12-2013

Development and Application of a GIS-based Long Island Sound Eelgrass Habitat Suitability Index Model

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Final Report

Funded by and Prepared for:

New England Interstate Water Pollution Control Commission
and
Long Island Sound Study

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November 2013
revised December 2013*

** December 2013 revisions included: (1) corrections to the presentation of statistical results shown in Figure 159 (only N content and Leaf Mass were changed), (2) formatting corrections to the Works Cited list, and (3) addition of NEIWPCC and LISS disclaimer on this page.*

This project was funded by an agreement awarded by the Environmental Protection Agency to the New England Interstate Water Pollution Control Commission in partnership with the Long Island Sound Study.

Although the information in this document has been funded wholly or in part by the United States Environmental Protection agency under agreement GRANT # LI97188101 to NEIWPCC, it has not undergone the Agency's publications review process and therefore, may not necessarily reflect the views of the Agency and no official endorsement should be inferred. The viewpoints expressed here do not necessarily represent those of Long Island Sound Study, NEIWPCC, or EPA, nor does mention of trade names, commercial products, or causes constitute endorsement or recommendation for use.

Suggested citation: Vaudrey, J.M.P., J. Eddings, C. Pickerell, L. Brousseau., C. Yarish. 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.

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1 Acknowledgements

The following technical staff at Cornell Cooperative Extension of Suffolk County need to be acknowledged for their significant contribution to this project. Without the hard work, skills and dedication of Stephen Schott, Kimberly Petersen Manzo, Barry Udelson and Nick Krupski this project would not have been possible. Thanks to Dr. Jang Kim at the University of Connecticut for the elemental analysis of macrophytes and Veronica Ortiz and Claudia Koerting for nutrient analyses. A number of University of Connecticut Marine Science undergraduate students assisted with the field and lab work: Adam Chlus (NRME department), Melissa Cote, Jennifer Dootz, Amanda Dostie II, Rafeed Hussein, Leigha Krize, Corey Leamy, Marissa Mackewitz, and Rachel Perry.

2 Table of Abbreviations

CCE-SC	Cornell Cooperative Extension of Suffolk County
CT DEEP	Connecticut Department of Energy & Environmental Protection
EHSI Model	Eelgrass Habitat Suitability Index Model
EHSI Sub-Model	Eelgrass Habitat Suitability Index Sub-Model
GIS	Geographic Information System
IDW	Inverse Distance Weighting
Kd	light attenuation coefficient
LIS	Long Island Sound
LISRC	Long Island Sound Resource Center
NOAA	National Oceanic and Atmospheric Administration
NPI	Nutrient Pollution Indicator
PIs	Principle Investigators
RPD	Relative Percent Difference
UCONN	University of Connecticut
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Service

3 Executive Summary

The primary objectives of the Eelgrass Habitat Suitability Index Model (EHSI Model) are to assist in the evaluation of sites being considered for eelgrass restoration efforts in the Long Island Sound (LIS) area and to identify areas where water quality issues reduce or eliminate the potential for natural eelgrass colonization. To achieve this goal, geospatial processing of data available from the Long Island Sound area was conducted using *ArcGIS v10.0* including the *3D Analyst* and *Spatial Analyst* extensions. The result is a series of maps presented in this report and a GIS-based model available for users to interact with the results and formulations of the model. This executive summary provides a brief overview of the model results. Full details on model development, calibration, and skill analysis are provided in the main section of this report.

3.1 Executive Summary - EHSI Model Development

The first step in model development was to conduct an exclusive analysis based on the bathymetry and clarity of the water column (Section 6.3, page 29). Light is a primary requirement for eelgrass success and thus, areas which are too deep and receive very little light will not support eelgrass, regardless of the quality of other parameters of interest. The exclusive analysis has the added benefit of reducing the model area which is included in the computational domain, thus increasing the speed of running the model. The area included in the computational model domain was determined by applying a criterion of > 2% of light reaching the bottom for inclusion in the computational domain (Figure 1). Note that all grey area shown in Figure 1 receives a model score of zero, though this area is not included in the skill analysis as the large amount of area receiving a score of zero would result in a biased estimate of the accuracy of the model (i.e. overestimating the accuracy of the model).

Figure 1: Exclusive Band.
The Exclusive Band was generated from a combination of water depth, mean tidal amplitude, and % Light Reaching the Bottom. The resulting area is theoretically suitable for eelgrass if all other parameters are also optimal. This is a copy of Figure 11 from Section 6.3.4 (page 34).

Once the computational model domain was defined, the values of the parameters likely to influence eelgrass success were examined. These included data which were available throughout LIS, though the majority of sampling stations were located in the deeper areas of LIS (for station locations, see figures in Section 6.4.3, page 39). Parameters investigated included: water clarity as percent of light reaching the bottom, total nitrogen, total phosphorus, sediment grain size (% silt & clay), sediment organic content, maximum water temperature, chlorophyll *a*, total suspended solids, pH, and salinity (Section 6.4.1, page 34). The final parameters chosen for inclusion in the model included percent light to the bottom, temperature, dissolved oxygen, sediment grain size as % silt & clay, and sediment organic content. A full discussion of the rationale behind parameter selection is included in Section 6.4.3 (page 39). In short, the criteria used for selection of parameters reduced cross-correlation between parameters (e.g. percent light to the bottom is a result of chlorophyll *a* and total suspended solids). Additionally, selected parameters were required to exhibit a range for data from LIS over which eelgrass will be sensitive to variations in the parameter value.

Values of the five chosen parameters were interpolated between stations and extrapolated into the margins of LIS. The justification and assessment of error associated with extrapolating values into the shallow areas are provided in Sections 6.4 (page 34) and 8.1 (page 146). For each parameter, a range of values over which the model score would vary was determined based on expert opinion and data from the literature (Section 6.4.2, page 37). Above and below this range, the model score would be zero for that parameter or the highest value possible (Table 1). Each parameter was assigned a weighting, a maximum score it could contribute to the model output (Table 1) (Section 6.4.4, page 44). A perfect score for all parameters sums to a total model score of 100. Parameter values are converted to model scores, which is termed *reclassification*.

The scores for each parameter are summed per grid cell (30.48 m x 30.48 m) to yield the total model score (Figure 2) (Section 6.4.5, page 47). A model value of greater than 88 is recommended when choosing restoration sites, though existing eelgrass beds are also found in grids with a model prediction of 50 or greater (Section 6.5.1, page 48). The choice of a minimum model score of greater than 88 improves the likelihood of success for the planting of restoration plots.

Table 1: Weighted Rankings of Selected Parameters.
The weightings for the five parameters were selected. This is a copy of Table 8 from Section 6.4.4 (page 44).

Parameter	Range	Weighted Score	Minimum (0)	Max Score
Percent Light to Bottom	25-50%	0-30	<25%	>50% is 30
Surface Temperature	21-25°C	0-20	>25°C	<21°C is 20
Low Dissolved Oxygen	3-6 mg/L	0-10	<3 mg/L	>6 mg/L is 10
SedimentGrain Size, % Silt & Clay	2-20%	0-20	>20%	<2% is 20
Sediment Total Organic Carbon	0.5-10%	0-20	>10%	< 0.5% is 20
Sum Weighted Parameters		0-100		

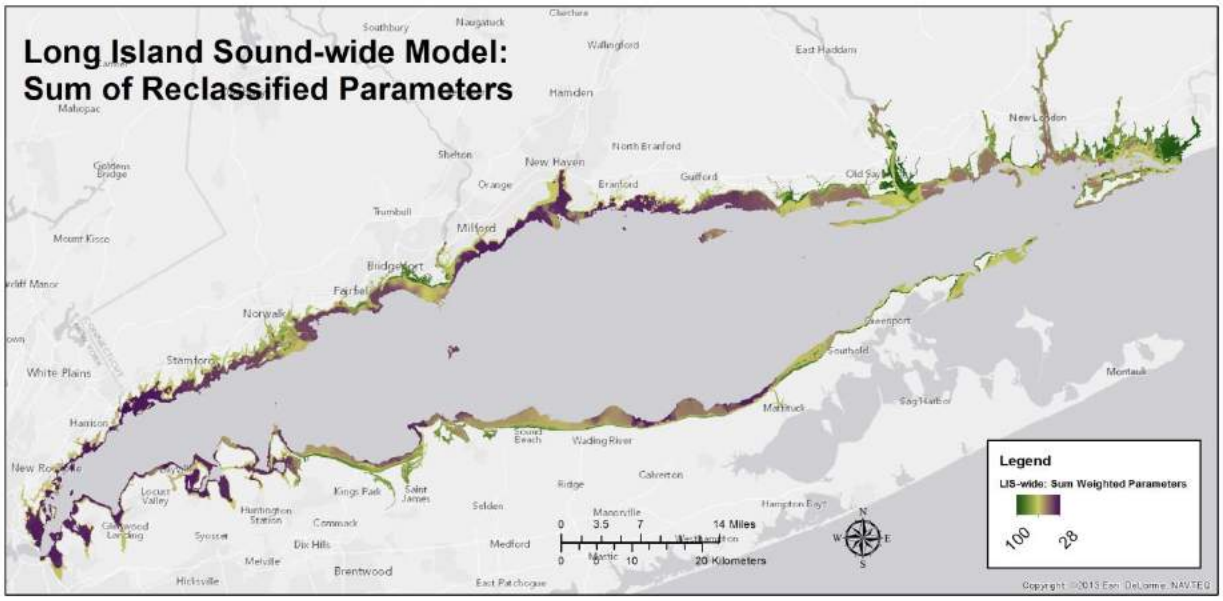


Figure 2: Sum of Ranked Parameters within the Exclusive Band.
The ranking results of the five selected parameters which were weighted and then summed to a maximum score of 100. A score of 100 is considered most ideal for eelgrass and 0 is least ideal. The lowest score within the exclusive band is 28. This is a copy of Figure 22 in Section 6.4.5 (page 47).

3.2 Executive Summary - EHSI Sub-Model Development (Case Study Sites)

Data on parameters of interest were collected in six case study sites. By collecting supplemental data at a higher spatial resolution, we were able to create model domains within the case study site with a higher resolution. The case study site Eelgrass Habitat Suitability Index Sub-Models (EHSI Sub-Models) were used to evaluate the uncertainty associated with the EHSI Model (Section 8, page 146). A discussion of the field methods and detailed results are provided in Section 7.3 (page 72) and maps of EHSI Sub-Model scores are presented in Section 7.6 (page 113).

The inclusion of a macroalgae term (coverage of detrimental green macroalgae) was investigated in the EHSI Sub-Model, as data were collected as part of this project. It was determined that even when the macroalgae is assigned 20% of the model score weighting, the inclusion does not have an appreciable effect on the model skill (Section 7.7.2, page 141). While the inclusion of macroalgae seems theoretically sound, it appears to be an over-parameterization of the model. For this reason, inclusion of macroalgae in the model is not recommended.

The EHSI Sub-Model for St. Thomas Point, NY, was used to investigate the effect of turbulence on the shallow limit of eelgrass (Section 7.8, page 143). Ideally, areas which are too shallow would also have been excluded from the computational model domain (Section 6.3.3, page 33). The shallow limit of eelgrass in Long Island Sound has been identified as equivalent to the mean tide level minus half the mean tidal range (Koch 2001). For example, in areas with a 1 m tidal range (equivalent to a 0.5 m tidal amplitude), the minimum depth will be 0.5 m below mean tide level. The lack of bathymetry data in

shallow areas precluded the inclusion of this shallow limit when evaluating areas for eelgrass habitat suitability.

The model domain extends to the shoreline even though it is recognized there will be a strip of area that is too shallow for eelgrass. While we can estimate a minimum depth for eelgrass based on tidal amplitude, wind and wave action also play a role in determining the minimum depth. St. Thomas Point (one of the case study sites) has had failed restoration plantings on two separate occasions due to locations that were heavily impacted by these effects. Review of the locations of these plantings identified a minimum depth of 2 m as suitable for eelgrass (Pickerell, *unpublished data*). When this minimum depth limit was combined with site specific bathymetry data collected during the field work associated with this project, the area of the St. Thomas Point EHSI Sub-Model domain that had scores suitable for restoration were eliminated due to being too shallow (Figures 150 & 151, page 145). Data for shallow water bathymetry are key to this type of analysis and are a major data gap when evaluating shallow areas of LIS for potential eelgrass habitat.

