*(4), 231-240.

- The Tampa Bay, FL, model linking chlorophyll concentration to nutrient loads supportive of water clarity protective of eelgrass[62] (see also http://www.usfsp.edu/cspace1/files/ 2015/03/Greening.pdf).
- Buzzard's Bay National Estuary Program recommendations of nitrogen loads protective of eelgrass (http://buzzardsbay.org/buzzards-bay-subwatersheds-land-use.htm).
- Massachusetts Estuary Project (website: http://www.oceanscience.net/estuaries/; peer-review report: http://www.capecodcommission.org/resources/waterresources/MEP_Panel__Report_12302011.pdf).
- Great Bay Estuary, NH (project report: http://des.nh.gov/organization/divisions/water /wmb/wqs/documents/20090610_estuary_criteria.pdf; peer-review report: http://www.portsmouthwastewater.com/PDFs/Joint_Report_Final_PeerReview_GreatBayEstuary_021314.pdf)

Task 4: Evaluate N Mitigation Strategies

Project Timeline (month)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
evaluate strategies								x	x	x								
interim report due											x							
revision, reporting, synthesis - final report											x	x	x	x	x	x	x	x

In order to achieve the recommended level of nutrient input protective of eelgrass, mitigation strategies must be assessed. Sewering of neighborhoods can be a beneficial approach[63], but is not likely to be sufficient in exclusivity. Therefore, a combination of strategies is required. We will investigate the potential effects of various mitigation strategies, linking the nitrogen sources within the watershed to potential impacts. Vaudrey has recently completed a project assessing sources of nitrogen within different sectors of the watershed of NRE; the final report of this work will be approved prior to the start of this project[64]. We will provide an overview of various strategies which could be used to reduce nitrogen input to the level identified as protective of eelgrass. These strategies will include low impact development techniques aimed at intercepting N before it enters groundwater and suggestions for target audiences with the greatest potential impact for responding to education campaigns. Mitigation strategies evaluated will target nitrogen emanating from:

- waste water
- storm water interception
- fertilizer use
- other categories at suggestion of the TAC

[62] Greening, H., & Janicki, A. (2006). Toward reversal of eutrophic conditions in a subtropical estuary: Water quality and seagrass response to nitrogen loading reductions in Tampa Bay, Florida, USA. *Environmental Management, 38*(2), 163-178.
[63] Mullaney, J. R. (2015). Evaluation of the effects of sewering on nitrogen loads to the Niantic River, southeastern Connecticut, 2005–11: U.S. Geological Survey Scientific Investigations Report 2015–5011, 30 p.
[64] Vaudrey, J. M. P., Kim, J. K., Yarish, C., Brousseau, L., Pickerell, C., & Eddings, J. (2013). Comparative analysis and model development for determining the susceptibility to eutrophication of Long Island Sound embayments: University of Connecticut and Cornell Cooperative Extension of Suffolk County.

Our role on this project will be to synthesize information relevant to the land use patterns and major sources of nitrogen identified in the Niantic River watershed. Data exist for these target categories. For example, Wood et al. (2015)[65] conducted a review of alternate home waste-water nitrogen mitigation strategies. The US EPA recently published an analysis which includes the cost effectiveness of point and non-point source mitigation strategies[66].

Task 5: Assess Transferability

Project Timeline (month)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
assess transferability												x	x	x				
draft report due															x			
revision, reporting, synthesis - final report																x	x	x

An assessment of the applicability of this study to other embayments will be conducted in the later stages of the project. We will highlight the transferability of the approach, what data may be required, and include suggestions for successful implementation.

Task 6: Identify Data Gaps

Project Timeline (month)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
identify data gaps												x	x	x				
draft report due															x			
revision, reporting, synthesis - final report																x	x	x

As part of this project, we will identify any data gaps which could improve the analysis and the assessment and tracking of changes to the ecosystem in the future.

[65] Wood, A., Blackhurst, M., Hawkins, T., Xue, X., Ashbolt, N., & Garland, J. (2015). Cost-effectiveness of nitrogen mitigation by alternative household wastewater management technologies. *Journal of Environmental Management, 150*, 344-354. doi: http://dx.doi.org/10.1016/j.jenvman.2014.10.002
[66] U.S. Environmenal Protection Agency Office of Water. (2015). A compilation of cost data associated with the impacts and control of nutrient pollution: U.S. Environmenal Protection Agency Office of Water. EPA 820-F-15-096.

Task 7: Reporting and QAPP Development

Project Timeline (month)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
QAPP development	x																	
QAPP review		x	x															
QAPP revision				x														
QAPP approval					x													
collate interim reports into a single draft report (v. 1)											x							
draft report (version 1) due												x						
TAC review of draft report (version 1)												x						
revise draft report													x	x	x			
draft report (version 2) due																x		
TAC review of draft report (version 2)																x		
revise draft report																	x	x
final report due																		x

Work on the QAPP will begin immediately. Reports will be provided on a regular basis, both in writing and orally at the NWG meetings. The due dates for the reports are provided in Section C.2. Reports to Management (page 46).

A.7. Quality Objectives and Criteria

All data, (new, existing, and modeled), will be examined in terms of the following data quality indicators (DQI)[67]:

• **Precision** is the measure of agreement among repeated measurements of the same property under identical, or substantially similar conditions; calculated as either the range or as the standard deviation. It may also be expressed as a percentage of the mean of the measurements, such as relative range or relative standard deviation (coefficient of variation).
• **Bias** is the systematic or persistent distortion of a measurement process that causes errors in one direction.
• **Accuracy** is a measure of the overall agreement of a measurement to a known value;
it includes a combination of random error (precision) and systematic error (bias) components of both sampling and analytical operations.
• **Representativeness** is the degree to which data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition.

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[67] EPA, 2002. Guidance for quality assurance project plans. EPA QA/G-5. U.S. EPA, Office of Environmental Information, Washington, DC.

• **Comparability** is a qualitative term that expresses the measure of confidence that one data set can be compared to another and can be combined for the decision(s) to be made.
• **Completeness** is a measure of the amount of valid data needed to be obtained from a measurement system.
• **Sensitivity** is the capability of a method or instrument to discriminate between measurement responses representing different levels of the variable of interest.

The data for this project fall into three different categories: Direct Measurements (A.7.1.), Non-Direct Measurements (A.7.2.), and Modeling (A.7.3). The application of the data quality measures listed above is described below for each of these categories.

A.7.1. Direct Measurements – Quality Objectives and Criteria

A.7.1.1. Quality Objectives for in situ collection of salinity data

-- To ensure that parameters measured will adequately describe the salinity in Niantic River Estuary.
-- To ensure that sample results are representative of the location sampled and are accurate.

A.7.1.2. Measurement Performance Criteria for in situ collection of salinity data

Water quality data collected as part of this project includes the deployment of Star-Oddi or YSI sonde loggers to record salinity and temperature. Information on other instruments are provided, as they will be used for verifying the sensor data. The objectives will be met by examining field and lab data collected from deployed sensors to quantify salinity. Laboratory baths will be used to cross-compare the sensor reading pre and post deployment. Definitions of quality control samples are provided in Section B.1.5 (page 35).

Precision
-- The precision of the Star-Oddi or YSI data loggers will be determined by reading a standardized solution three times within a two-day period.
-- The precision of the Star-Oddi, YSI 6600 sonde or YSI ProPlus and associated probes (temperature, salinity) will not be determined in the field, as changes in the water column between profiles can account for some variability between sampling times. The sonde will be calibrated before a sampling day (section B.1.6. and B.1.7.).

Bias
-- The bias of the Star-Oddi loggers will be determined by reading the calibration solutions before and after each deployment, as well as cross-calibration in a common water bath. (see Section B.1.7.).
-- The bias of the probes associated with the YSI sonde or YSI ProPlus will be determined by reading the calibration solutions before and after each deployment. (see Section B.1.7.).
-- The bias of the GPS will be checked in reference to a fixed point with known GPS coordinates.

Accuracy and Sensitivity
-- Manufacturer accuracy and sensitivity objectives for navigation and hydrographic sampling are presented in Table 2.
-- Section B.1.provides details on sampling procedures established to ensure data quality. Sections B.1.6.and B.1.7. contain instrument calibration methods and specifications.

Representativeness

-- Representativeness is addressed primarily in sampling design (section B.2.1.). The sampling practices and laboratory measurements that will be performed during the water quality monitoring have already been used in many systems to characterize the water column and are, therefore, considered to yield data representative of the study area.

Comparability

-- Logger results will be compared with an additional method for assessing salinity. This will be conducted with a sonde.

Completeness

-- The water quality data are collected *in situ,* so it is expected that 100% of the samples collected will be analyzed. Occasionally, time periods within a deployment are identified as compromised, most often due to fouling of the probes. Periodic cleaning and reading values from a common water bath pre- and post-deployment will be used to assess the degree of fouling. A sample loss of 10% for the entire project will not compromise the objectives of the project.

Table 2: Accuracy and Sensitivity of Field Instruments
This table provides the specifications for all instruments which may be used in this project.

Sensor	Model	Units	Range	Accuracy	Sensitivity (Resolution)
temperature, deployed	Star-Oddi DST CTD	ºC	-1 to 40ºC	± 0.10 ºC	0.032 ºC
salinity, deployed	Star-Oddi DST CTD	psu	6 to 35 psu	± 0.1 psu	0.02 psu
The following are available for cross-checking, but not part of the current sampling plan.					
depth	YSI 6600 series sonde, non-vented, shallow	m	0 to 9.1	± 0.018 m	0.001
temperature	YSI 6560 Sensor	ºC	-5 to +50	± 0.15 ºC	0.01
temperature	YSI 5560 Sensor	ºC	-5 to +70	± 0.20 ºC	0.01
salinity	YSI 6560 Sensor	ppt	0 to 70	± 0.1ppt or 1% of reading, whichever is greater	0.01
salinity	YSI 5560 Sensor	ppt	0 to 70	± 0.1ppt or 1% of reading, whichever is greater	0.01
temperature, deployed	HOBO Pendant® Temperature/Light Data Logger 64K - UA-002-64	ºC	-20 to 70ºC	± 0.53ºC from 0 to 50ºC*	0.14 ºC at 25ºC*

A.7.2. Non-direct Measurements – Quality Objectives and Criteria

Data synthesis will begin with the collation of available data into a common database and an assessment of the data quality. The sources of data are included in Table 5 (page 39).

All secondary data acquired for the project must be evaluated for conformance to QA/QC procedures required under EPA quality assurance guidance for acceptable data quality. Since much of the data sought may not have been produced under an approved EPA QAPP, the PIs will be responsible for this evaluation and determination of data acceptability. For peer-reviewed publications, the methodologies may adequately support good QA/QC protocols and be quantitatively acceptable, but gray literature and unpublished data files will likely require contact with the authors and, by interview or from recorded files, a determination of QA/QC procedural acceptability will be made. This determination will rely on availability of specific data quality indicators (DQI) recommended by EPA[68] that assess precision, bias, accuracy, representativeness, comparability, completeness and sensitivity (Table 3). When available, these values will be reported as metadata in the final database. If there are inadequate data available to assess one or more DQIs, the metadata file will indicate that inadequacy, thus flagging the data, which may limit its utility.

Table 3. Data Quality Indicators (DQI) and their application.

DQI	Review Criteria
Precision	Verify if measures of precision were completed and reported. Consider: • Analytical instrument consistency • Methodology • Field splits/duplicate performance • Laboratory splits and spikes
Bias	Check for bias in data distribution • Reference samples • Spikes
Accuracy	Be sure data accurately reflect matrix condition • Reference samples • Percent recovery or bias
Representativeness	Verify that data reflect the prevailing environmental condition • Consider precision, bias and accuracy • Check sampling design for spatial and temporal acuity • Consider professional and peer review commentaries
Comparability	Compare and contrast results from similar studies • Use all DQIs to explain differences and their potential resolution • Check all QA metadata and protocols for error
Completeness	Review data reporting adequacy • All data should be reported • Validity and qualification of observations
Sensitivity	Check cause and effect relationships and variable discrimination • Method detection limits • Instrument detection limits • Quantification limits

[68] EPA. (2002b). Guidance for quality assurance project plans. EPA QA/G-5. Washington, DC: U.S. EPA, Office of Environmental Information.

Processing of compiled data will often identify data that appear to be "outliers", or have incomplete or inadequate detection or quantification limits or other metadata shortcomings that could be caused by a DQI inadequacy. The data can be flagged, or further evaluated by the study's investigator(s) to see if a correction needs to be made. In the compilation of the database, fields will be included for appropriate metadata and QA notations that help complete QA/QC needs that might not be in the original publication or attached to the original data files. If necessary, the data will be converted to consistent units to compare with project data.

Data Limitations

Data will be categorized for acceptability using DQIs as:

- Acceptable – meets the needs for this project
- Acceptable with Qualifications
- Data required some correction or reworking to make it acceptable
- Acceptance criteria not all met, but judged adequate for some uses
- Essential data, but with acceptance criteria concerns – flagged and qualified
- Unacceptable

It is likely that data from the literature will not provide an ideal spatial and temporal distribution that completely meets the goals and objectives of this project. If it becomes necessary to include data of uncertain quality to test outcomes from a limited amount of quality approved data, interpretations will be treated with due caution and appropriately identified and qualified in both the text and (automatically) in the database. However, every effort will be made to use only quality-approved data so as not to complicate interpretations and the final report, and in cases where there is any question as to the quality or limitations of data, the conservative option not to use the data will prevail if there are adequate approved data.

A.7.3. Statistical Analysis – Quality Objectives and Criteria

This section will describe the quality objects for the statistical analysis included in this project.

- *Acceptance criteria for intended use of existing data*: Existing data will be used as input to the statistical analysis. These data will be judged acceptable following the criteria outline in Section A.7.2. Non-direct Measurements – Quality Objectives and Criteria (page 30). The sources of existing data to be used in this effort are provided in B.9. Data Acquisition (Non-direct Measurements) (page 39).
- *Acceptability of statistical analysis*: The objective of the statistical analysis is to evaluate and assess the strength of relationships between environmental state (eelgrass extent, phenology of eelgrass, hypoxia, macroalgae) and anthropogenically influenced drivers and pressures (e.g. drivers: land use changes, nutrient inputs, climate change; pressures: river flow, temperature, sunlight). The specific statistical methods used for this effort will depend will depend on the type, quantity and quality of the observations in the database that is developed during the data synthesis portion of the project. Statistical acceptability criteria depend on the test being used, but in general, P values corresponding to $\alpha < 0.05$ would be considered highly statistically significant, while α between 0.05-0.10 would be considered provisionally significant.

A.7.4. Ecosystem Modeling – Quality Objectives and Criteria

This section will describe the several different levels of quality objectives for the various stages of modeling included in this project.

- *Acceptance criteria for intended use of existing data*: Existing data will be used as input to the model. These data will be judged acceptable following the criteria outline in Section A.7.2. Non-direct Measurements – Quality Objectives and Criteria (page 30). The sources of existing data to be used in this effort are provided in B.9. Data Acquisition (Non-direct Measurements) (page 39).
- *Acceptability of model calibration*: Section B.7.2. Model Calibration (page 36) discusses the approach to be taken to determine whether the ecosystem model is properly calibrated. Project managers are defining model calibration as how well the model is able to reproduce current observations of nutrients, dissolved oxygen, and eelgrass extent under various temperature scenarios. The expectation is to reproduce trends, versus matching daily events. Water quality data for multiple surveys at each station exist, macrophyte data is more limited in space and/or time. The following criteria are a first pass at establishing acceptable model calibration outputs; these may be modified following consultation with the TAC:
    - *At least 75% of the model output values for any given parameter at a sampling station should be within two standard deviations of the mean field measurement at that station for that season.*
    - *The percentage of total variability and uncertainty that is attributable to lack-of-fit of the model should not exceed 25% in any of the calibration model fits.*
- *Acceptability of model output*: The goal for model output is to have uncertainty associated with a predicted value at a given location within 25% of the predicted value with 95% confidence. This criterion may be modified following consultation with the TAC.
    - *Skill (the degree to which model results match observed data) assessments of model output will include: root mean square error, relative absolute error, Skill Score[69], Willmott Skill[70,71], and Brier Skill Score. Other goodness-of-fit evaluations may also be considered.*
- *Additional data quality criteria:* The above criteria tend to be quantitative in nature. However, certain stages of model development will benefit from qualitative or general assessments of the model output. For example, a qualitative assessment would graphically evaluate how well the model output fits the trends and ranges of data throughout the system. This evaluation will be documented in the final report using graphs. A metric which assesses the whole model over the whole time period will also be employed: *Relative Operating Characteristics (ROC)[72,73].*

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[69] Liu, Y., MacCready, P., Hickey, B. M., Dever, E. P., Kosro, P. M., & Banas, N. S. (2009). Evaluation of a coastal ocean circulation model for the Columbia river plume in summer 2004. *Journal of Geophysical Research C: Oceans, 114*(3).
[70] Willmott, C. J. (1981). On the validation of models. *Physical Geography, 2*(2), 184-194.
[71] Willmott, C. J., Ackleson, S. G., Davis, R. E., Feddema, J. J., Klink, K. M., Legates, D. R., O 'Donnell, J., & Rowe, C. M. (1985). Statistics for the evaluation and comparison of models. *Journal of Geophysical Research C: Oceans, 90*(C5), 8995-9005.
[72] Mason, S. J., & Graham, N. E. (1999). Conditional probabilities, relative operating characteristics, and relative operating levels. *Weather and Forecasting, 14*(5), 713-725.
[73] Sheng, Y. P., & Kim, T. (2009). Skill assessment of an integrated modeling system for shallow coastal and estuarine ecosystems. *Journal of Marine Systems, 76*(1-2), 212-243.

A.8. Special Training / Certification

The project collaborators will meet as a group (virtually or in person) to review the data analysis. Oversight of staff and quality checks on sample collection and analysis are covered in sections B.1.5. and C.1.2.