3.3 Executive Summary - EHSI Model Calibration and Skill Summary

The accuracy of the model was determined by examining the model output relative to existing naturally occurring eelgrass beds and restored eelgrass beds (Section 6.5, page 48). Aerial surveys of eelgrass distribution were conducted in 2002, 2006, and 2009 in the eastern end of Long Island Sound (Tiner et al. 2003, 2007, 2010). The 2012 aerial survey was not included in the skill summary because data were not released until late November 2013 (Tiner et al. 2013). These surveys illustrate that eelgrass is not present in all locations which are deemed suitable for eelgrass in the natural environment. Excluding depths greater than 9.2 m (where eelgrass is highly unlikely to occur), eelgrass beds are found in only 4.6% of the aerial survey study range. The model uses a threshold value above which eelgrass may expect to be found. If at least 4.6% of the model grids within the aerial survey study range above this threshold are scored as suitable for eelgrass, the model will be considered skilled. Skill assessment of the EHSI Model is presented in Section 6.5 (page 48). In grids with a model score of > 88, eelgrass may be expected in approximately 10.56% of the area under current conditions in Long Island Sound (Section 6.5, page 48). The fact that model grid cells within the aerial survey region scoring above 88 contain eelgrass 10.56% of the time indicates the model is skilled at predicting eelgrass presence, as values greater than 4.6% indicate improving accuracy.

A second method for assessing the accuracy of the EHSI Model is to compare the model scores to those of the more finely resolved and more tightly constrained EHSI Sub-Model results, which may only be done in the EHSI Sub-Model domains. The two model outputs were evaluated relative to the critical thresholds: eelgrass restoration should be targeted in areas with model scores greater than 88 (Section 6.5.1, page 48) & eelgrass is not predicted in areas with model scores less than 51 (Section 6.5.1, page 48). For the threshold of greater than 88 (or less than 89), the EHSI Model matches the EHSI Sub-Model 73% of the time (Table 23). This indicates that the EHSI Model is accurate (assuming the EHSI Sub-Model is the standard against which we judge accuracy) about 73% of the time, making the EHSI Model relatively skilled at predicting suitable areas for restoration efforts. The second threshold of less than 51

(or greater than 50) identifies model output indicating the area is unlikely to be suitable for eelgrass, either natural or restored populations (Section 6.5.1, page 48). For the threshold of less than 51 (or greater than 50), the EHSI Model matches the EHSI Sub-Model 86% of the time (Table 23). Thus the EHSI Model is highly skilled at predicting areas which are unsuitable for eelgrass.

In the EHSI Model, data available throughout Long Island Sound, typically sampled in the deeper areas of the Sound, were interpolated between stations and extrapolated into the shallow margins of the Sound. The case study sites provided site specific data with which to compare and assess the extrapolated LIS-wide data. This topic is discussed in detail in Section 8.1 (page 146) and reviewed briefly here. The greatest difference in the model score due to the parameter values were seen for light and temperature. For each of these parameters, three of the six case study sites exhibited a difference in model score > 3 (out of 100) for the parameter. Good agreement was seen between the EHSI Model and the EHSI Sub-Model for both sediment characteristics: grain size (% silt & clay) and organic content. Good agreement between the models was also evident for oxygen. A comparison of the case study site data with the parameter estimates based on the LIS-wide datasets indicates that light and temperature are the two parameters most in need of additional data. The light parameter (percent of surface light reaching the bottom) is a function of the light attenuation coefficient and the bathymetry of the site, thus better bathymetry data in shallow waters is also a priority. Sediment characterization is not required, but may be needed if sediment is thought to have changed since the last surveys for a particular area. Additional site specific oxygen data is unlikely to be helpful.

Within the case study sites, data from stations were interpolated to the edge of the EHSI Sub-Model domains, though the typical proximity of <200 m of stations to the edge limit this error. To quantify the effect of interpolation on overestimation or underestimation of model score at the edges of the domain, the values of parameters were examined relative to the ranges over which the model score varies. This topic is addressed fully in Section 7.7.3 (page 142). In all cases, the rationale for determining error was to find the area which had the greatest potential contribution of error, thus these are “worst case” scenarios. The total error associated with extrapolating to the edge of the model domain, summing up the error associated with all five parameters, ranges from -3% to 4% (some reduce the model score, some improve the model score). The 4% value is associated with only one site with a distance of 300 m between the station and the model domain. A model score with 4% error at the edges of the domain is considered acceptable for justifying the extrapolation of data to the edge of the domain in the EHSI Sub-Model as applied to the case study sites.

3.4 Executive Summary – Sea Level Rise Scenarios

Water depth influences the amount of light reaching the bottom and is important to eelgrass survival because of its high light requirement. Considering sea level rise predictions over the coming years, it was desirable to evaluate the impact sea level rise will have on the extent of the area potentially suitable for eelgrass (Section 6.6, page 56). The EHSI Model predicts that 651.8 km^2 of Long Island Sound is within the depth range appropriate for eelgrass (see Section 6.3 for a discussion of how this was calculated). The model predicts loss of area potentially suitable for eelgrass along the deep edge of the model

domain ranging from 3.3 km^2 to 18.5 km^2 by 2030 and 7.3 km^2 to 45.6 km^2 by 2050; these values vary with the source of the sea level rise prediction and include the upper and lower 90% confidence interval for sea level rise predictions in LIS.

It is important to note that these estimates refer to loss of *potential* habitat, not to the loss of *existing* eelgrass beds. As noted in Section 6.5.3 (page 54), eelgrass is found in only a small fraction of the area where conditions are suitable, thus the losses predicted by the model refer to the potential habitat and not the actual loss of currently existing beds. The greatest losses of suitable areas are predicted to occur along the deep edge of the areas along the Connecticut coast between Bridgeport and Clinton.

The sea level rise analyses were applied only to the study area and did not include an estimate of land that would be inundated. This inundated land may create new suitable areas for eelgrass. However, as stated in Section 6.3.1 (page 11), bathymetry data in shallow areas are not available, so the model domain extends to the shoreline. For these reasons, land areas were not included in the sea level rise results. An additional caveat regarding the migration of eelgrass inland as sea level rises is the limiting effect of hardened shorelines. While eelgrass may migrate inward to a degree, it will likely stop at the current shoreline due the effect of human uses and habitation in the highly urbanized Long Island Sound.

3.5 Executive Summary – Using Model Output to Identify Impairments

One use of the model is to examine what factors are *currently* limiting to eelgrass success in a particular area; this topic is covered in Section 6.4.5 (page 47). By examining the maps of the model scores associated with each parameter, the parameter with low model scores can be identified. For example, in the far western Sound, both grain size (Figure 20) and dissolved oxygen (Figure 19) are unsuitable for eelgrass; but light, temperature, and sediment organic content receive at least partial scores in some areas of the western Sound (Figures 17 - 19). While a first approximation at what factors may limit eelgrass success in an area can be achieved by examining Figures 17 - 19, the GIS model files allow a user to zoom into a particular area then toggle through the layers of model scores associated with each parameter to better evaluate which parameter is causing the impairment.

3.6 Executive Summary – Data Gaps

The development of the model has revealed gaps in the available data and yielded suggested additions to the model to improve accuracy of the model's ability to predict suitable sites for eelgrass. A full discussion of gaps is provided in Section 10.2 (page 168), but a short overview is provided here:

- The highest priority data need is for higher resolution bathymetry data.
- Light and temperature are the two parameters most in need of additional data, following bathymetry. The issue with both of these parameters is the need for a deployed instrument to monitor these values, which vary over a daily cycle and exhibit day-to-day variability. Deployments of inexpensive light and temperature sensors capable of recording every 15 minutes would assist with better characterizing these parameters.

- Additional site specific information in areas of particular interest can further improve the accuracy of the model.

3.7 Executive Summary – Concluding Remarks

- The EHSI Model provides a reasonably accurate representation of habitat suitability for eelgrass throughout Long Island Sound. Comparison of the model output with current eelgrass distribution, and the siting of successful and failed restoration attempts, indicates the model will be useful when making future plans for restoration efforts.

- While the EHSI Model is one tool which may be used to make decisions regarding restoration, the final decision should include local knowledge of the site and a site evaluation by an experienced restoration specialist. An additional tool for evaluating site suitability is the Nutrient Pollution Indicator (NPI), which involves short deployments of eelgrass on floating racks. The NPI was a sensitive indicator and integrator of local water quality (Section 9, page 158).

- Site specific data, as gathered for the case study sites, can further refine where to site a restoration bed within an area of interest. The EHSI Sub-Model can be applied to sites where additional data are available. This higher resolution model can assist restoration specialists with choosing the best location within a target area. While longer term data would be ideal, a single site visit in mid-summer is sufficient.

- While more data overall would improve model accuracy, the information of highest priority is shallow water bathymetry. Data on light and temperature from deployed instruments are also of high priority.

4 Project Background

Eelgrass (*Zostera marina* L.) is the most common marine angiosperm in the Northern Hemisphere. In Long Island Sound (LIS) the species could once be found in almost every bay, harbor and river. Today however, the population is much reduced and generally limited to the eastern reaches of the estuary (Tiner et al. 2010).

Unlike macroalgae and phytoplankton, eelgrass is a submerged rooted vascular plant that requires a substantial amount of light in order to thrive (Valiela et al. 1997). Due to this requirement, this species is typically found in shallow coastal areas with good water quality. Eelgrass, like most other seagrasses, grows in dense patches or "meadows" that persist more or less year round. Given the fact that these meadows modify the environment they grow in, eelgrass has been described as an "ecosystem engineer" (Koch 2001). This "engineering" relates to the ability of densely packed shoots to alter water flow which removes particles, nutrients, and carbon from the water column and deposit them to the benthos.

With regard to ecosystem services, seagrass meadows represent a unique niche which serves as habitat and nursery grounds to many recreationally and commercially important species (Heck Jr. et al. 2003). The close association between eelgrass and the bay scallop in local waters is a good example of this relationship (Thayer & Stuart 1974; Irlandi et al. 1995). In addition, although it is difficult to establish a precise economic value for eelgrass in this region, seagrasses in other areas have been documented to support commercial fisheries worth as much as \$3500 ha^{-1} yr^{-1} (Watson et.al., 1993). Given that eelgrass supports so many commercially valuable species in LIS (e.g., bay scallops, striped bass, fluke, winter flounder, etc.), it is not unrealistic to assume that the local value is also substantial.

Despite attempts to protect this critically important marine habitat, eelgrass populations have been declining both globally and locally (Orth et al. 2006; Yarish 2006). The causes of the declines are likely due to a combination of anthropogenic and natural factors (Short and Wyllie-Escheverria 1996). The rise of human population along the coast has led to a greater delivery of nutrients and particulate matter to coastal waters (Boynton et al. 1992; Valiela et al. 1992). Sediment in the water column and nutrient stimulated blooms of both phytoplankton and macroalgae can shade the eelgrass while the direct use of coastal waters by humans increases the amount of physical disturbance to eelgrass habitats (Johnson et al. 2007). Natural stressors on eelgrass include high summer temperatures, bioturbation, grazing by waterfowl, storm scour of beds, and disease (Bintz et al. 2003; Keser et al. 2003; Rivers and Short 2007). While these disturbances are termed "natural," they can be linked to anthropogenic influences via reduced water quality, introduction of invasive species, and the effects of climate change (Short and Neckles 1999).

Given the considerable ecological value of seagrasses worldwide much effort has been focused on restoration of this habitat (Fonseca et al. 1998; Campbell 2002; Pickerell et al. 2005; Paling et al. 2009; Marion & Orth, 2010). However, while much of this work has focused on planting methods and other logistical concerns, in practice, the most significant factor affecting the success of seagrass restoration efforts is site selection (Fonseca, personal communication; Fonseca et al. 1998; Van Katwijk 2009). Based on this understanding, site selection methods have been proposed that "synthesizes available

historic and literature-based information, reference data, and simple field measurements to identify and prioritize locations for large-scale eelgrass transplantation" (Short et al. 2002). Given the amount of data and the scale of the analysis often involved with such work this type of site selection methodology is amenable to analysis using Geographic Information System (GIS) software. Based on the work of Short and others in Massachusetts, CCE-SC developed just such a site selection model for work in the Peconic Estuary on the East End of Long Island (CCE-SC 2007). Completion of this study showed that this type of method could be used to identify appropriate eelgrass planting sites in New York waters.

Although CCE-SC has used a GIS-based site selection system to guide eelgrass restoration efforts in the Peconic Estuary a similar approach has never been attempted in the Long Island Sound for various reasons, not the least of which were lack of funding and a perceived lack of data. For the Peconic Estuary project we were fortunate in that the smaller scale of the system combined with a more extensive and comprehensive data set relating to water quality (nutrients), hardened shorelines, commercial fishing, and recreational boating were available or easily compiled. For the present study, we were not as fortunate in that meaningful data at an estuary wide scale was generally not available for many parameters. In some cases this data was only available for small areas within the Sound where previous research had been conducted. In other cases the data may exist, but due to the logistics of getting it from numerous sources and the likelihood that the data sets may not be equivalent or compatible, it was determined that this would not meet our QAPP requirements and we could not include this information. Despite these limitations, we believe the data sets for the parameters that have the greatest influence on site selection (depth, light and temperature) for eelgrass survival in Long Island Sound were incorporated into the our model, as evidenced from the positive results in the skill analysis scoring. The work presented herein represents creation of a model for Long Island Sound.