Specialized training or certification with respect to GIS and modeling is not required in order to successfully complete the project. The staff collecting/creating data are proficient in ArcGIS and modeling and have significant experience using the software and associated data in similar applications.

A.9. Documents and Records

The following project-related materials will be kept by UCONN as appropriate and retained on file (either as hard copy, electronic file or both) until at least December 31, 2020.

- **Field Data Sheets (from salinity loggers)** – Field data sheets will be retained by J. Vaudrey for all sites.
- **Automated Sampler Data Reports (from salinity loggers)** – Original copies of the downloaded data files will be retained by the PIs. A trained technician is responsible for downloading the data. Only the local field manager or an authorized designee may delete data from the instruments.
- **Secondary Source Data** – all secondary data collected and used for this project and the associated metadata will be saved both in its original format (read only spreadsheet and database files) and transferred into Excel.
- **Modeling Records** - calibration and sensitivity analyses results, records of written rationale for selection of models or modules, record of code verification (e.g., hand-calculated checks, comparison to other models), sources of existing data used, and any adjustments to model parameter values that result from model calibration.

The following project-related materials will be kept by the PI for as long as possible and for a minimum of three years from the date of the final Financial Status Report to the funder, as stipulated by 40 CFR § 31.42. Provided below is the list of project documentation and records that will be generated throughout project execution. All of the documentation listed below will be generated in digital format, unless a hard copy is required.

- Jun 1, 2016 *QAPP*, Initial Version
- Sep 1, 2016 *QAPP*, Revised Version
- Sep 15, 2016 Model Choice Justification *for TAC Review*
- Oct 1, 2016 Data Synthesis *Interim Report*
- Nov 15, 2016 Model Overview *for TAC Review*
- Jan 20, 2017 Model *Interim Report*
- Feb 20, 2017 Target N Load Recommendations *Interim Report*
- Mar 1, 2017 N Mitigation Strategies *Interim Report*
- Apr 1, 2017 *Draft Report* (version 1, no assessment of transferability or data gaps)
- Aug 1, 2017 *Draft Report* (version 2, including assessment of transferability or data gaps)
- Nov 15, 2017 *Final Report*

Section B – Data Generation and Acquisition

This project uses exiting data for the bulk of the objectives. The only new data generated will be salinity observations in Niantic River Estuary, used as verification of the NYHOPS modeled salinity results.

B.1. Sampling Process Design (Experimental Design)

A surface and bottom salinity logger will be deployed in each of the three boxes used by the NYHOPS model to represent the Niantic River Estuary (Figure 4, page 33). These data will supplement existing salinity data from previous deployments of loggers and from point surveys which are ongoing. Failure to collect these data will not be a detriment to the project; the loggers are available for use for free and the PIs felt the data could be a good addition to the project.

Loggers will be deployed from docks or from existing floats, with permission from the owners. Niantic River Estuary has very few areas with stagnations of water; stations will be placed in areas with good water exchange to best represent that section of the estuary.

The surface logger will be deployed 0.5 m below the surface and the bottom logger will be deployed 0.5 m above bottom. If the average water depth at a given station is less than 2 m, depth below surface and depth above bottom will be adjusted to 0.25 m.

Loggers will be deployed intermittently, for two-week periods, throughout the year. The goal is to have three deployments, covering fall, spring, and summer. Ice covers the upper Niantic River Estuary in most winters, so deployments are not planned for winter.

B.2. Sampling Methods

Salinity loggers will collect data every 15 minutes for a two-week period. Data are stored internally and downloaded when the instrument is retrieved. A description of the loggers is provided in Section A.7.1 (page 28).

Salinity loggers provided by Star-Oddi are factory calibrated. The loggers will be put into a common water bath, stirred by a submersible pump, both pre- and post-deployment. Over a two-day period, temperature and salinity in the bath will be varied by adding salt water and fresh water. A YSI sonde (Table 2, page 29) will be calibrated according to manufacturer guidelines and used to verify the salinity and temperature in the common water bath at least five times over the two days. The salinity loggers will be placed in a salinity standard at the start and end of the two-day common water bath (Sodium Chloride, 0.5078N, Conductivity = 47,600uS/cm, APHA for Salinity, Ricca Chemical; Fisher Scientific #7225-16).

Data are downloaded from the loggers prior to deploying, to verify that all sensor are reading within specifications. Data will be downloaded following the post-deployment water bath. These data will be added to the library of data collated for this project. All data will be made available through UConn's Digital Commons.

B.3. Sample Handling and Custody

The field manager (senior personnel assigned to oversee field work on any given day) is responsible for ensuring data are stored in an appropriate manner

B.4. Analytical Methods

B.4.1. Direct Measurements

The salinity loggers will be deployed in a common water bath before deployment and following deployment (fully described in Section B.2.). Salinity will be varied in the bath, allowing for multiple values for inter-comparison among loggers. These pre- and post-baths will serve to cross-calibrate all instruments and to determine if the deployed loggers exhibited any drift over the course of the deployment. The deployed loggers will be inter-calibrated by applying a multiplicative correction if initial values differ from the reference value.

B.4.1. Statistical Analyses

Statistical analysis will be conducted in accordance with the EPA Guidance for Data Quality Assessment: Practical Methods for Data Analysis (EPA QA/G-9 , QA00 Update)[74]. An initial data review consisting of basic statistics and graphical representation (e.g. hierarchical cluster analysis, GIS layer construction) of the data will be conducted to evaluate the data for patterns, relationships, or potential anomalies. Based on the results of the initial data review, appropriate statistical methods will be selected in order to meet the data quality objectives and criteria.

When possible, we will investigate spatial and temporal patterns in environmental state variables with exploratory techniques available in the PRIMER 6 (Plymouth Routines in Multivariate Ecological Research) software package[75,76,77]. Examples of the statistical techniques that may be used in this analysis include hierarchical clustering (e.g. Cormack, 1971)[78], principal components analysis (PCA, e.g. Chatfield & Collins, 1980) (PCA, e.g. Chatfield & Collins, 1980)[79] and/or multi-dimensional scaling (MDS, e.g. Kruskal & Wish, 1978)[80]. The exact statistical methods that are employed will depend on the type, quantity and quality of the observations in the database and the degree to which the underlying assumptions for a particular statistical technique have been met (e.g. normal distribution, independence, etc.). Graphical means, such as pairwise scatter plots (i.e. draftsman plots) of all variables may be used to verify assumptions and identify the need for data transformation prior to statistical analysis by assessing the relationship between pairs of variables and the distribution of samples across the range of each variable.

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[74] EPA (2000) EPA *Guidance for Data Quality Assessment: Practical Methods for Data Analysis* (EPA QA/G-9 , QA00 Update). Washington, DC: U.S. EPA Office of Environmental Information

[75] Anderson, M. J., Gorley, R. N., & Clarke, K. R. (2008). *PERMANOVA+ for PRIMER: Guide to software and statistical methods.* Plymouth, UK.: PRIMER-E Ltd.

[76] Clarke, K. R. (1993). Non-parametric multivariate analysis of changes in community structure. *Australian Journal of Ecology, 18*, 117-143.

[77] Clarke, K. R., & Warwick, R. M. (2001). *Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition*. Plymouth, U.K.: PRIMER-E Ltd.

[78] Cormack, R. M. (1971). A review of classification. *Journal of the Royal Statistical Society: Series A, 134*, 321-367.

[79] Chatfield, C., & Collins, A. J. (1980). *Introduction to multivariate analysis*. London: Chapman and Hall.

[80] Kruskal, J. B., & Wish, M. (1978). *Multidimensional scaling*. Beverley Hills, California: Sage Publications.

B.5. Quality Control

Data from the deployed salinity loggers will be compared to the pre- and post-water bath to determine the instrument drift. If post deployment water bath values exhibit a linear relationship with the reference, a linear regression will be used to determine the drift over the course of the deployment and to post-correct the values. If the data do not vary in a linear fashion, the logger will not be deployed. The budget for this grant does not include funds for instrument or instrument repair, as it is primarily a data synthesis project. Thus, a malfunctioning instrument will be retired and fewer instruments will be deployed. As stated before, this will not impact the integrity of the project, as these salinity readings are supplemental.

B.6. Instrument/Equipment Testing, Inspection, and Maintenance

Loggers will be inspected and tested prior to each field deployment, as reviewed in Section B.2.

B.7. Calibration

B.7.1. Instrument/Equipment Calibration and Frequency

Calibration of the salinity loggers occurs at the factory. Comparison to salinity standards verifies the calibration. The budget for this grant does not include funds for instrument or instrument repair, as it is primarily a data synthesis project. Thus, a malfunctioning instrument will be retired and fewer instruments will be deployed. As stated before, this will not impact the integrity of the project, as these salinity readings are supplemental.