5 General Approach to Model Development

The development of any model incorporates a series of steps moving from defining the purpose through the final stages of model testing. In recognition of the broad audience with interests in this model, a brief summary of these steps are provided below with links to sections of the report where these steps are discussed in detail. Most readers will be familiar with the steps involved with hypothesis driven experimental science. Modeling also follows a series of steps, though some readers may be less familiar with the process. Jakeman et al. (2006) provide a review of model development, detailing the ten major steps in the modeling process. The steps employed in model development are presented in a diagram (Figure 3) and followed by a brief description of the steps as they apply to the development of the GIS-based Eelgrass Habitat Suitability Index Model. The goal of this section is to introduce the general approach to model development and testing employed in this project. The details of each step are provided later in this report.

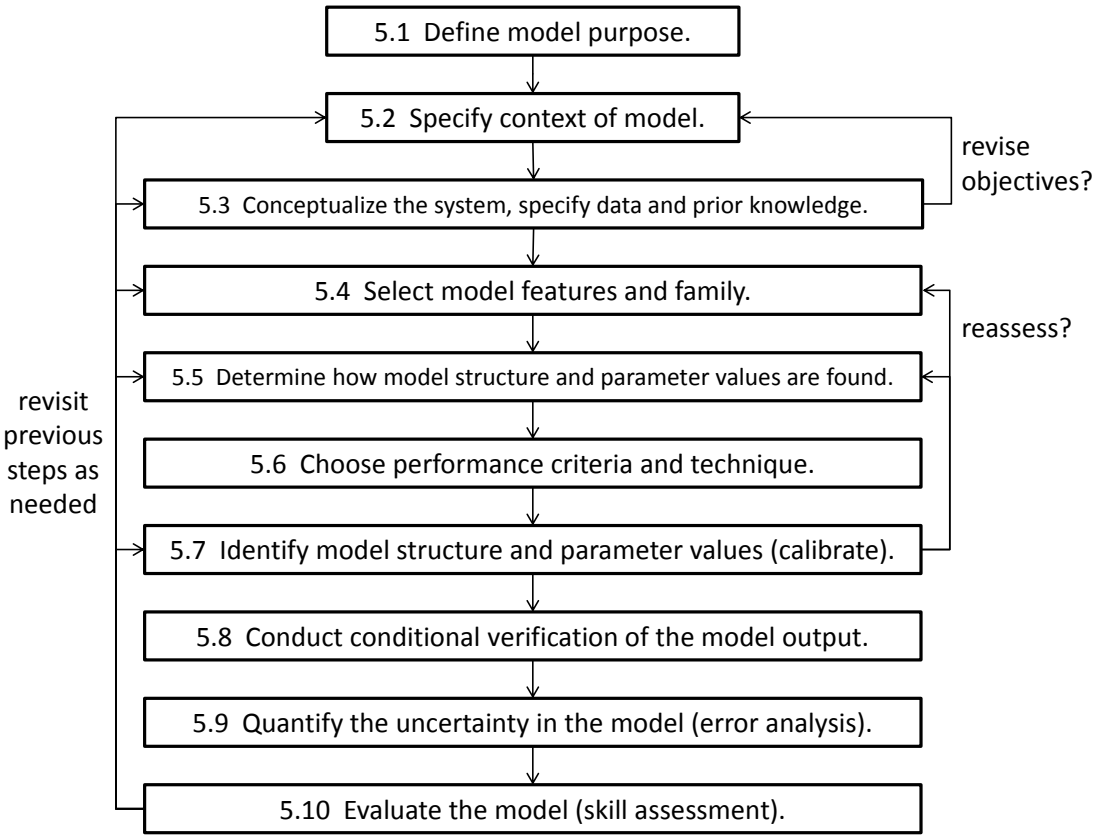


Figure 3: Overview of Basic Modeling – 10 Steps
The numbers in the boxes refer to the Section in the text where the step as it pertains to this model is covered.

5.1 Define Model Purpose

→ The primary objectives of this model are to assist in the evaluation of sites being considered for eelgrass restoration efforts in Long Island Sound and to identify areas where water quality issues reduce or eliminate the potential for natural eelgrass colonization.

A number of secondary objectives have been identified.

- Identify gaps in the data which, if filled, will improve our understanding of shallow water habitat characteristics and improve the ability of the model to predict suitable sites for restoration efforts.
- Evaluate the conditions in current eelgrass areas in order to identify which beds are likely to exhibit greater variability due to marginal conditions.
- In areas considered unsuitable for restoration, identify the impairments within the limitations of the model framework (for example, if the site is unsuitable due to the presence of a contaminant such as herbicides, the model will not indicate this issue).
- Predict the loss of potential eelgrass habitats due to projected sea level rise.

5.2 Specification of the Modeling Context: scope and resources

The GIS-based Eelgrass Habitat Suitability Index Model is specifically developed for Long Island Sound. While the model framework and formulations are transferrable to other locations, the ranges of parameters may vary according to identified eelgrass habitat criteria in other locations. The model may also be reconfigured to represent conditions for other species (e.g. the macroalgae *Saccharina latissima*), provided that the other species are most influenced by the same forcing factors as are included in the model (light availability, temperature, hypoxia, sediment grain size, and sediment organic content).

The model output consists of a score assigned per 30.48 m x 30.48 m (100 ft. x 100 ft.) grid in a GIS-based map. The model score ranges between 0 and 100, with 0 being unsuitable for eelgrass in general and 100 being best suited for eelgrass restoration efforts. The critical thresholds defined for restoration success and areas considered unsuitable for eelgrass in general are identified in Section 6.5.1 (page 48).

Two versions of the model were developed: a EHSI Model and a EHSI Sub-Model restrained in areal extent to six case study sites (e.g., Clinton Harbor, CT). The EHSI Model was developed based on datasets which are available throughout the Long Island Sound domain (Section 6, page 27). These datasets consist of data sampled from the main stem of Long Island Sound and extrapolated into the shallow margins of the Sound where eelgrass is most likely to occur. The appropriateness of extrapolating data from Long Island Sound into shallow, unsampled areas is one of the major assumptions of the model. In order to evaluate this assumption, field work was conducted in six case study sites (Section 7.3, page 72). The EHSI Model was applied to each of these six case study sites, using the higher resolution, site-specific field data to develop a EHSI Sub-Model (Section 7, page 64). The comparison of output from the EHSI Model and the EHSI Sub-Model as applied to the six case study sites was used to evaluate the interpolation of LIS data into the shallow edges.

Temporally, the model is representative of current conditions in Long Island Sound. In order to evaluate changing conditions (i.e., increasing temperatures, lower light availability, etc.), the data used to drive the model would need to be adjusted to reflect the predicted conditions.

The accuracy of the model was determined by examining the model output relative to existing naturally occurring eelgrass beds and restored eelgrass beds (Section 6.5, page 48). Aerial surveys of eelgrass distribution were conducted in 2002, 2006, and 2009 in the eastern end of Long Island Sound (Tiner et al. 2003, 2007, 2010). These surveys illustrate that eelgrass is not present in all locations which are suitable for eelgrass. Excluding depths greater than 9.2 m (where eelgrass is highly unlikely to occur), eelgrass beds are found in only 4.6% of the aerial survey study range. The model uses a threshold value above which eelgrass may expect to be found. If at least 4.6% of the model grids within the aerial survey study range above this threshold include eelgrass, the model will be considered skilled. Skill assessment of the EHSI Model is presented in Section 6.5 (page 48).

5.3 Conceptualization of the system, specification of data and prior knowledge

The success of eelgrass within the system is known to be linked to a number of forcing factors. Light, temperature, water quality, and the amount of other primary producers have all been identified as affecting eelgrass (Section 6.4.1, page 34). Criteria for eelgrass success in Long Island Sound have been identified for these parameters (see Table 13, Section 7.3, page 72).

Data on many of the parameters identified as criteria for determining the habitat quality for eelgrass are available from the Connecticut Department of Energy & Environmental Protection (CT DEEP) surveys of Long Island Sound. Other data on sediment characteristics are available from the United States Geological Service (USGS). All data considered of primary importance to eelgrass is available for the main stem of Long Island Sound. Information on the data density and processing of the data are included in Sections 6.3 and 6.4.

Development of the model proceeded under certain assumptions:

Data in the main stem of Long Island Sound are sufficient to predict conditions along the margin of the Sound. This assumption will be tested by comparing data from the case study sites to conditions predicted from interpolating Long Island Sound data between stations and extrapolating data into the case study sites (Section 8.1, page 146).

Data density is sufficient to resolve differences in site suitability throughout Long Island Sound. This assumption will be tested by comparing the output of the EHSI Model to the output from the EHSI Sub-Models conducted within case study sites where field data were collected as part of this project (Section 8.2, page 150).

Parameters most likely to affect the suitability of a site for eelgrass in Long Island Sound are understood. A history of research on this topic coupled with local knowledge of current beds in Long Island Sound and experience with successful and unsuccessful restoration efforts in Long Island Sound are used to support this assumption. No model will be a perfect representation of reality. Skill assessment will indicate the degree to which the model captures the effect of the model parameters on eelgrass site suitability (Sections 6.5 and 7.7.2).

5.4 Selection of Model Features and Family

The model is structured as a GIS map with grid sizes of 30.48 m x 30.48 m (see Section 6.4.1, page 34 for grid cell choice justification). The model yielded a map of predicted scores based on the input variables. The model scores range between 0 and 100, with higher scores indicating higher suitability for eelgrass.

Within each model grid, the value for each parameter included in the model is assessed relative to an acceptable range for that parameter. The parameter is reclassified into a score value. The model score for a grid is the sum of the scores of the individual parameters for that grid. For example, oxygen is one parameter included in the model. In the initial formulation, oxygen was defined as 10% of the total

score. The optimal dissolved oxygen value was defined as greater than 6 mg/L. Anything below 3 mg/L was defined as not supportive of eelgrass. The oxygen values are reclassified based on these ranges and the weighting assigned to oxygen in the overall model score. Thus values above 6 mg/L will contribute 10 points to the model score (Figure 4). Values below 3 mg/L will contribute 0 points to the model score. The model score for values between 3 and 6 mg/L is determined as a linear interpolation between 0 and 10 points. Section 6.4 (page 34) provides details on the ranking analysis.

The model family is best characterized as a "black box" model, meaning that empirical data are used to define relationships of forcing factors (the five parameters) to model output (score) without specifying the exact biological processes involved. Instead of focusing on the mechanistic processes, a statistical linear relationship between the forcing factors and model output is employed. The model is deterministic; in other words, the same input will always yield the same output.

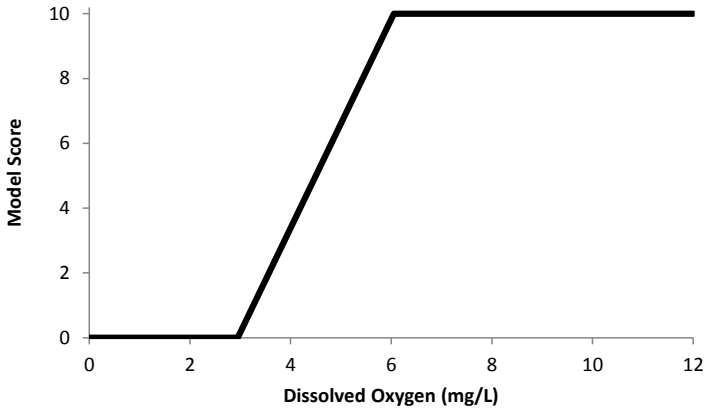


Figure 4: Example of Determination of Model Score Within a Grid.
The optimal range for eelgrass is defined as > 6 mg/L, receiving the highest weighted score possible. Values below 3 mg/L received the lowest score possible. Oxygen was defined as contributing 10% to the total model score, thus the reclassified oxygen ranges between a model score of 0 and 10 for oxygen values between 3 and 6 mg / L.

5.5 Choice of How Model Structure and Parameter Values are to be Found

The choice of parameters included in the model was based on an evaluation of the data available for the parameters identified as important to eelgrass success (Section 6.4, page 34). Many variables were initially considered and reviewed for inclusion in the model. All data available for the Long Island Sound estuary as a whole were initially evaluated for inclusion in the model.

The Occam's Razor principle of parsimony was employed when deciding upon the parameters to include (Jakeman et al. 2006). This refers to choosing the lowest number of parameters that yield accurate results. In modeling, the inclusion of additional parameters past a certain point increases uncertainty

without a substantial increase in accuracy. This is due to estimation of parameters or processes, each having an error associated with the estimate which reflects temporal and spatial variability, sparseness of data, and error associated with interpolating between sample points and extrapolating into other areas where no data are present. As each new parameter is added to a model, the error of the model estimate increases. Eventually, the increased accuracy due to additional parameters is not detectable within the error associated with the model.

5.6 Choice of Performance Criteria and Technique

To be included, a parameter had to exhibit expected values which spanned a range from detrimental to eelgrass success through supportive of eelgrass. For example, pH was not a sensitive indicator for eelgrass in Long Island Sound, as the current range of pH values and predicted changes to pH are unlikely to be detrimental to eelgrass.

The model parameters were also chosen to reduce correlation among the parameters. While this cannot be eliminated totally, it can be reduced. As an example, data were available for light in the water column, chlorophyll concentration, and total suspended solids in the water column. The percent of surface light reaching the bottom is a product of the light attenuation coefficient and depth of the water column. The light attenuation coefficient is the sum of light attenuation due to the water, chlorophyll, total suspended solids (which also may include some larger chlorophyll containing plankton), and colored dissolved organic matter. To reduce the potential biasing effects of correlation among these values, only the percent of surface light reaching the bottom was included in the final model.

The final model includes five parameters: percent of surface light reaching the bottom, temperature, dissolved oxygen, sediment grain size, and sediment organic content (Section 6.4, page 34). Sediment grain size and organic content are often correlated, but each of these parameters is important to eelgrass success.

5.7 Identification of Model Structure and Parameter Values (Thresholds, Calibration)

The acceptable ranges for parameter values were defined through literature ranges of criteria for eelgrass success coupled with local expert knowledge of Long Island Sound eelgrass habitats (Section 6.4, page 34).

The structure of the model refers to the weighting assigned to each of the chosen parameters. An initial model was run with the weighting determined by expert opinion on the likely influence of certain parameters (Section 6.4.4, page 43). By comparing model scores to existing eelgrass beds, a threshold was determined for the minimum value required for a restoration effort (Section 6.5.1, page 48).

Other model structures were examined and output results compared to the locations of existing eelgrass beds (Section 6.5, page 48). The goal was to find the model structure with the highest

predictive power. Four alternate model formulations were analyzed and the following weighting scheme was chosen as the final weighting structure for the EHSI Model:

- percent light reaching the bottom 30%
- temperature 20%
- low dissolved oxygen 10%
- sediment grain size 20%
- sediment organic content 20%

An alternate method for investigating the model structure would be to run the model many times (dozens to hundreds) allowing the model structure to vary with each run. While this iterative process is appropriate for models where a unique or well-defined structure is expected, it would not be appropriate for this model as we know that certain forcing factors on eelgrass success are not included (e.g. effect of wind fetch on the shallow edge of beds, timing and frequency of wind and storm events). An iterative tuning of the model would allow more degrees of freedom than are justified by the data and result in over-calibration of the model.

5.8 Conditional Verification of Model Output

Conditional verification of the model was conducted at every step where model output was generated. This process involves examining the data maps to verify data values relative to what is known about the systems.

During model development, maps of the values for parameters were examined to ensure that interpolation between data points and extrapolation of the data from the main stem of Long Island Sound into the shallow margins reflected typical ranges expected for these systems based on previous work conducted by the PIs and data available from the literature on values for LIS.

5.9 Quantification of Uncertainty

Uncertainty in models can have many sources, including an incomplete understanding of the system and sparse data, the two sources most likely to affect this model. To quantify the degree of these uncertainties, model outputs are compared to the eastern Sound area where aerial mapping of the eelgrass in the region has been conducted (Section 6.5, page 48). From this assessment, estimates of the fraction of model predictions which will accurately predict eelgrass success were determined. To address the issue of sparse data, field data were collected in the six case study sites (Section 7.3, page 72). EHSI Sub-Models applied to each of these sites were compared to model output from the EHSI Model to determine the error associated with the EHSI Model, assuming that EHSI Sub-Model predictions based on local datasets collected as part of this project reflected accurate estimates for these areas (Section 8, page 146).

5.10 Model Evaluation (Skill Analysis)

Evaluation of the model relative to the field data available on current locations of natural eelgrass beds and restoration efforts was used to assess the skill of the model (Section 6.5, page 48). The eelgrass distribution data were not used as inputs to the model, though they were used to identify the model threshold to use when choosing restoration sites.

6 EHSI Model Development

6.1 Overview

The Long Island Sound is a complex system encompassing approximately 3,420 km^2 with a depth range of 0 – 98 meters and a semidiurnal tide which increases in amplitude from east to west. The purpose of the EHSI Model was to identify the areas in Long Island Sound which are more suitable for eelgrass growth and/or restoration. The EHSI Model included the following steps:

1) Delineate the study area (Section 6.2, page 28).
2) Conduct an "Exclusive Analysis" (Section 6.3, page 29) which highlights areas which can theoretically accommodate eelgrass taking into account depth, tidal amplitude and % Light Reaching the Bottom. The resulting area is referred to as the "Exclusive Band" and acted as the active model domain for all further LIS-wide processes. By reducing the full model domain to this much smaller active model domain, the model run time was significantly reduced.
3) Conduct a "Ranking Analysis" (Section 6.4, page 34) which analyzed water column and sediment characteristics to rank the suitability of all areas within the Exclusive Band. Each model grid (30.48 m by 30.48 m) was assigned a suitability score ranging from 0-100.
4) Conduct model calibration and skill assessment (Section 6.5, page 48) to determine the ideal weightings of parameters and to assess the predictive power of the model.
5) Examine the impact of sea level rise scenarios on area suitable for eelgrass (Section 6.6, page 56).

Geospatial processing for the EHSI Model was conducted using *ArcGIS v10.0* including the *3D Analyst* and *Spatial Analyst* extensions. The Projected and Geographic coordinate systems for the study were selected from the Connecticut Area Hydrography feature class (CT DEEP) and applied to the environmental settings for all obtained and created GIS layers (Figure 5).

Projected Coordinate System:
NAD_1983_StatePlane_Connecticut_FIPS_0600_Feet
Projection: Lambert_Conformal_Conic
False_Easting: 999999.99999600
False_Northing: 499999.99999800
Central_Meridian: -72.75000000
Standard_Parallel_1: 41.20000000
Standard_Parallel_2: 41.86666667
Latitude_Of_Origin: 40.83333333
Linear Unit: Foot_US

Geographic Coordinate System: GCS_North_American_1983
Datum: D_North_American_1983

Figure 5: Projected and Geographic Coordinate Systems.
The Projected and Geographic Coordinate Systems were selected from the Connecticut Area Hydrography (CT DEEP).

6.2 Study Area

The study area encompassed the entire Long Island Sound, from the Throgs Neck Bridge, NY, east to the Pawcatuck River at the Connecticut - Rhode Island border (Figure 6). Hydrography data for the study area were downloaded from the New York State GIS Clearinghouse and CT DEEP. The shorelines of Fishers Island, Little Gull Island, Big Gull Island, and Plum Island were also fully enclosed in the study area. Further information regarding the development of the study area can be found in Eddings (2012), provided as Appendix 1.

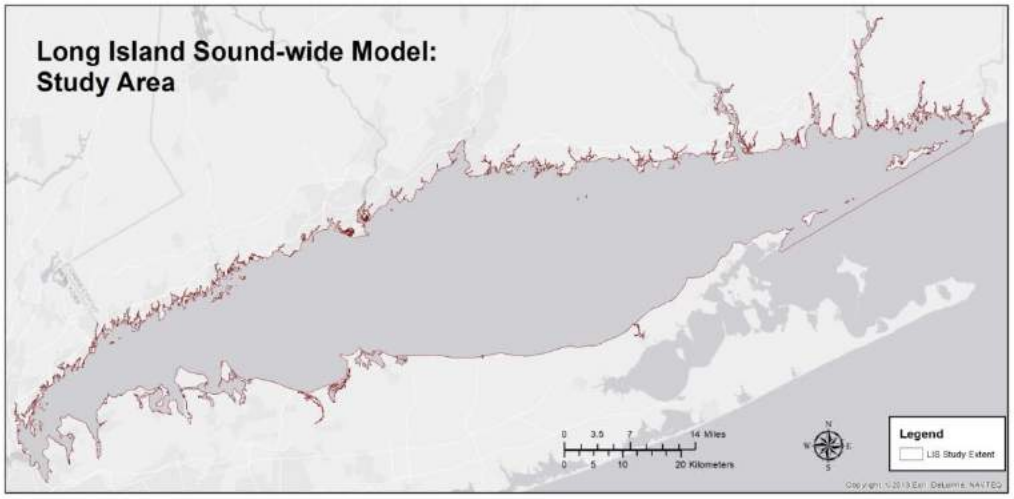


Figure 6: Long Island Sound Study Area.
The study area extends from the Throgs Neck Bridge, NY in the west to the Pawcatuck River at the Connecticut - Rhode Island border in the east.

6.3 Exclusive Analysis

6.3.1 OVERVIEW

The goal of the exclusive analysis was to identify areas which are definitely unsuited as habitat for eelgrass (Section 5.5). The definition of "unsuitable" does not take into account the water quality and habitat quality issues. Instead, these exclusive analyses identify areas which would not support eelgrass even under the very best water quality and habitat characteristic conditions. Eliminating these areas speeds the computation process and eliminates areas that might otherwise have had a model score greater than zero (e.g. good habitat and water quality, but just too deep). The band is termed to computational model domain.

The exclusion of areas was based on the requirement of eelgrass for at least some light reaching the bottom. Thus, bathymetry, mean tidal amplitude, and % Light Reaching the Bottom were used in the exclusive analysis to identify the deep edge of the computational model domain (Table 2).

Eelgrass also has a shallow water limit, a depth which is too shallow to support eelgrass. The lack of shallow water bathymetry precluded the inclusion of this shallow water limit on the computational model domain. Instead, the computational model domain extends to the shoreline. This issue is discussed in Section 6.3.3 (page 33).

Table 2: Exclusive Analysis Parameters.
The exclusive analysis incorporates bathymetry, mean tide and % Light Reaching the Bottom to identify theoretically suitable areas.

Parameter	**Summary**	**Source**
Bathymetry	This data is critical to identifying the shallow regions in which eelgrass can survive.	Long Island Sound Resource Center and NOAA Raster Nautical Charts
Mean Tidal Amplitude	Tidal amplitude varies throughout LIS and has a direct impact on the bathymetry analysis.	NOAA Tides & Currents
Percent Light Reaching the Bottom	Sufficient light is critical for eelgrass growth. Values for the light attenuation coefficient (Kd) were applied in the following equation: $\% \text{ Light Reaching the Bottom} = e^{-Kd*Depth}$ Where 'e' is the base of the natural logarithm	CT DEEP, June – September for 2009-2011

6.3.2 DEFINING THE DEEP EDGE OF THE EXCLUSIVE BAND

A bathymetry model was developed from data available from the Long Island Sound Resource Center (LISRC) and the National Oceanic and Atmospheric Administration (NOAA) Raster Nautical Charts to cover the entire study area including adjoining embayments. The result was a complete bathymetry model for LIS ranging in depth from 0 to 98 meters (Figure 7). The tidal datum used was biased towards the presentation of shoals, in other words, depths were for Mean Lower Low Water (MLLW, low tide during the spring tidal phase).

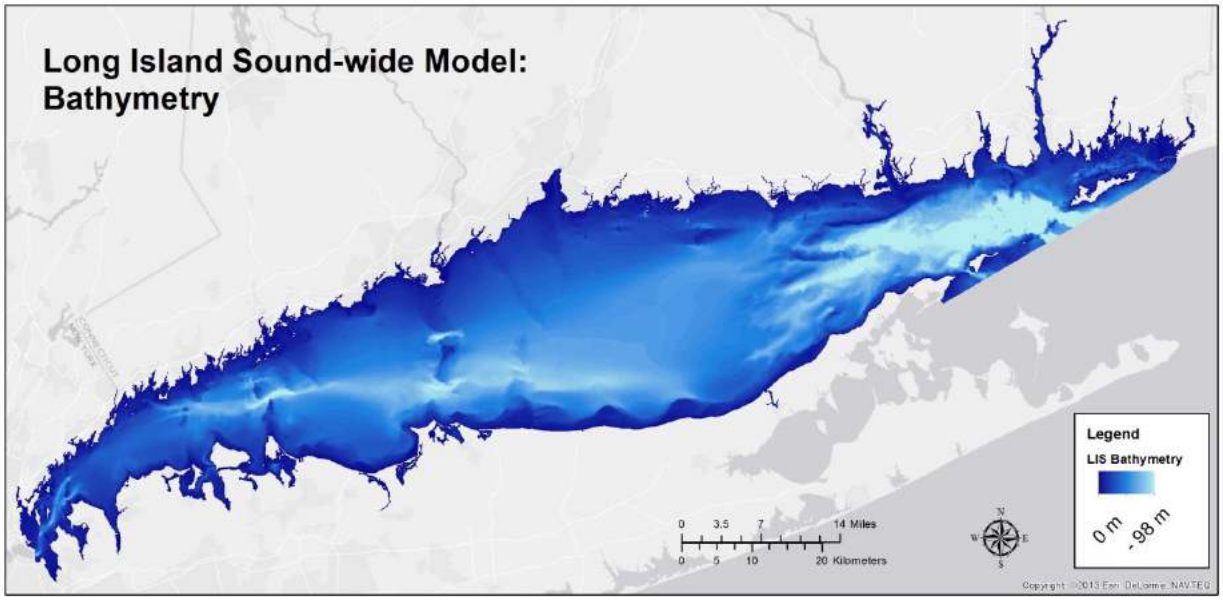


Figure 7: Long Island Sound Wide Bathymetry Model.