B.7.2. Model Calibration[81]

Water quality data on such measures as nutrients (dissolved inorganic and organic nitrogen, dissolved inorganic phosphorus), chlorophyll-*a*, dissolved oxygen, sediment flux measurements, and macrophyte data that were collected from earlier surveys in NRE, in addition to flow measurements obtained from the United States Geological Survey and the NYHOPS model, will be used in calibrating the ecosystem model to this particular application. Section B.9. Data Acquisition (Non-direct Measurements)(Page 39) documents the sources of these data, and Section A.7.4. Ecosystem Modeling – Quality Objectives and Criteria (page 32) specifies the criteria for which these data will be judged acceptable for use in model calibration. The calibration will judge the extent to which the model is able to predict current water quality measures that agree with what was actually observed in the surveys. For instance, the extent to which the model accurately captures observed trends in the water quality data at the various sampling points in NRE, after taking into account the underlying variability in these monitored data, will be determined and appropriately documented.

In this particular application, model testing is also occurring during the model calibration process, as the inputs to the model calibration and the model's corresponding outputs represent a given water quality

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[81] *wording from this section was modeled after wording presented in:* EPA. (2002a). Guidance for quality assurance project plans for modeling. EPA QA/G-5 (pp. 121). Washington, DC: U.S. EPA, Office of Environmental Information.

scenario. The performance criteria upon which the calibration will be deemed acceptable is noted in Section A.7.4. Ecosystem Modeling – Quality Objectives and Criteria (page 32). Within the model calibration exercise, model rate coefficients will be adjusted as necessary to meet the calibration criteria and to reflect current scientific knowledge and various process rates that fall within a reasonable range of values found in the scientific literature. A list of internal variables used to calibrate the model outputs are included below for the EcoGEM model. Internal variables used for calibrating the model include *Rf0* and *Bff0* in the table below (Table 4). All other variables are assessed within the full range of the values shown. If another model is chosen, similar variables should apply. Addition of macrophytes to the model is a modification that will be implemented as part of this project. The rationale for any needed model adjustments based on the results of the calibration process will be documented according to the procedures specified in Section A.9. Documents and Records (page 33).

Table 4: Constants and Coefficients used in the EcoGEM model.

variable name	typical value	units	description	reference
CtoCHL	42 (30 to 60)	g C : g Chl	carbon to chlorophyll ratio	Valiela (1995), Cloern et al. (1995), Brush et al. (2002)
CtoNmolar	6.625	moles C : moles N	conversion of C to N	Redfield Ratio; Kremer and Nixon (1978)
CtoPmolar	106	moles C : moles P	conversion of C to P	Redfield Ratio; Kremer and Nixon (1978)
PhytResp	0.52 (0.02 to 1.2)	d^{-1}	phytoplankton respiration as a fraction of phytoplankton stock	Oviatt and Smith field data (*pers. comm.*), corresponds to Falkowski and Woodhead (1992)
Rf0	0.047	d^{-1}	water column grazing coefficient at 0°C	*optimized value*
RfQ	0.095	$^oC^{-1}$	phytoplankton respiratory quotient (Q_{10} for respiration)	Brush's (2002) Greenwich Bay model, from Sampou & Kemp (1994)
ppben	0.238 (0.23 to 0.25)	1/d	fraction of NPP24 delivered to the benthos	Nixon (1981) = 0.238 NPP24 Brush (2002) = 0.25 NPP24 Kemp et al (2005) = 0.24 phyt_bio
Brr0	0.00489 (0.001 to 0.2)	$^oC^{-1}$	benthic respiration (remin) coeff at 0°C	*optimized value*
BrrQ	0.14	d^{-1}	benthic respiratory quotient (Q_{10} for respiration)	Brush (2002) based Greenwich Bay model value .
DenitrifConst	0.4	unitless	fraction of the sediment N denitrified	Kremer used a straight fraction of 0.5 in the CLUE model
PQ	1.3 (1 to 1.4)	moles O_2 : moles C	O_2 produced : C assimilated	Valiela (1995) Smith and Oviatt (*pers. comm.*) photosynthetic equation
RQphyt	0.89 (narrowly constrained)	moles C : moles O_2	Org C respired : O_2 consumed	Williams and del Giorgio (2005) Hedges et al. (2002) Williams and Robertson (1991) Smith and Oviatt (*pers. comm.*)
RQgraz	0.97 (0.78 to 1.16)	moles C : moles O_2	Org C respired : O_2 consumed	Hernández-León and Ikeda (2005) Smith and Oviatt (pending)
RQsedN	1 : 30.5 (1:14.8 to 1:46.2)	moles N : moles O_2	N regenerated : O_2 consumed	Fulweiler and Nixon's sediment core data, this project
Kphyto	0.017 (0.015 to 0.019)	m^{-1} $(ug/L)^{-1}$	diffuse attenuation coeff. due to phytoplankton	
Ko	0.527 (0.512 to 0.542)	m^{-1}	diffuse attenuation coefficient due to water	
DryDepNha	6	Kg N ha^{-1} y^{-1}	dry deposition	Clark and Kremer (2005)
WetDepNuM	30 (9 – 200)	uM N	nitrogen concentration in wet precipitation (33)	Clark and Kremer (2005) Nat'l. Atm. Deposition Program

B.8. Inspection/Acceptance of Supplies and Consumables

Salinity standards will be inspected for expiration date and for obvious signs of degradation (e.g. clumping of chemical which should have no moisture incorporated).

B.9. Data Acquisition (Non-direct Measurements)

Data relevant to the Niantic River Estuary will be collated and metadata will be assessed to insure the quality of the data meets the standards for this project. Relevant data are included in Table 5. These existing data form the core of this work, which is a synthesis of existing data. A full description of the objectives of this project and how data will be used was included in Section A.6. (page 12).

Data will be included in an Excel format, though other database options may also be used (e.g. Microsoft Access, etc.). Information on the source of each data point and the data quality indicators will be included in the file.

Table 5: Data sources relevant to Niantic River Estuary

Type	Agency/Organization	Format	Contact	Example	Date
Water quality, autotroph, nutrient loading and internal cycling study	Niantic River Nitrogen Work Group Dominion Millstone Environmental Lab P.O. Box 128, Waterford, CT 06385; CT DEEP - LIS Study, 79 Elm Street, Hartford, CT 06106	Electronic, paper	Don Landers, (860) 444-4235 Donald.F.Landers@dom.com; Kelly Streich Kelly.Streich@ct.gov; (860)-424-3864	Biweekly water dissolved organic and inorganic nitrogen, phosphorous, DO, salinity, temperature macrophyte/particulate CHN, Isotopic N, macrophyte, biomass at 5 stations in Niantic River and Bay	2011-present
Water Quality Monitoring – Latimer Brook	Niantic River Watershed Committee	Electronic	Judy Rondeau, Judy.Rondeau@comcast.net; (860) 887-4163 x 401	Monthly Latimer Brook water quality monitoring (temp., DO, pH, conductivity, nitrate) at 9 stations	April 2012 - present
Water Quality Monitoring	Save the River/ Save the Hills; P.O. Box 505; Waterford, CT 06385	paper, electronic	Fred Grimsey; (860) 442-8349	Physical oceanography, meteorological conditions & nutrients.	2002-2003
Ecological monitoring study	Dominion Millstone Environmental Lab P.O. Box 128, Waterford, CT 06385	Electronic, paper	Don Landers, (860) 444-4235, Donald.F.Landers@dom.com	Fish & invert. species composition & abundance. Physical oceanography & meteorological conditions. Eelgrass abundance & distribution surveys	Annual Reports 1976-present

Type	Agency/Organization	Format	Contact	Example	Date
Water Quality, Nonpoint source pollution, OLISP Individual and General Permit applications, LIS TMDL,	CT DEEP, 79 Elm St., Hartford, CT 06106	Electronic, paper	Mary-beth Hart; Marybeth.Hart@ct.gov; Kelly Streich; Kelly.Streich@ct.gov; (860)-424-3864	Water quality impairment data for developing CWA 303d biennial reports. Set limits for bacteria and nutrient loads in Niantic River. Data requests to support OLISP permits (docks, dredging)	
Tributary Water Quality (nutrients, chemicals, bacteria), Stream Flow	USGS CT Water Science Center; 101 Pitkin St, E Hartford, CT 06108	Electronic / web based report available online, electronic	John Mullaney; 860-291-6760; jmullane@usgs.gov	Real time stream gauging (web-based), water quality, nutrient, chemistry, bacterial data extraction requests. http://pubs.er.usgs.gov/publication/sir20135008	2005, 2008-2011, 2012 data to be publishe
Groundwater nutrient loads	USGS CT Water Science Center; 101 Pitkin St, E Hartford, CT 06108	Electronic / web based report available online, electronic	John Mullaney; 860-291-6760; jmullane@usgs.gov	Evaluation of the Effects of Sewering on Nitrogen Loads to the Niantic River http://pubs.usgs.gov/sir/2015/5011/	2005-2011
Nitrogen loading models. Water quality, macroalgae, eelgrass, sediments, modeling	CT DEP Long Island Sound Research Fund; www.lisrc.uconn.edu/eelgrass/index.html	Report, web based	Jim Kremer/Jamie Vaudrey; 860-405-9149; Jamie.vaudrey@uconn.edu	Establishing restoration objectives for eelgrass in Long Island Sound. Part II: Case studies	2002-2003
Habitat characterization/ evaluation of eutrophication and hypoxia	Department of Marine Sciences, University of Connecticut, 1080 Shennecossett Rd, Groton, CT 06340	Report in prep.	Jamie Vaudrey; 860-405-9149; Jamie.vaudrey@uconn.edu	Summertime water quality(DO, Sal., pH, temp., light attenuation, secchi, dissolved nutrients), sediment quality (TOC, %silt/clay) and habitat characterization	2011-2014
Sediment Bio-geochemistry, Denitrification, ANAMMOX	Department of Marine Sciences, University of Connecticut, 1080 Shennecossett Rd, Groton, CT 06340	Report in prep.	Craig Tobias; Craig.Tobias@uconn.edu	Summertime sediment core sampling at numerous sites in the Niantic River Stable N isotope study	2012
Eelgrass monitoring, mapping and habitat assessment	CT DEP Long Island Sound Research Fund; www.lisrc.uconn.edu	Final Grant Report CWF-314-R	Charles Yarish; Charles.Yarish@uconn.edu	Environmental monitoring, seagrass mapping and biotechnology as a means of fisheries habitat enhancement along the Connecticut coast	2006