A predicted maximum depth value for eelgrass of 9.2 m was chosen to reduce the model area in order to improve model computation speeds without risking the chance of excluding suitable areas of eelgrass. This value will capture known deeper beds and was calculated using a 10% minimum requirement for light reaching the bottom and clear water with a light attenuation coefficient of 0.25/m. The light attenuation coefficient (Kd) quantifies the degree of light penetration in the water column with low values indicating a clearer water column and high values indicating a more turbid water column. A value of 0.25/m expresses a high but realistic water clarity value.

Tidal amplitude (which is half the tidal range) is variable across LIS, ranging from 0.4 m in the east to 1.22 m in the west, which has a significant impact on the water depth suitable for eelgrass along a gradient from east to west in Long Island Sound (Koch 2001). For instance if the MLLW depth of a station is 5 m with a tidal amplitude of 0.5 m, the average depth experienced by eelgrass will be 5.5 m. The same MLLW depth in the western Sound with a tidal amplitude of 1.2 m would have an average depth of 6.2 m. The maximum suitable depth of 9.2 m for eelgrass can be modified to reflect the variability in

tidal amplitude across Long Island Sound. Mean tidal amplitude at seventy three tide recording stations were used to calculate a maximum depth of eelgrass at each tide recording station:

"Maximum Depth for Eelgrass" = 9.2 m – "Mean Tidal Amplitude"

The results were a unique *Maximum Depth for Eelgrass* at each tide station, which were subsequently interpolated to create a coverage for the complete study area (Figure 8).

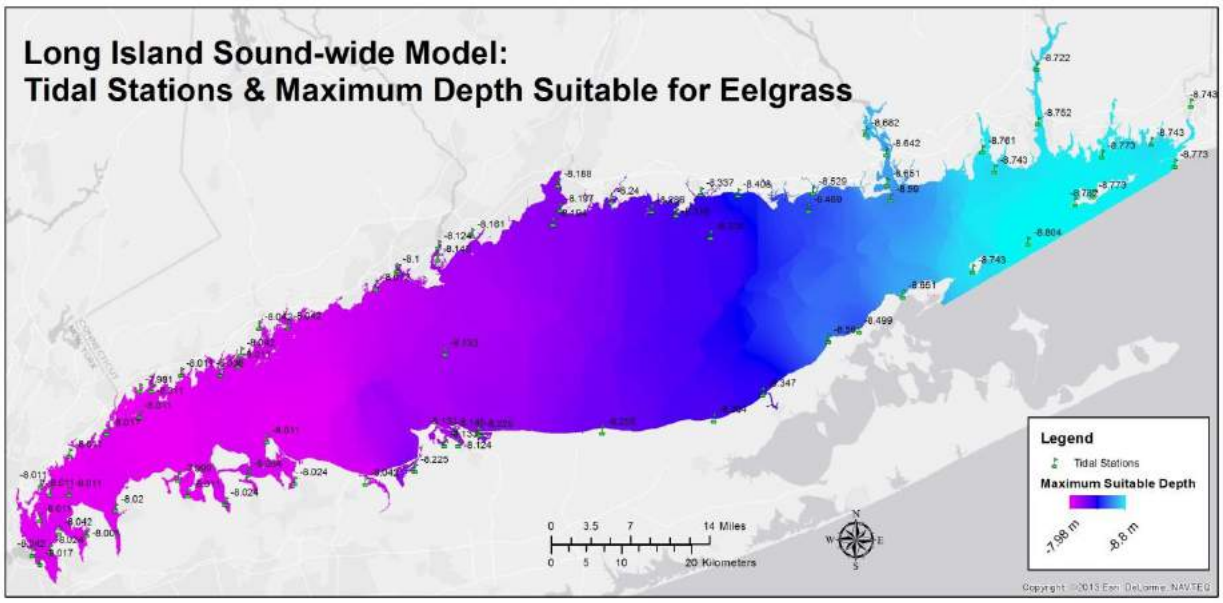


Figure 8: Tidal Stations and Maximum Depth for Eelgrass.
Seventy three tide stations yielding mean tidal amplitude were applied to map the predicted maximum depth. The maximum depth values at each tide station were interpolated to cover the entire study area.

The data generated for the maximum suitable depth for eelgrass (Figure 8) were used with bathymetry data (Figure 7) to identify those areas which are suitable for eelgrass by depth:

If "LIS Bathymetry" <= "Maximum Suitable Depth" then 1, else 0

This equation was applied in Raster Calculator; all cells that were true were returned with a cell value of 1, while all cells that were false were returned with a value of 0. The following two examples illustrate how decisions were made in the program:

- 5.3 <= 8.7: True or 1, as the depth at this location is 5.3 m and the maximum allowable depth for inclusion in the exclusive analysis at that location is 8.7 m
- 48 <= 8.9: False or 0, as the depth at this location is 48 m and the maximum allowable depth for inclusion in the exclusive analysis at this location is 8.9 m.

Figure 9 represents the areas of LIS which were returned as "True" to maximum suitable depth for eelgrass.

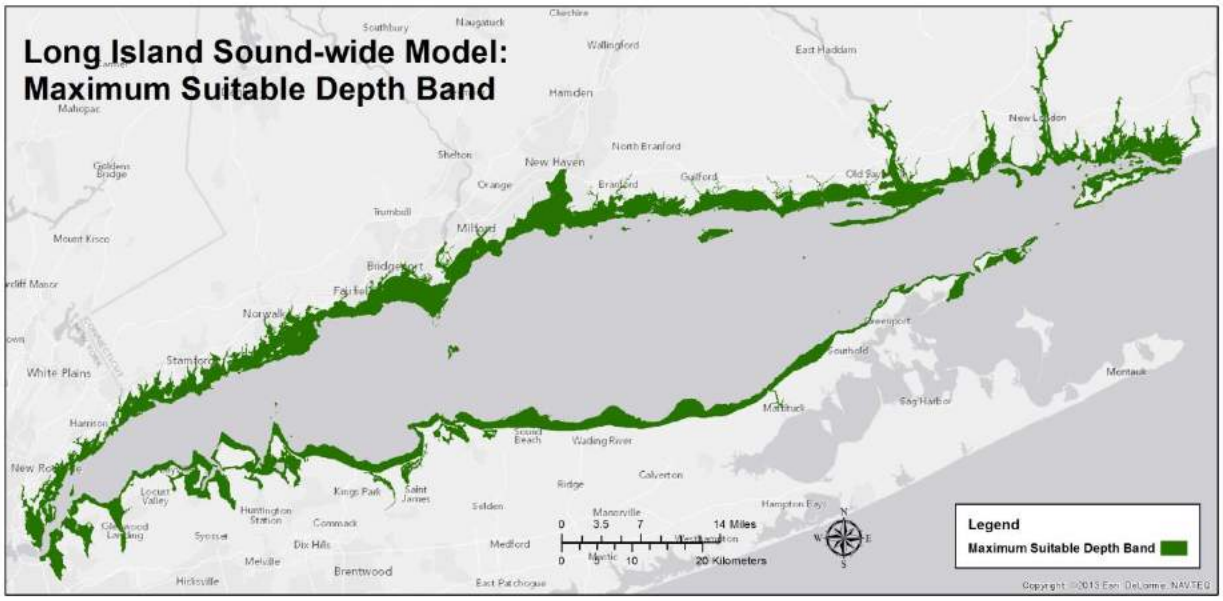


Figure 9: Suitable Depth Band.
The suitable depth for eelgrass was calculated from the maximum suitable depth (Figure 8) throughout LIS and the Bathymetry Model (Figure 7).

Lastly, areas with % light reaching the bottom of less than 2% are highly unlikely to see improvement that is significant enough to sustain eelgrass in even the distant future. The % light reaching the bottom was estimated for the entire study area from water column light data (photosynthetically active radiation) collected by CT DEEP at stations in Long Island Sound. Only data from June through September during 2009 through 2011 were used as they cover the bulk of the growing season of eelgrass and were months with data at most stations, and the period form 2009 - 2011 represent current conditions in the Sound. The light attenuation coefficient (Kd) was calculated from light profiles and interpolated using the Inverse Distance Weighted tool in ArcGIS. These values were applied with the bathymetry model values within each grid cell of 30.48 m x 30.48 m in the following equation:

$$\textbf{Percent Light Reaching the Bottom} = 100 * e^{(-Kd * z)} \qquad \textbf{Equation 1}$$

where "z" is the depth of the water column and Kd is the light attenuation coefficient (m^{-1}) (Figure 10). Within the suitable depth band (Figure 9), any areas with % light reaching the bottom <= 2% were eliminated.

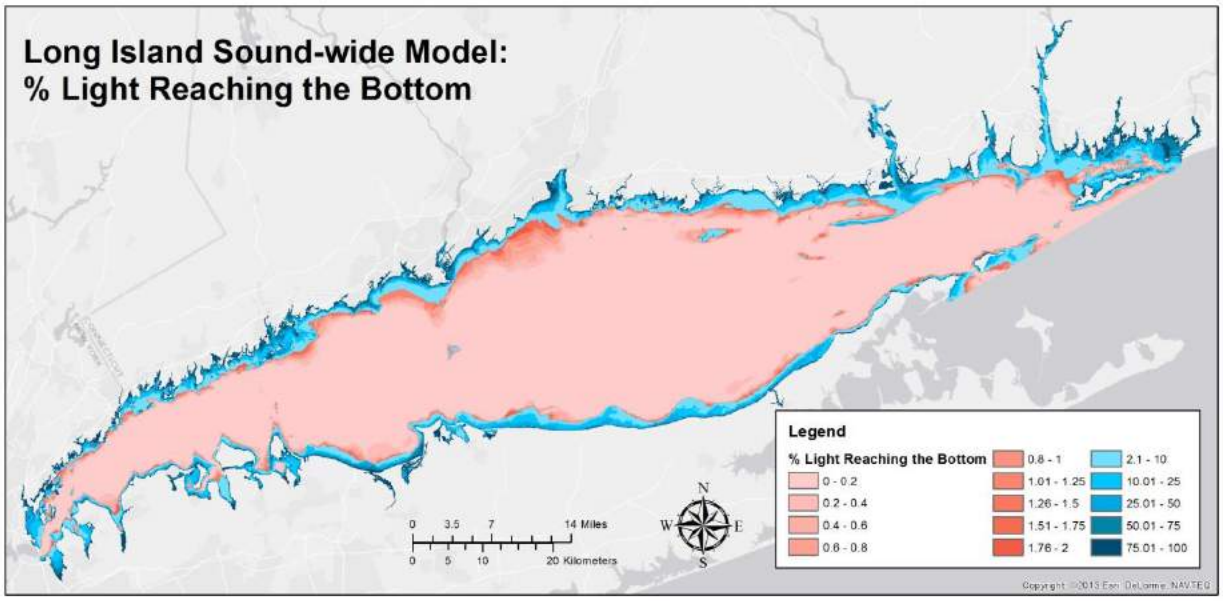


Figure 10: Percent Light Reaching the Bottom Interpolated Surface Raster.
The combination of Kd and depth were used to calculate the values of Percent Light Reaching the Bottom throughout the study area.

6.3.3 Defining the Shallow Edge of the Exclusive Band

Ideally, areas which are too shallow would also have been excluded from the computational model domain. The shallow limit of eelgrass in Long Island Sound has been identified as equivalent to the mean tide level minus half the mean tidal range (Koch 2001). For example, in areas with a 1 m tidal range (equivalent to a 0.5 m tidal amplitude), the minimum depth will be 0.5 m below mean tide level. In other words, eelgrass in LIS must be submerged at all times, we do not find intertidal eelgrass in LIS. The lack of bathymetry data in shallow areas precluded the inclusion of this shallow limit when evaluating areas for eelgrass habitat suitability. The model domain extends to the shoreline even though it is recognized there will be a strip of area which is too shallow for eelgrass.

The estimates of maximum suitable depth presented in Figure 8 include an estimate of the tidal range along the shoreline of LIS as determined from 73 tidal stations. The tidal amplitude (which is the difference between mean sea level and tidal low water) is equivalent to the shallow depth limit for eelgrass in LIS. The color scale in Figure 6 can be adjusted to provide an estimate of the shallow edge of the exclusive band by using a value of 0.4 m in the east (lightest blue) to 1.22m in the west (lightest pink). The inability to apply this shallow edge to the exclusive band stems from the lack of accurate bathymetry data in these shallow areas.

An additional factor affecting the shallow limit for eelgrass survival is the effect of storm scour and wind-induced turbulence in shallow areas. The tidal amplitude provides the first best guess of the shallow water limit, but the effect of fetch and dominant wind direction may drive this shallow edge limit deeper. An example of this effect on the shallow limit of eelgrass is presented for one of the case study sites, St. Thomas Point (Section 7.8, page 143). The shallow water limit based on tidal amplitude at St.

Thomas Point should be 0.55 m. Based on local knowledge of eelgrass survival following storm events and winter weather and anecdotal observations of the dynamics of sediment transport at St. Thomas Point, the predicted shallow limit of eelgrass is 2 m (Section 7.8, page 143).

Additional bathymetry data for shallow areas and inclusion of a model predicting wave stress on the bottom would increase the predictive power of the model in shallow waters. Unfortunately, due to circumstances beyond our control, inclusion of wave exposure data, as originally planned for this study, was not possible given that Dr. Mark Fonseca, one of the original project participants lost his GIS technician and then retired from NOAA himself during the project and as a result could not run this analysis for the study area.

6.3.4 Final Results of Exclusive Analysis

The exclusive band includes area of suitable depth and light environment for eelgrass throughout Long Island Sound (Figure 11). The exclusive band predicts that 651.8 km^2 of Long Island Sound is within the depth range appropriate for eelgrass. This band constitutes the area in which the model was run.

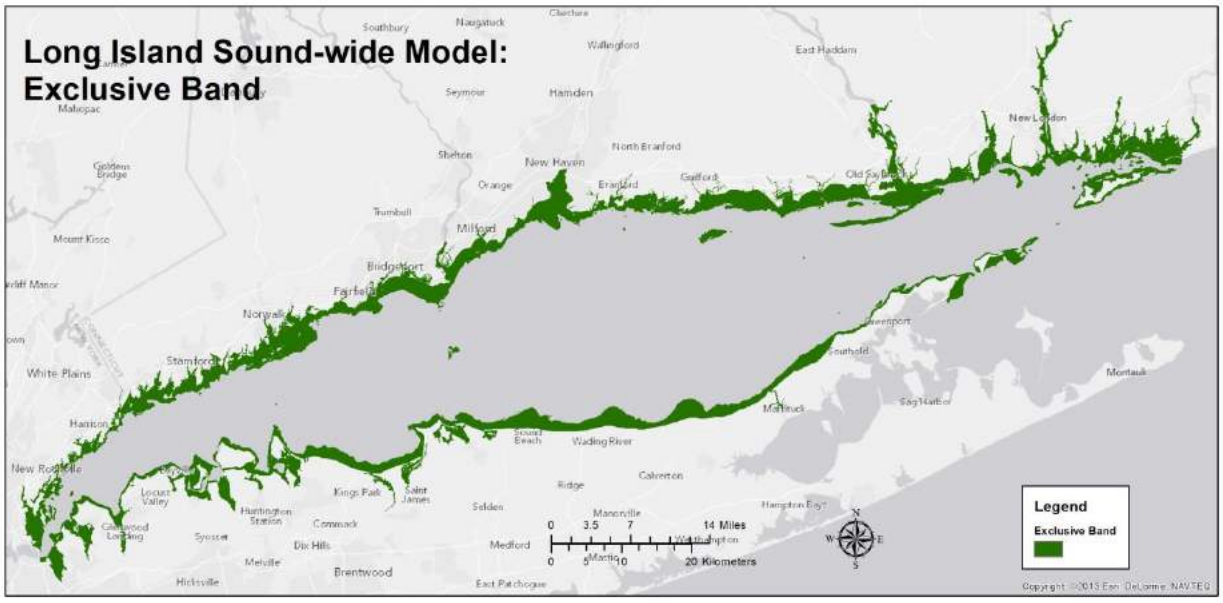


Figure 11: Exclusive Band.
The Exclusive Band was generated from a combination of water depth, mean tidal amplitude, and % Light Reaching the Bottom. The resulting area is theoretically suitable for eelgrass if all other parameters are optimal.

6.4 Ranking Analysis

6.4.1 Overview

A number of parameters were identified as having an impact on the habitat suitability of an area for eelgrass. A review of habitat criteria for eelgrass in Long Island Sound is provided in Vaudrey (2008a)

and presented in Section 7.3 (page 72) as part of the discussion of field data. Chris Pickerell and his team of restoration specialists at CCE-SC have also developed criteria for evaluating Long Island Sound sites for suitability for restoration efforts (Table 3). It should be mentioned that conditions necessary for planting/restoration of eelgrass typically need to exceed those required to sustain eelgrass. In other words, just because an area currently supports grass does not necessarily mean that it is ideal for restoration. In some cases the natural meadow could be in decline although the signs may not be immediately evident. In addition, it should be noted that large natural meadows have an inherent stability and ability to withstand at least short term stresses whereas even the largest scale restoration planting has very little ability to withstand stress of any kind.

Table 3: Site Selection Criteria Used by Cornell Cooperative Extension of Suffolk County
Criteria are based on experience of typical values within successful restoration sites.

		CRITERIA FOR SELECTING RESTORATION SITES		
	Parameters (General)	**Optimal**	**Minimum**	**Maximum**
water column	Light (Kd)	<0.46	N/A	0.75
	Total Nitrogen	<0.029mg/L	N/A	0.05mg/L
	Total Phosphorous	<0.071mg/L	N/A	0.08mg/L
sediment	Sediment Grain Size	<2% silt & clay	N/A	15% silt & clay
	Sediment % Organics	<0.5%	N/A	2%
	Sediment Sulfide Concentration			
physical forcing	Peak Water Temperature	<21C	N/A	24 C
	Wind Exposure/Fetch	Complete protection from NW winds	Some protection from seasonal winds	N/A
	Current Velocity			
community	Bioturbation	None	N/A	1 spp. of concern max
	Attached Macroalgae	Multiple species- *Laminaria* preferred	1 species	Seasonal
	Drift Macroalgae	None	N/A	N/A
	Beneficial Grazers	Presence of at least 1 of the following species: *Lacuna vincta, Illyanassa obsoleta, Bittium alternatum, Littorina littorina, Mitrella lunata, Polychoerus caudatus, Idotea balthica, Elisia catulus*		
	Species of Concern/Bioturbators	Significant presence of any of these spp. may exclude this site from consideration: Libinia spp., Carcinus maenas, Cancer irroratus, Cygnus olor, Branta canadensis		
physical environment	Presence of Rocks	1-3/m^2	1/m^2	N/A
	Hardened shoreline	none	N/A	Within 15 meters
	Shellfishing activity	None		
	Shellfishing closure areas	Prefer sites that are permanently closed to shellfishing		
	Boating/Mooring/Marina areas	Any marinas, mooring fields or other active boating areas will be excluded from consideration		
history	Historical eelgrass presence	Within 100m of an historical eelgrass bed		

Once the list of desired criteria was developed, sources of data which covered the entire area of Long Island Sound were found. In all, eleven parameters were evaluated Sound-wide (Table 4). Each parameter had a range based on known eelgrass criteria. Outside of this range, the parameter was

considered completely supportive of eelgrass or completely detrimental to eelgrass, depending on whether the value was above or below the listed range. These ranges are defined in the following section, though the sources of literature values for determining the ranges are provided in Table 4.

All the parameter data were received as point values at select sampling locations throughout LIS (see figures in Section 6.4.2, page 37 for locations of stations). These data were interpolated between stations to cover the entire study area. Due to the sparseness of data, the model grid cell size for the LIS-wide domain was set to 30.48 m x 30.48 m for all processing. Each grid cell in the model domain contained a calculated value.

Although water quality data were collected by CT DEEP across a larger period of time, only data from 2009 through 2011 were selected for the study. The effect of new policies and advancements in the reduction of point source pollutants has improved the overall water clarity and water quality of LIS over the last decade. Inclusion of data prior to 2009 would have a negative influence on the results. A longer time period of data collection was used for sediment related parameters because it is believed that sediment characteristics have not significantly changed.

Table 4: Eleven Original Parameters.
Eleven parameters with data coverage for the entire study area were reviewed. Only the first five parameters in the table were selected for the final ranking analysis. The sources of the ranges were largely determined by a review of LIS habitat criteria for eelgrass conducted by Vaudrey (2008), which refers to the many sources of data used for establishing these criteria. For this project, data from additional sources were used to add to Vaudrey's review.

Parameter	**Summary**	**Time Period for Included Data**	**Data Source / Source for Ranges**
Percent Light Reaching the Bottom (%)	Being a benthic plant, % Light Reaching the Bottom is important to the high light requirement of eelgrass for photosynthesis	Growing Season (March thru September), 2009-2011	data: CT DEEP ranges: Vaudrey (2008)
Temperature (˚C)	Surface temperature from stations in deeper water was assumed to represent shallow regions of the exclusive band	July and August, 2009-2011	data: CT DEEP ranges: Lee et al. (2007)
Dissolved Oxygen (mg/L)	Eelgrass requires sufficient oxygen in the water column. Sufficient oxygen decreases the levels of reduced compounds which can be toxic to eelgrass plants (e.g. hydrogen sulfide, ammonium)	July and August, 2009-2011	data: CT DEEP ranges: Holmer and Bondgaard (2001), Wazniak et al. (2007)
Sediment Grain Size (% silt & clay)	Sandy and gravel bottoms are easier for eelgrass to attach	1964-2010	data: Woods Hole Oceanographic Institute ranges: Vaudrey (2008)

Parameter	Summary	Time Period for Included Data	Data Source / Source for Ranges
Sediment Total Organic Carbon (%)	High organic carbon in the sediment is unsuitable for eelgrass.	1974-1997	data: Long Island Sound Resource Center ranges: Vaudrey (2008)
Chlorophyll *a* (ug/L)	Representation of green algae in the water column during the growing. Absorbs red and blue wavelengths before it can be captured by eelgrass	Growing Season (March thru September), 2009-2011	data: CT DEEP ranges: Vaudrey (2008), Wazniak et al. (2007)
Total Suspended Solids (mg/L)	High levels of suspended solids in the water column can shade eelgrass, reducing the light required for photosynthesis	2009-2011	data: CT DEEP ranges: Vaudrey (2008)
pH	Acidic environments are unsuitable for eelgrass survival	2009-2011	data: CT DEEP ranges: van der Heide et al. (2008)
Salinity (ppt)	Freshwater is unsuitable for eelgrass survival	2009-2011	data: CT DEEP ranges: Duarte (2002), Touchette (2007)
Total Dissolved Nitrogen (mg/L)	High nitrogen loading into the water body can result in algal blooms and be detrimental to eelgrass	2009-2011	data: CT DEEP ranges: adapted from Wazniak et al. (2007) using a LIS specific ratio for TDN:TN
Total Dissolved Phosphorous (mg/L)	Ranges are based on annual averages (Wazniak et al., 2007)	2009-2011	data: CT DEEP ranges: adapted from Wazniak et al. (2007) using a LIS specific ratio for TDP:TP

6.4.2 Interpolation and Initial Reclassification of Data

All parameters presented in Table 4 were imported into *ArcGIS v10.0* and the point data were interpolated to cover the whole of Long Island Sound (see figures in this section for locations of stations, sources of data are provided in Table 4). Interpolation tools were assessed and Inverse Distance Weighting (IDW) was considered the most suitable for the Sound-wide analysis. IDW is a weighted distance average and as such, the generated values must be within the range of values at each location. Additionally, IDW maintains barriers around land masses and incorporates a set number of point values with respect to distance in the calculation process, excluding points that are further away (see http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#/IDW/00q90000001s000000/ for further information about IDW and the interpolation process). Once imported to *ArcGIS*, all parameters were interpolated with the IDW tool, estimating each parameter's values in each grid cell throughout the study area.

The resulting interpolated parameter values in each grid cell were weighted equally relative to each other and a ranking of 0 to 10 over the selected range was applied (Table 5). The selected ranges were based on values obtained from the literature on eelgrass habitat requirements (Table 4). This process of transforming a parameter value to a model score is termed **reclassification**.

Table 5: Scoring Criteria for Environmental Parameters.
This table shows the scoring range for each parameter and the range of each interval between scores 0 and 10. Cells labeled "n/a" for Salinity indicate that the low and high values are the same.