Type	Agency/Organization	Format	Contact	Example	Date
Oxygen Depletion in Connecticut Estuarine Waters	CT DEP Long Island Sound License Plate Funding provided to The Coast and Harbor Institute in Woods Hole, MA (PI's – Gaines, A.G., and S.M. Pratt)	Final Grant Report dated January 15, 2003	Kelly Streich; Kelly.Streich@ct.gov; (860) 424-3864	Oxygen depletion and hydrogen sulfide study for select coastal ponds and estuaries in Connecticut (including the Niantic River)	2003
Watershed nitrogen loading modeling	U.S. EPA, Office of Research and Development National Health and Environmental Effects Research Laboratory Atlantic Ecology Division; 27 Tarzwell Drive, Narragansett, RI 02882, 401-486-9749	Published paper Estuarine, Coastal and Shelf Sci. 89:125-136	Jim Latimer; Latimer.Jim@epa.gov M.A. Charpentier	Application of a watershed nitrogen loading model to 74 New England estuaries (including the Niantic River)	2010
Nitrogen loading and eelgrass relationships	U.S. EPA, Office of Research and Development National Health and Environmental Effects Research Laboratory Atlantic Ecology Division; 27 Tarzwell Drive, Narragansett, RI 02882, 401-486-9749	Published paper Estuarine, Coastal and Shelf Sci. 90:231-240	Jim Latimer Latimer.Jim@ epa.gov S.A. Rego	Quantification of the extent of eelgrass as a function of watershed-derived nitrogen loading for 62 New England embayments	2010
Long-term eelgrass monitoring study	Dominion Millstone Environmental Lab, P.O. Box 128, Waterford, CT 06385	Published Paper J. Sea Res. 49:11-26	M. Keser, J.T., Swenarton, J.M. Vozarik & J.F. Foertch Contact: John.T.Swenarton@ dom.com	Decline in eelgrass (*Zostera marina*) in Long Island Sound near Millstone Point, Connecticut (USA) unrelated to thermal input.	2003
Hydrodynamic dye study of the Niantic River. Flushing rate	Dominion Millstone Environmental Lab, P.O. Box 128, Waterford, CT 06385	Paper report	Don Landers, (860) 444-4235, Donald.F.Landers@dom.com	Application of a 2-D particle tracking model to simulate entrainment of winter flounder larvae at the Millstone Nuclear	1988
Biological – shellfish, eelgrass Water quality – DO, temperature	Northeast Fisheries Science Center, Aquaculture and Enhancement Division, Milford Laboratory, National Marine Fisheries Service, 212 Rogers Avenue, Milford, CT, 06460	Published paper Aquacult. Internat. 8: 139-158	R. Goldberg, J. Pereira & P. Clark	Strategies for enhancement of natural Bay scallop, *Argopecten irradians*, populations: A case study in the Niantic River estuary, Connecticut, USA.	2000

Type	Agency/Organization	Format	Contact	Example	Date
Water quality study, physical modeling	Long Island Sound Foundation Collection, UConn Avery Point Campus Library; Dominion Millstone Environmental Lab Library	Paper report, 3 volumes	Don Landers; (860) 444-4235; Donald.F.Landers@dom.com	A study of the Niantic River estuary, Niantic, Connecticut: Progress report phases I & II, data file of the Niantic River estuary. Ronald C. Kollmeyer, David A. McGill, USCGA Office of Research and Development	1970-1971

Decision Basis for Excluding Data

As detailed above, data will be evaluated using the DQIs listed in Table 3 (page 30). Examples of acceptance criteria for data relevant to this project are presented in Tables 6 & 7 (page 43).

Data will be categorized for acceptability using DQIs as:

- Acceptable – meets the needs for this project
- Acceptable with Qualifications
- Data required some correction or reworking to make it acceptable
- Acceptance criteria not all met, but judged adequate for some uses
- Essential data, but with acceptance criteria concerns – flagged and qualified
- Unacceptable

Data which are not labeled as “Acceptable” or “Unacceptable” may still be used, but any conclusions or analyses involving these data will note that flagged data were used, thus weakening the conclusions. All data evaluated will be reported in the QA/QC report and a justification for use or exclusion of data sources will be documented.

One aspect of data quality not covered by the EPA DQIs listed in Table 3 is the identification of outdated data. With changes in climate, coastal human populations and land development, bioinvasions, and disease outbreaks; data collected in the past may not be relevant to the ecosystem as it exists today. For model development, data collected within the last 10 years will be included. Older bathymetry data may be used, if more current data are unavailable and there is some indication that the data are still accurate. For all other data, data collected more than 10 years ago may be included to indicate conditions in the past. Use of older data will be noted whenever it is used (e.g. included in metadata for GIS files, clearly identified in reports, noted in data files).

Table 6. Physical variable precision goals and QA requirements.

Variable	Precision Goal	QA Sample Type	Frequency of QA	Data Generated
Depth	0.5 m	Performance verification at certified calibration facility	Annually	CTD response vs. calibration standards; annual drift
Depth	0.5 m	QC check against vessel's depth finder	Every cast	Difference between CTD station depth and on-board depth finder
Temperature	0.5 °C	Performance verification at certified calibration facility	Annually	CTD response vs. calibration standards; annual drift
Temperature	0.5 °C	QC check against secondary thermistor in DO sensor module	Every cast	CTD temperature vs. oxygen sensor temp
Salinity	0.5 psu	Performance verification at certified calibration facility	Annually	CTD response vs. calibration standards; annual drift
Dissolved Oxygen	0.5 mg/L	New membrane installation and calibration at laboratory	At least monthly; always prior to cruise	CTD response at zero and 100% saturated water; new coefficient values
PAR	NA	Performance verification at certified calibration facility	At least every other year**	Sensor response vs. calibration standard; drift
pH	0.3 units	QC check with standard buffers	Daily during cruise	Difference between probe and standard
Secchi depth	0.3 meter	Three replicate observations and check by second crew member	At each site	precision and comparison with second crew member observation

** Manufacturer recommendations indicate annual calibration. CTDEEP recommends biannual calibration. However, this calibration is not critical as the light attenuation coefficient relies on the relative light levels, versus the absolute values.

Table 7. Chemical variable precision goals and QA requirements.

Variable	Accuracy Goal	Precision Goal	QA Sample Type	Frequency of QA	Data Generated
Ammonia (NH_3)	85-115%	15%	Standards, spikes, lab and field duplicates	Per batch; one cruise	Relative accuracy and precision
Nitrate + Nitrite (NO_3^-+NO_2)	85-115%	15%	Standards, spikes, lab and field duplicate	Per batch; one cruise	Relative accuracy and precision
Orthophosphate (PO_4^{3-}) or (DIP)	85-115%	15%	Standards, spikes, lab and field duplicates	Per batch; one cruise	Relative accuracy and precision
total nitrogen	85-115%	15%	Standards, spikes, lab and field duplicates	Per batch; one cruise	Relative accuracy and precision
Chlorophyll *a* (Chl a)	85-115%	15%	Standards, spikes, field blanks, field duplicates	Per batch; one cruise	Relative accuracy and precision; estimate of field contamination

B.10. Data Management

Data will be received from the sources listed in Table 5 (page 39) and transferred to an Excel file, if it is not already in that format. A data log will be kept, identifying the source of the data, name of the file, and summarize available metadata. Data will be shared among project personnel via Dropbox. When complete, the files and associated metadata will be made available to the Niantic Nitrogen Workgroup and available through UConn's Digital Commons. Backup to an external hard drive (when files are changed) will occur at least weekly. Jamie Vaudrey will be the custodian of all up-to-date data files.

The ecosystem model will be written in MatLab and available as an executable file upon completion of the project. The model will run on a standard desktop PC. Input files that are static will be stored as a MatLab data file (.mat) and accessed directly by the program when run; the end-use will not have access to these files. Input data which may be manipulated by the end-user will be accessible in an Excel file. MatLab will read from the Excel file directly. The Excel file will be protected such that end-users cannot manipulate the data format in such a way as to make the transfer to MatLab inaccurate. The units associated with various state variables will be clearly labelled in the Excel file, MatLab output, and documentation. The executable file will output data into an Excel file, as well as in a MatLab format (.mat).