Parameter	0	1	2	3	4	5	6	7	8	9	10
Percent Light Reaching the Bottom (%)	< 46.0	46.1 to 47.0	47.1 to 48.0	48.1 to 49.0	49.1 to 50.0	50.1 to 51.0	51.1 to 52.0	52.1 to 53.0	53.1 to 54.0	54.1 to 55.0	> 55.0
Temperature (˚C)	> 25.0	24.6 to 25.0	24.1 to 24.5	23.7 to 24.0	23.2 to 23.6	22.8 to 23.1	22.3 to 22.7	21.9 to 22.2	21.4 to 21.8	21.0 to 21.3	< 21.0
Dissolved Oxygen (mg/L)	< 3.0	3.0 to 3.3	3.31 to 3.70	3.71 to 4.00	4.01 to 4.30	4.31 to 4.70	4.71 to 5.00	5.01 to 5.30	5.31 to 5.70	5.71 to 6.00	> 6.00
Sediment Grain Size (% silt & clay)	> 20.0	18.1 to 20.0	16.1 to 18.0	14.1 to 16.0	12.1 to 14.0	10.1 to 12.0	8.1 to 10.0	6.1 to 8.0	4.1 to 6.0	2.1 to 4.0	< 2.1
Sediment Total Organic Carbon (%)	> 10.00	9.00 to 10.00	7.90 to 8.99	6.80 to 7.89	5.80 to 6.79	4.70 to 5.79	3.70 to 4.69	2.60 to 3.69	1.60 to 2.59	0.50 to 1.59	< 0.50
Chlorophyll *a* (ug/L)	> 15.0	13.9 to 15.0	12.8 to 13.8	11.7 to 12.7	10.6 to 11.6	9.4 to 10.5	8.3 to 9.3	7.2 to 8.2	6.1 to 7.1	5.0 to 6.0	< 5.0
Total Suspended Solids (mg/L)	> 30.0	26.8 to 30.0	23.4 to 26.7	20.1 to 23.3	16.8 to 20.0	13.4 to 16.7	10.1 to 13.3	6.8 to 10.0	3.4 to 6.7	0.1 to 3.3	0.0
pH	> 9.000	8.980 to 9.000	8.957 to 8.979	8.934 to 8.956	8.911 to 8.933	8.889 to 8.910	8.867 to 8.888	8.845 to 8.866	8.823 to 8.844	8.801 to 8.822	< 8.801

Parameter	0	1	2	3	4	5	6	7	8	9	10
Salinity (ppt)	< 10	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	>= 10
Total Dissolved Nitrogen (mg/L)	> 0.470	0.463 to 0.470	0.458 to 0.463	0.451 to 0.457	0.444 to 0.450	0.438 to 0.443	0.431 to 0.437	0.425 to 0.430	0.418 to 0.424	0.410 to 0.417	< 0.410
Total Dissolved Phosphorus (mg/L)	> 0.080	0.075 to 0.080	0.070 to 0.074	0.064 to 0.069	0.059 to 0.063	0.053 to 0.058	0.048 to 0.052	0.042 to 0.047	0.037 to 0.041	0.030 to 0.036	< 0.030

6.4.3 SELECTION OF PARAMETERS FOR INCLUSION IN THE EHSI MODEL

Several parameters were evaluated and found to be insensitive because all values were adequate for eelgrass site suitability. Thus, inclusion of these parameters would contribute no variability to the model score across the LIS area. These parameters included pH, salinity, TDN, and TDP. When choosing which to exclude, future changes in these parameters were considered. Salinity and pH are unlikely to change to such an extent that eelgrass will be affected. TDN and TDP did show some variability across the Sound, but were generally low enough that they were unlikely to have an effect on eelgrass. With projected reductions in nutrient input, these values are predicted to become even lower. The field data collected in the case study sites supported the *a priori* choice to exclude these parameters (see Section 7.3, page 72).

Chlorophyll *a* concentrations and total suspended solids are often used as proxies for the light attenuation coefficient (Kd) when light data are unavailable. High quality light data were available from the CT DEEP cruises, so these parameters were not included in the model because the percent of light reaching the bottom inherently includes the effect of phytoplankton and total suspended solids in the water column.

Five parameters relating to water quality and sediment characteristics were identified as critical for inclusion in the model and yielded variability within a range where eelgrass is sensitive to changes in the parameter (Table 6): percent light reaching the bottom, temperature, dissolved oxygen, sediment grain size (% silt and clay), and sediment organic content (Figures 12 - 16).

The eastern Sound had considerably less data for temperature and dissolved oxygen, as the CT DEEP surveys decrease the density of stations in this area which is not as susceptible to hypoxia. The interpolations into shallow areas based on fewer stations was evaluated by comparing interpolated data to the data collected as part of this study (see Section 7.3, page 72).

Table 6: Ranking Analysis Selected Parameters.
These five parameters were applied to the ranking analysis within the exclusive band.

Parameter	**Summary**	**Source**
Percent Light Reaching the Bottom (%)	Kd measures light in the water column, the % Light Reaching the Bottom is a measures to the benthic eelgrass. Kd value calculation: *% Light = e^(Kd*Depth)* Where 'e' is the base of natural logarithm	CT DEEP, June through September for 2009-2011
Temperature (^{o}C)	Temperatures in the water column may exceed the thermal tolerance for eelgrass and result in reduction of photosynthesis and growth rates or lead to death.	CT DEEP, July and August for 2009-2011
Dissolved Oxygen (mg/L)	Eelgrass requires sufficient oxygen in the water column. Sufficient oxygen reduces the levels of reduced compounds which can be toxic to eelgrass plants (e.g. hydrogen sulfide, ammonium). The lowest values are during July and August.	CT DEEP, July and August for 2009-2011
Sediment Grain Size (% silt and clay)	The type of sediment can impact the survival of benthic flora and influence the success of a species that attempts to root in this sediment	Woods Hole Oceanographic Institute, 1964-2010
Sediment Total Organic Carbon (%)	Existing eelgrass beds have relatively organic rich sediment due to settling and trapping of particles. Restoration of eelgrass indicates much lower organic content is preferred by beds in the process of establishment.	Long Island Sound Resource Center, 1974-1997

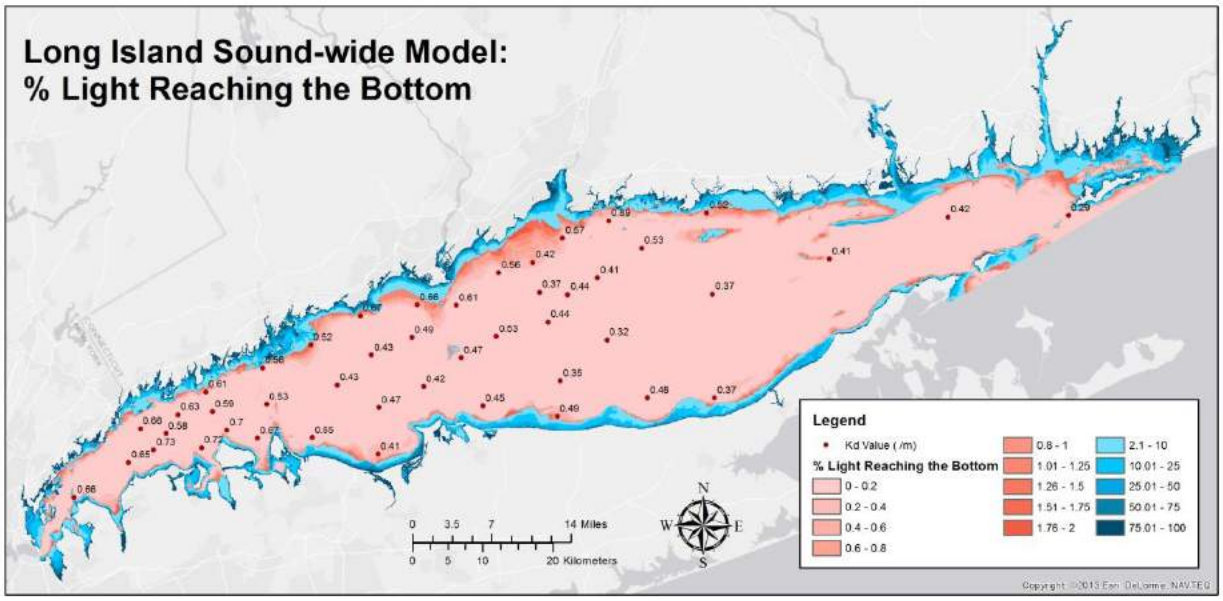


Figure 12: % Light Reaching the Bottom.
The combination of Kd and depth calculated the values of % Light Reaching the Bottom throughout the study area. The Kd data were collected at the CT DEEP stations shown in Figure 13. The bathymetry data were available at a much finer resolution.

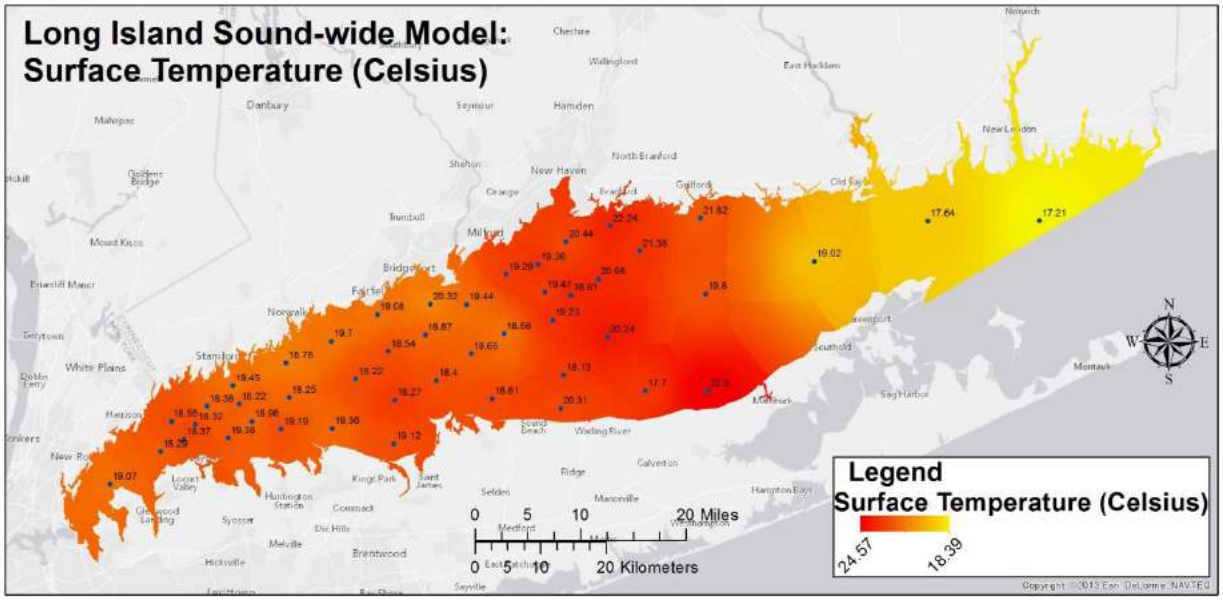


Figure 13: Surface Temperature, Interpolated.
Surface Temperature, 2-3 m below the surface, was averaged at each station and interpolated to cover the study area.

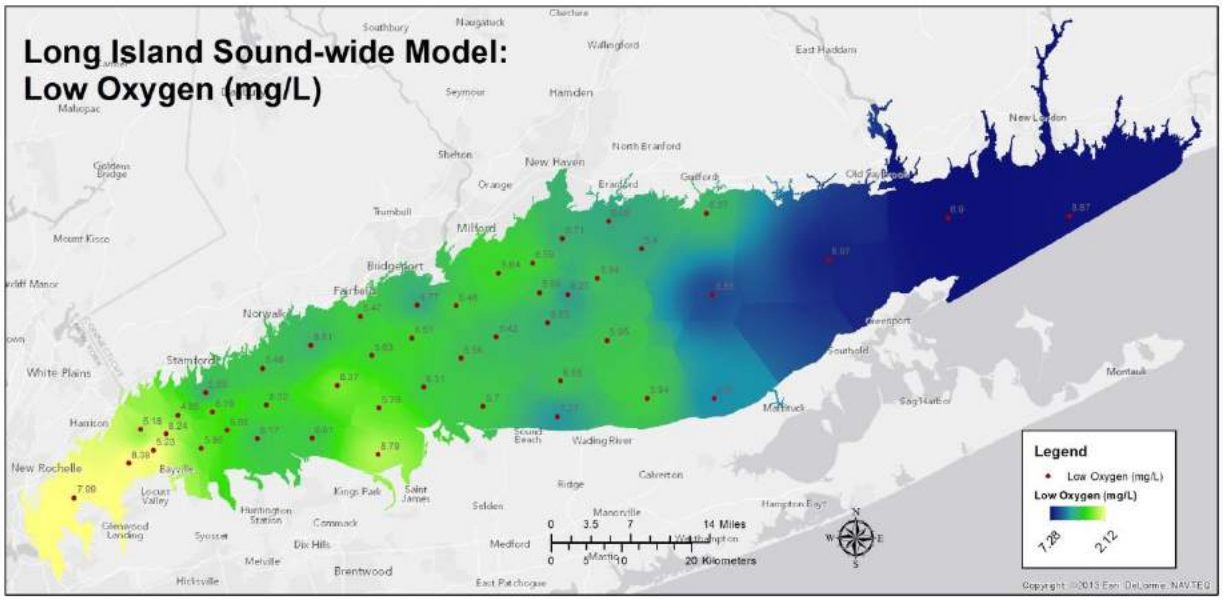


Figure 14: Low Oxygen, Interpolated.
Data from CT DEEP was interpolated to cover the entire study area.