Section C – Assessment and Oversight

C.1. Assessments and Response Actions

The Primary Investigator will complete periodic project reviews to ensure that the quality assurance measures detailed in this document are followed. The results of such reviews will be transmitted to the NWG Project Officer and the TAC at the NWG meetings.

A report detailing the results of any quality assurance assessments conducted to address an issue will be included in the final report for this project and will also be provided to all signatories of this quality assurance project plan. In the overall management of the project, minor non-compliance will be addressed and corrected immediately. Where deficiencies or non-conformances have been identified, the Project PIs will determine and document the following items and will provide the documentation to the EPA Project Officer and the EPA QA Officer:

a. The nature and scope of the problem;
b. The root cause(s);
c. The programmatic impact;
d. The required corrective action;
e. Actions needed to prevent recurrence;
f. Method of assessing and verifying the effectiveness of the corrective action;
g. Timetable for implementation; and,
h. The staff responsible for implementing and follow-up reporting.

Beyond the reporting of problems that are identified by the periodic review of the project datasets (detailed above), assessment of existing data for utilization in the project is a key component of quality assurance. A file (data catalog.xlsx) will provide an overview of the status of data files. The file will be created by the research technician assigned to conduct the initial collation of data (E. Manz). The work will be conducted under the guidance of J. Vaudrey and J. Krumholz. This file will include:

- file name of original data file – this is the file as it was received
- file name of the revised data file – this is the file revised to conform to the needs of this project
- source – the name of the person providing the data
- type – short summary of the type of data included in the file, broad categories
- agency/organization – the custodians of the original data files
- format – describes the format of the data (electronic, paper, report in prep., etc.)
- overview of data – a more detailed summary of the type of data included in the file; includes mention of the timing of collection, number of stations, etc.
- QA/QC Precision – comments on the data quality indicators, mentions what type of assessment was made to respond to this category (see Table 3, page 30)
- QA/QC Bias – comments on the data quality indicators, mentions what type of assessment was made to respond to this category (see Table 3, page 30)
- QA/QC Accuracy – comments on the data quality indicators, mentions what type of assessment was made to respond to this category (see Table 3, page 30)
- QA/QC Representativeness – comments on the data quality indicators, mentions what type of assessment was made to respond to this category (see Table 3, page 30)
- QA/QC Comparability – comments on the data quality indicators, mentions what type of assessment was made to respond to this category (see Table 3, page 30)
- QA/QC Completeness – comments on the data quality indicators, mentions what type of assessment was made to respond to this category (see Table 3, page 30)
- QA/QC Sensitivity – comments on the data quality indicators, mentions what type of assessment was made to respond to this category (see Table 3, page 30)
- DQI – Vaudrey will determine the appropriate DQI based on the QA/QC data, with the input of J. Krumholz and C. Calabretta.
- start and end date for data included in the file
- check list of parameters included in the data file

The following types of assessments and evaluations refer to the ecosystem model, with comparable assessments applied to the statistical analysis of the synthesized data.

- *Testing the Model* - The ability of the selected model to correctly represent modeled conditions will be assessed focusing on changes in eutrophication due to changes in nutrient load. A sensitivity analysis will be performed to determine the effect of boundary conditions on model output, focusing on non-point nutrient sources. The goal of this analysis is to test the sensitivity of the model under various conditions to assure its responses are reasonable. If needed, further verification will be done by comparing model prediction results with survey data.

- *Performing Multiple Runs of the Model to Simulate Interannual Variability* - To assess the extent to which seasonality impacts the model outputs and, ultimately, to incorporate interannual variability into our assessment of stressors on the system, the model will be fitted under different scenarios for nutrient loading and stream flow conditions.
- *Evaluating Existing Data* - As described in Section B.9. Data Acquisition (Non-direct Measurements) (page 39), modeling staff will evaluate data to be used in calibration and as model input according to criteria discussed in Section A.7.4. Ecosystem Modeling – Quality Objectives and Criteria (page 32) and will follow-up with the various data sources on any concerns
- *Calibrating the Model* - The model calibration procedure is discussed in Section B.7.2. Model Calibration (page 36), and criteria for acceptable outcomes are provided in Section A.7.4. Ecosystem Modeling – Quality Objectives and Criteria (page 32).
- *Sensitivity Analyses* – Model sensitivity will be assessed by examining three categories: range of constants and coefficients, boundary condition ranges, and interannual variability. The tests employed and criteria for evaluating the results are presented in Section A.7.4. Ecosystem Modeling – Quality Objectives and Criteria (page 32).

C.2. Reports to Management

All of the documentation listed below will be generated in digital format, unless a hard copy is required. These interim, draft, and final reports will include updates on the current status of the project. The reports will be distributed to the TAC and project partners.

- Jun 1, 2016 *QAPP*, Initial Version
- Sep 1, 2016 *QAPP*, Revised Version
- Sep 15, 2016 Model Choice Justification *for TAC Review*
- Oct 1, 2016 Data Synthesis *Interim Report*
- Nov 15, 2016 Model Overview *for TAC Review*
- Jan 20, 2017 Model *Interim Report*
- Feb 20, 2017 Target N Load Recommendations *Interim Report*
- Mar 1, 2017 N Mitigation Strategies *Interim Report*
- Apr 1, 2017 *Draft Report* (version 1, no assessment of transferability or data gaps)
- Aug 1, 2017 *Draft Report* (version 2, including assessment of transferability or data gaps)
- Nov 15, 2017 *Final Report*

Section D – Data Validation and Usability

D.1. Data Review, Verification, and Validation

It is a requirement of this project that all data be reviewed, verified, and validated prior to and after entry into the project database. The measurement quality objectives, sensitivity requirements, and monitoring thresholds are used to accept, reject, or qualify the environmental monitoring data generated for this project. This process was covered in Section C.1. (page 44).

Data will be initially reviewed by the technician assigned to collate the data (E. Manz). At this initial stage, all data are cataloged and a summary of the QA/QC procedures used during generation of the data is created.

The next stage involves an evaluation of the data as suitable for use in the project. The first step is the assigning of the DQI status (J. Vaudrey, with input from J. Krumholz and C. Calabretta). The second step is assessing the suitability of data for use in this project. While data may be suitable from a QA/QC perspective, it may not be appropriate for use in the project. Vaudrey, Krumholz, and Calabretta will assess data, considering the following:

- age of the data – does it represent conditions today, can it be considered representative of a past state
- does the sampling design of the dataset meet the needs of the current project, is the spatial and temporal extent representative of the relationships being explored
- is the dataset incomplete – are there key pieces of data missing, would this affect the conclusion drawn from the data
- other considerations may arise as we start to examine the data

These decisions will be documented in an interim report and reviewed by the TAC.

For the modeling components of the project, the following activities will be conducted and reviewed in the final report:

- review the model predictions for reasonableness and relevance by comparing to observed field data not used in calibration and literature data for similar estuaries,
- determine the consistency with the requirements documented in Section A.7.4. Ecosystem Modeling – Quality Objectives and Criteria (page 32) on acceptable uncertainty, and
- confirm that all steps of the modeling process were followed correctly.

Section C.1. Assessments and Response Actions (page 44) provides details on these assessments. Any problems will be reported to the project manager and corrective actions discussed with the TAC. The findings, including any limitations associated with their use, will be discussed in the project report.

D.1.1. Departures from Validation Criteria - Model

Departures from the criteria established in this QAPP may make the model results unusable for determining potential management actions that would support water quality improvements in NRE. If the skill assessment deviates from the criteria established in Section A.7.4. Ecosystem Modeling – Quality Objectives and Criteria (page 32), the deviations must be discussed with the TAC and a summary of the discussion provided in the final report. The TAC may decide that deviations from the QA/QC established in this document may be acceptable, depending on the type of deviation. For example, the model output predictions of state variables on a daily averaged, box-wide average. Available field data may be points in time, so may not adequately represent the daily average. Field data may also be limited spatially, providing data form only one location in a box. In these cases, the model predictions may not match the field data within the established criteria, but the mismatch is explainable by comparing data which are not a perfect match in terms of the spatial or temporal distributions being compared.

D.2. Verification and Validation Methods

Data collated for the synthesis portion of this project are summarized in a data catalogue, in an Excel format. Formulas in Excel will flag data that may be missing and check that any averaging or summing is done correctly. For example, dissolved ammonia, nitrate, and nitrite can be summed to yield dissolved inorganic nitrogen. If one of these species of nitrogen is missing, a flag will appear, indicating that DIN cannot be calculated due to a missing constituent. However, if nitrite kin other samples from that season and that station are typically near 0 mg/L (which most are for NRE), then DIN may be calculated using only ammonia and nitrate – data would be flagged to indicate this was the case. Conditional formatting will be used to color code data and identify potential outliers. These outliers will be examined to be certain the error was not a data entry error, versus a truly high or low value (data entry checking is a standard part of data entry, as discussed in Section D.1.; this is an additional level of verification).

The accuracy of data entry conducted during the synthesis portion of this project will be verified through independent review of a random sample of at least 10 percent of the database and data calculations. These data will be judged acceptable following the criteria outline in Section A.7.2. Non-direct Measurements – Quality Objectives and Criteria (page 30).

Statistical analysis will be conducted in accordance the EPA's *Guidance for Data Quality Assessment: Practical Methods for Data Analysis* (EPA QA/G-9 , QA00 Update)[82] as detailed in Section B.4.1. Statistical Analysis.

Verification of the mathematical basis of the model has already been conducted for the models to be evaluated; they have undergone peer-review. Modifications to the chosen model will be reviewed by the TAC. If the TAC feels that additional peer review is required, the mathematical formulations will be reviewed by people external to the project. Verification of the computer code will be conducted by Vaudrey. This is done by setting various variable to zero and isolating processes in the model to ensure that the code is replicating expected patterns and reflects the mathematical basis of the model. For example, primary production should respond to light and nutrients. Turning off grazing will allow for a comparison of primary production to independent calculations for production.

Section A.7.4. Ecosystem Modeling – Quality Objectives and Criteria (page 32) provides the types of statistical assessments used to validate the ecosystem model is providing accurate predictions of conditions in the NRE relative to changes in inputs. Hindcasting will illustrate that the model can accurately predict the impact of management scenarios on the NRE system. For validation runs, the input and outputs will be stored as a single Excel file, to allow for logging of the impact of various runs. Figures in the final report will illustrate and interpret these runs. Results of the ecosystem model validation will be provided in interim reports to the TAC, as well as presented at a NWG meeting. Vaudrey will be responsible for this phase of the reporting. Model output will be compared to data not used in the calibration of the model. This will occur once the code has been verified and calibration has been completed.

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[82] EPA (2000) EPA *Guidance for Data Quality Assessment: Practical Methods for Data Analysis* (EPA QA/G-9 , QA00 Update). Washington, DC: U.S. EPA Office of Environmental Information

D.3. Reconciliation with User Requirements

Data collated for the synthesis portion of this project will be presented in figures in the interim and final reports. These overview figures will allow for identification of trends and outliers. Original data files will be maintained, with data converted into consistent units and formats in files generated for this project. Data will be summarized in a data catalog, including the metadata described in Section C.1. Assessments and Response Actions (page 44).

Plans for testing the ecosystem model are worked into all phases of the project. Ecosystem model simulations will be planned to reproduce the statistical distribution properties of the field data, using data not previously used in the calibration phase. Evaluation will be done by comparing cumulative frequency distribution plots of data to frequency distribution plots from comparable model predictions. This quantitative evaluation will be integrated with qualitative assessments discussed in Section A.7.4. Ecosystem Modeling – Quality Objectives and Criteria (page 32). The TAC will provide reviews on a regular basis.

Statistical analysis will be conducted in accordance the EPA's *Guidance for Data Quality Assessment: Practical Methods for Data Analysis* (EPA QA/G-9 , QA00 Update)[83] as detailed in Section B.4.1. Statistical Analysis.

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[83] EPA (2000) EPA *Guidance for Data Quality Assessment: Practical Methods for Data Analysis* (EPA QA/G-9 , QA00 Update). Washington, DC: U.S. EPA Office of Environmental Information

Section E – Works Cited

Anderson, M. J., Gorley, R. N., & Clarke, K. R. (2008). *PERMANOVA+ for PRIMER: Guide to software and statistical methods.* Plymouth, UK.: PRIMER-E Ltd.

Brush, M. J. (2002). *Development of a numerical model for shallow marine ecosystems with application to Greenwich Bay, RI.* Ph.D. Doctoral Dissertation, Univeristy of Rhode Island, Narragansett, RI.

Brush, M. J., Brawley, J. W., Nixon, S. W., & Kremer, J. N. (2002). Modeling phytoplankton production: problems with the Eppley curve and an empirical alternative. *Marine Ecology Progress Series, 238*, 31-45.

Brush, M. J., & Nixon, S. W. (2010). Modeling the role of macroalgae in a shallow sub-estuary of Narragansett Bay, RI (USA). *Ecological Modelling, 221*, 1065–1079.

Burkholder, J. M., Tomasko, D. A., & Touchette, B. W. (2007). Seagrasses and eutrophication. *Journal of Experimental Marine Biology and Ecology, 350*(1-2), 46-72.

Chatfield, C., & Collins, A. J. (1980). *Introduction to multivariate analysis*. London: Chapman and Hall.

Clark, H., & Kremer, J. N. (2005). Estimating direct and episodic atmospheric nitrogen deposition to a coastal waterbody. *Marine Environmental Research, 59*, 349-366.

Clarke, K. R. (1993). Non-parametric multivariate analysis of changes in community structure. *Australian Journal of Ecology, 18*, 117-143.

Clarke, K. R., & Warwick, R. M. (2001). *Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition*. Plymouth, U.K.: PRIMER-E Ltd.

Cloern, J. E., Grenz, C., & Vidergar-Lucas , L. (1995). An empirical model of the phytoplankton chlorophyll: carbon ratio - the conversion factor between productivity and growth rate *Limnology and Oceanography, 40*(7), 1313-1321

Cormack, R. M. (1971). A review of classification. *Journal of the Royal Statistical Society: Series A, 134*, 321-367.

Cummings, C., Zuke, A., DeStasio, B., & Krumholz, J. (2015). Coral growth assessment of an established artificial reef in Antigua. *Ecological Restoration, 33*(1), 90-95. doi: 10.3368/er.33.1.90

EPA. (2002a). Guidance for quality assurance project plans for modeling. EPA QA/G-5 (pp. 121). Washington, DC: U.S. EPA, Office of Environmental Information.

EPA. (2002b). Guidance for quality assurance project plans. EPA QA/G-5. Washington, DC: U.S. EPA, Office of Environmental Information.

Falkowski, P. G., & Woodhead, A. D. (Eds.). (1992). *Primary productivity and biogeochemical cycles in the sea*. New York, NY: Plenum Press.

Forrester, G. E., O'Connell-Rodwell, C., Bailey, P., Forrester, L. M., Giovannini, S., Harmon, L., Karis, R., Krumholz, J., Rodwell, T., & Jarecki., L. (2011). Evaluating Methods for Transplanting Endangered Elkhorn Corals in the Virgin Islands. *Restoration Ecology, 19*(3), 299-306. doi: 10.1111/j.1526-100X.2010.00664.x

Ganju, N. K., Brush, M. J., Rashleigh, B., Aretxabaleta, A. L., del Barrio, P., Grear, J. S., Harris, L. A., Lake, S. J., McCardell, G., O'Donnell, J., Ralston, D. K., Signell, R., Testa, J. M., & Vaudrey, J. M. P. (2015). Progress and Challenges in Coupled Hydrodynamic-Ecological Estuarine Modeling. *Estuaries and Coasts*, 1-22. doi: 10.1007/s12237-015-0011-y

Greening, H., & Janicki, A. (2006). Toward reversal of eutrophic conditions in a subtropical estuary: Water quality and seagrass response to nitrogen loading reductions in Tampa Bay, Florida, USA. *Environmental Management, 38*(2), 163-178.

Hedges, J. I., Baldock, J. A., Gélinas, Y., Lee, C., Peterson, M. L., & Wakeham, S. G. (2002). The biochemical and elemental composition of marine plankton: a NMR perspective. *Marine Chemistry, 78*, 47-63.

Hernández-León, S., & Ikeda, T. (2005). Zooplankton respiration. In P. A. del Giorgio & P. J. l. B. Williams (Eds.), *Respiration in Aquatic Ecosystems* (pp. 57-82). Oxford: Oxford University Press.

Howes, B. L., Ramsey, J. S., & Kelley, S. W. (2001). Nitrogen Modeling to Support Watershed Management: Comparison of Approaches and Sensitivity Analysis: prepared for: Massachusetts Department of Environmental Protection Bureau of Resource Protection and U.S. Environmental Protection Agency Region I.Project #00-06/104.

Kemp, W. M., & Boynton, W. R. (2012). Synthesis in estuarine and coastal ecological research: what is it, why is it important, and how do we teach it? *Estuaries and Coasts, 35*(1), 1-22. doi: 10.1007/s12237-011-9464-9

Kleinschmidt Associates. (2006). Niantic River Watershed Protection Plan (pp. 263): Connecticut Department of Environmental Protection, Office of Long Island Sound Programs, http://www.ct.gov/dep/cwp/view.asp?a=2719&q=379296&depNav_GID=1654.

Kremer, J. N., & Nixon, S. W. (1978). *A Coastal Marine Ecosystem* (Vol. 24). New York: Springer-Verlag.

Kremer, J. N., Vaudrey, J. M. P., Ullman, D., Bergondo, D. L., Nasota, N., Kincaid, C., Codiga, D. L., & Brush, M. J. (2010). Simulating property exchange in estuarine ecosystem models at ecologically appropriate scales. *Ecological Modelling, 221*, 1080-1088.

Krumholz, J. (2011). Quantifying and Monitoring Ecological Response to No-Take Marine Reserves. *Journal of Ecology and Environment, 2(1)*, E3. doi: 10.5296/jee.v2i1.696

Krumholz, J. (2012). *Spatial and Temporal Patterns in Nutrient Standing Stock and Mass-Balance in Response to Load Reductions in a Temperate Estuary.* University of Rhode Island, Graduate School of Oceanography. Retrieved from Open Access Dissertations. Paper 79. http://digitalcommons.uri.edu/oa_diss/79Open (Open Access Dissertations. Paper 79. http://digitalcommons.uri.edu/oa_diss/79Open)

Krumholz, J., Barber, T., & Jadot, C. (2010). Avoiding "Band-Aid" Solutions in Ecosystem Restorations. *Ecological Restoration, 28*(1), 17-19. doi: 10.3368/er.28.1.17

Krumholz, J. S., & Brennan, M. L. (2015). Fishing for common ground: Investigations of the impact of trawling on ancient shipwreck sites uncovers a potential for management synergy. *Marine Policy, 61*, 127-133. doi: 10.1016/j.marpol.2015.07.009

Krumholz, J. S., & Jadot, C. (2009). Demonstration of a new technology for restoration of Red Mangrove (*Rhizophora mangle*) in high-energy environments. *Marine Technology Society Journal 43*(1), 64-72. doi: 10.4031/MTSJ.43.1.10

Kruskal, J. B., & Wish, M. (1978). *Multidimensional scaling*. Beverley Hills, California: Sage Publications.

Latimer, J. S., & Charpentier, M. (2010). Nitrogen inputs to seventy-four southern New England estuaries: application of a watershed nitrogen loading model. *Estuarine, Coastal and Shelf Science, 89*, 125-136.

Latimer, J. S., & Rego, S. A. (2010). Empirical relationship between eelgrass extent and predicted watershed-derived nitrogen loading for shallow New England estuaries. *Estuarine, Coastal and Shelf Science, 90*(4), 231-240.

Liu, Y., MacCready, P., Hickey, B. M., Dever, E. P., Kosro, P. M., & Banas, N. S. (2009). Evaluation of a coastal ocean circulation model for the Columbia river plume in summer 2004. *Journal of Geophysical Research C: Oceans, 114*(3).

Long Island Sound Study. (2015). Long Island Sound Comprehensive Conservation and Management Plan: Returning the Urban Sea to Abundance.: US Environmental Protection Agency, Long Island Sound Office, Stamford, CT.

Mason, S. J., & Graham, N. E. (1999). Conditional probabilities, relative operating characteristics, and relative operating levels. *Weather and Forecasting, 14*(5), 713-725.

Mullaney, J. R. (2013). Nutrient concentrations and loads and Escherichia coli densities in tributaries of the Niantic River estuary, southeastern Connecticut, 2005 and 2008–2011: U.S. Geological Survey Scientific Investigations Report 2013–5008, 27 p.

Mullaney, J. R. (2015). Evaluation of the effects of sewering on nitrogen loads to the Niantic River, southeastern Connecticut, 2005–11: U.S. Geological Survey Scientific Investigations Report 2015–5011, 30 p.

Nixon, S. W. (1981). Remineralization and nutrient cycling in coastal marine ecosystems. In B. J. Neilson & L. E. Cronin (Eds.), *Estuaries and Nutrients* (pp. 111-138). N.J.: Humana Press.

Nixon, S. W. (2009). Eutrophication and the macroscope. *Hydrobiologia, 629*, 5-19.

Officer, C. B. (1980). Box models revisited. In P. Hamilton & R. B. McDonald (Eds.), *Estuarine and Wetland Processes with Emphasis on Modeling* (Vol. 11, pp. 65-114). New York: Plenum Press.

Officer, C. B., & Kester, D. R. (1991). On estimating the non-advective tidal exchanges and advective gravitational circulation exchanges in an estuary. *Estuarine, Coastal and Shelf Science, 32*(1), 99-103. doi: 10.1016/0272-7714(91)90031-6

Sampou, P. A., & Kemp, M. (1994). Factors regulating plankton community respiration in Chesapeake Bay. *Marine Ecology Progress Series, 110*(2-3), 249-258.

Sheng, Y. P., & Kim, T. (2009). Skill assessment of an integrated modeling system for shallow coastal and estuarine ecosystems. *Journal of Marine Systems, 76*(1-2), 212-243.

Short, F. T., Klein, A. S., Burdick, D. M., Moore, G. E., Granger, S., Pickerell, C., Vaudrey, J., Bayley, H., & Evans, N. T. (2012). The eelgrass resource of Southern New England and New York: science in support of management and restoration success: Final Report submitted to The Nature Conservancy, 122 p.

Shumchenia, E. J., Pelletier, M. C., Cicchetti, G., Davies, S., Pesch, C. E., Deacutis, C. F., & Pryor, M. (2015). A biological condition gradient model for historical assessment of estuarine habitat structure. *Environmental Management*.

U.S. Environmenal Protection Agency Office of Water. (2015). A compilation of cost data associated with the impacts and control of nutrient pollution: U.S. Environmenal Protection Agency Office of Water. EPA 820-F-15-096.

Valiela, I. (1995). *Marine Ecological Processes* (2nd ed.). New York, New York, U.S.A.: Springer-Verlag New York, Inc.

Vaudrey, J. M. P. (2007). *Estimating total ecosystem metabolism (TEM) from the oxygen rate of change: a comparison of two Connecticut estuaries.* Ph.D. Doctoral Dissertation, University of Connecticut, Groton.

Vaudrey, J. M. P. (2008a). Establishing restoration objectives for eelgrass in Long Island Sound - Part I: review of the seagrass literature relevant to Long Island Sound (pp. 58). Groton, CT: Final Grant Report to the Connecticut Department of Environmental Protection, Bureau of Water Protection and Land Reuse and the U.S. Environmental Protection Agency. http://www.lisrc.uconn.edu/eelgrass/index.html (select Literature Reviews > Seagrass Literature Survey Report).

Vaudrey, J. M. P. (2008b). Establishing restoration objectives for eelgrass in Long Island Sound - Part II: case studies (pp. 64). Groton, CT: Final Grant Report to the Connecticut Department of Environmental Protection, Bureau of Water Protection and Land Reuse and the U.S. Environmental Protection Agency. http://www.lisrc.uconn.edu/eelgrass/index.html (select Literature Reviews > Case Study Report).

Vaudrey, J. M. P. (2014). 2014 working report on the Narragansett Bay EcoGEM model (pp. 68): University of Connecticut.

Vaudrey, J. M. P., Eddings, J., Pickerell, C., Brousseau., L., & Yarish., C. (2013). Development and application of a GIS-based Long Island Sound Eelgrass Habitat Suitability Index Model: Final report submitted to the New England Interstate Water Pollution Control Commission and the Long Island Sound Study. 171 p. + appendices.

Vaudrey, J. M. P., Kim, J. K., Yarish, C., Brousseau, L., Pickerell, C., & Eddings, J. (2013). Comparative analysis and model development for determining the susceptibility to eutrophication of Long Island Sound embayments: University of Connecticut and Cornell Cooperative Extension of Suffolk County.

Vaudrey, J. M. P., & Kremer, J. N. (2010). 2010 working report on the Narragansett Bay EcoGEM model (pp. 68): University of Connecticut.

Vaudrey, J. M. P., Kremer, J. N., Branco, B. F., & Short, F. T. (2010). Eelgrass recovery after nutrient enrichment reversal. *Aquatic Botany, 93*, 237-243. doi: http://dx.doi.org/10.1016/j.aquabot.2010.08.005

Williams, P., & del Giorgio, P. (2005). Respiration in aquatic ecosystems: history and background. In P. del Giorgio & P. Williams (Eds.), *Respiration in Aquatic Ecosystems* (pp. 1-17): Oxford University Press.

Williams, P. J. l. B., & Robertson, J. E. (1991). Over-all planlton oxygen and carbon dioxide metabolism: the problem of reconciling observations and calculations of photosynthetic quotients. *Journal of Plankton Research, 13*, 153-169.

Willmott, C. J. (1981). On the validation of models. *Physical Geography, 2*(2), 184-194.

Willmott, C. J., Ackleson, S. G., Davis, R. E., Feddema, J. J., Klink, K. M., Legates, D. R., O 'Donnell, J., & Rowe, C. M. (1985). Statistics for the evaluation and comparison of models. *Journal of Geophysical Research C: Oceans, 90*(C5), 8995-9005.

Wilson, R. F., Fennel, K., & Mattern, P. (2013). Simulating sediment-water exchange of nutrients and oxygen: A comparative assessment of models against mesocosm observations. *Continental Shelf Research, 63*, 69-84.

Wood, A., Blackhurst, M., Hawkins, T., Xue, X., Ashbolt, N., & Garland, J. (2015). Cost-effectiveness of nitrogen mitigation by alternative household wastewater management technologies. *Journal of Environmental Management, 150*, 344-354. doi: http://dx.doi.org/10.1016/j.jenvman.2014.10.002

Woods Hole Group. (2014). Southern New England and New York Seagrass Research Towards Restoration – Phase II: prepared for The Nature Conservancy, Cold Spring Harbor, NY. 133 pages, with appendices.