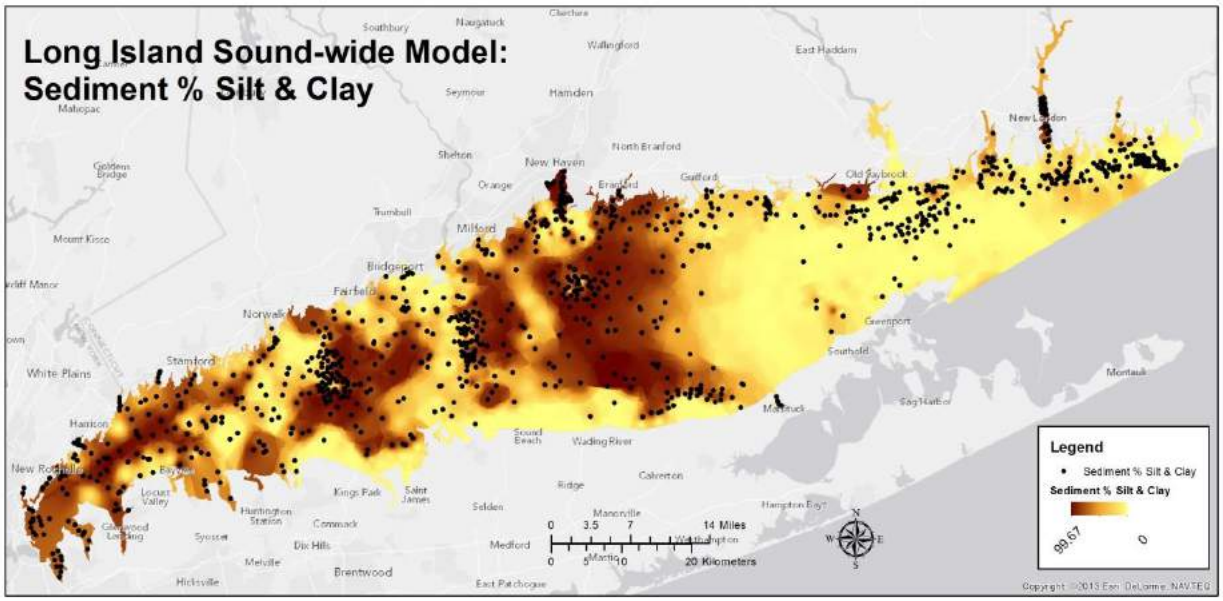


Figure 15: Sediment Grain Size, % Silt & Clay, Interpolated.
Data from WHOI was interpolated to cover the entire study area.

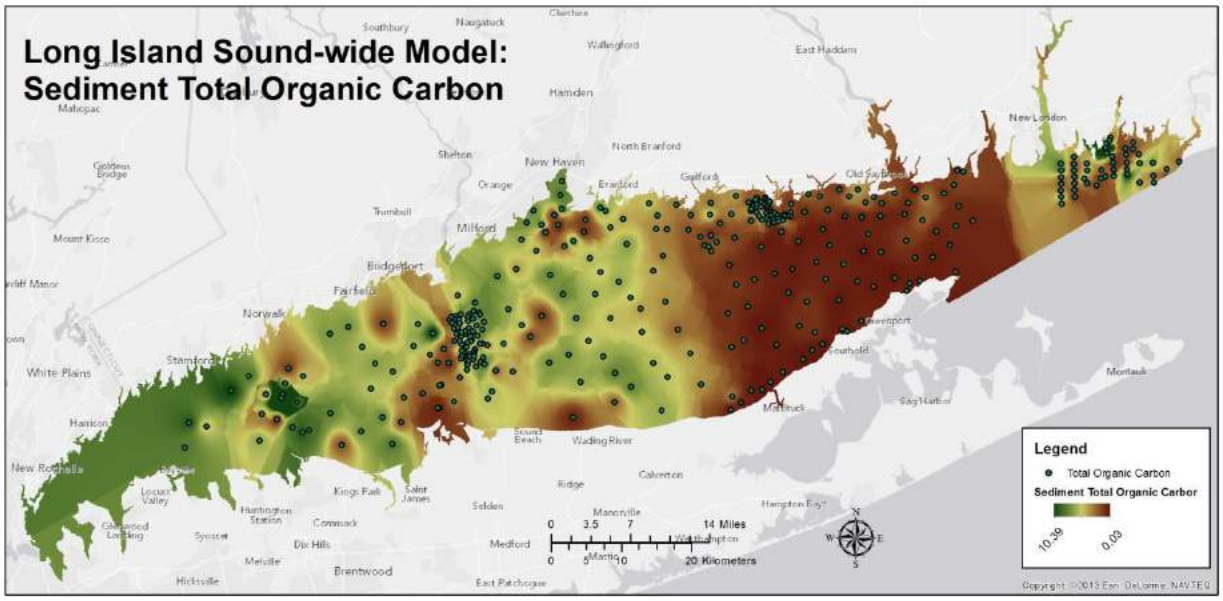


Figure 16: Sediment % Organic Content, Interpolated.
Data from Long Island Resource Center was interpolated to cover the entire study area.

6.4.4 RECLASSIFICATION OF PARAMETERS CHOSEN FOR THE EHSI MODEL

In order to incorporate the values of the five parameters into the model, each parameter was assigned a weight, the percent of the score (out of 100) which would be assigned to that parameter (Table 7). Within the defined range of values for a parameter (Table 8), the parameters received a proportion of the weighted score (e.g. an oxygen value of 4.5 would get a model score of 5 in the original weighting scheme). Outside of the range for a parameter, the score would be 0 or the full value of the weight (e.g. oxygen of 2 mg/L gets a model score of 0, oxygen of 8 mg/L gets a score of 10). This process of converting a parameters unit to a score is termed **reclassification**.

The weightings for the "original" model (Table 7) were based on expert opinion of the Principle Investigators as to what extent each factor was most likely to influence eelgrass distribution. Once the original model was developed, these weightings were adjusted through the calibration step and the model with the greatest likelihood of accurately predicting successful restoration sites was chosen. The results shown below for model output are from the "best model" which proved to be modification 3 (see Section 6.5 for a description of the calibration process).

Each parameter (Figures 12 - 16) was reclassified in *ArcGIS Model Builder*; the original unit was converted to a score. Maps of each reclassified parameter for modification 3 (Table 7) are provided in Figures 17 - 19.

Table 7: Calibration Scenarios

	original	modification 1	modification 2	modification 3	modification 4
Percent Light Reaching the Bottom	50%	20%	40%	30%	20%
Surface Temperature	20%	20%	30%	20%	10%
Low Dissolved Oxygen	10%	20%	10%	10%	10%
Sediment Grain Size, % Silt & Clay	10%	20%	10%	20%	30%
Sediment Total Organic Carbon	10%	20%	10%	20%	30%

Table 8: Weighted Rankings of Selected Parameters.
The weightings for the five parameters were selected.

Parameter	**Range**	**Weighted Score**	**Minimum (0)**	**Max Score**
Percent Light to Bottom	25-50%	0-30	<25%	>50% is 30
Surface Temperature	21-25°C	0-20	>25°C	<21°C is 20
Low Dissolved Oxygen	3-6 mg/L	0-10	<3 mg/L	>6 mg/L is 10
SedimentGrain Size, % Silt & Clay	2-20%	0-20	>20%	<2% is 20
Sediment Total Organic Carbon	0.5-10%	0-20	>10%	< 0.5% is 20
Sum Weighted Parameters		0-100		

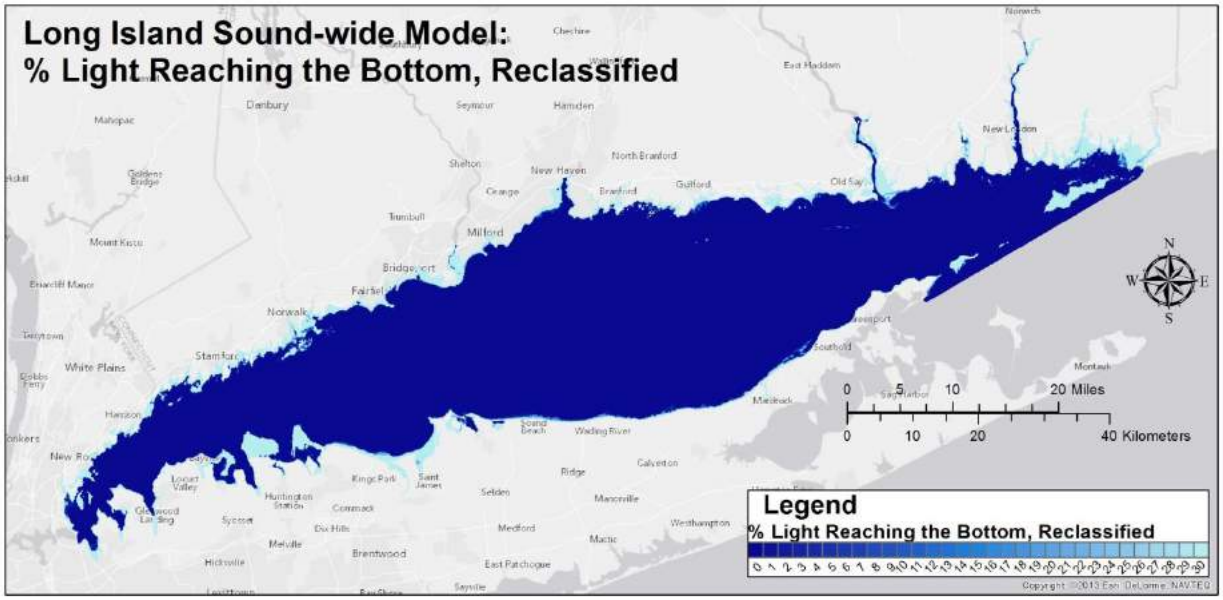


Figure 17: % Light Reaching the Bottom.
Percent Light Reaching the Bottom was reclassified to a maximum score of 30.

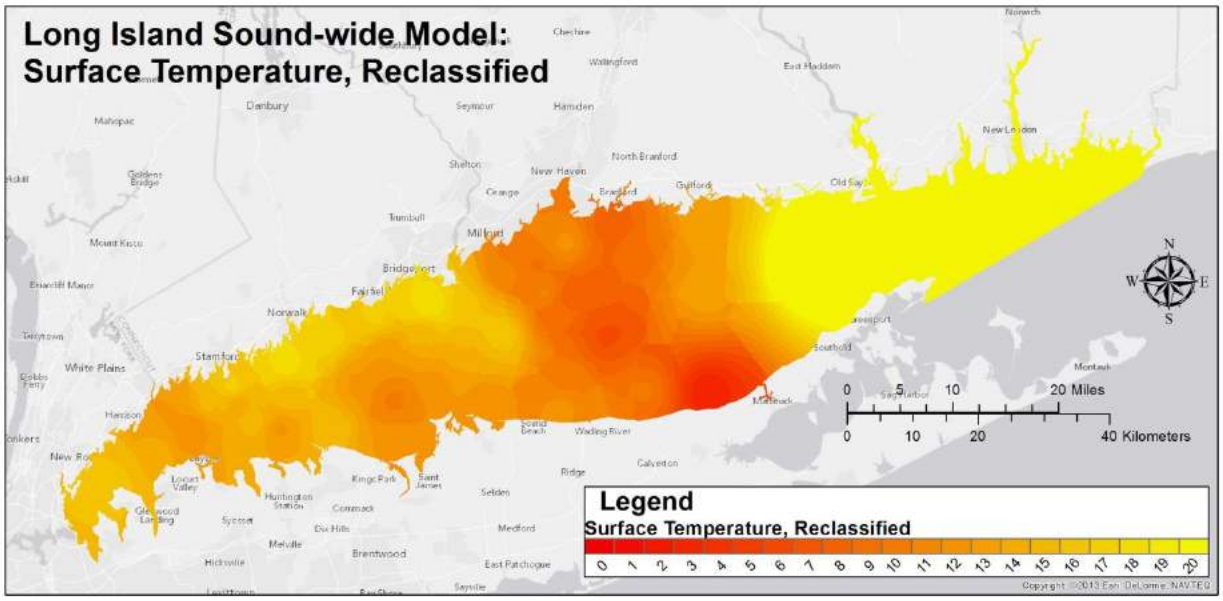


Figure 18: Surface Temperature, Reclassified.
Surface Temperature was reclassified to a maximum score of 20.

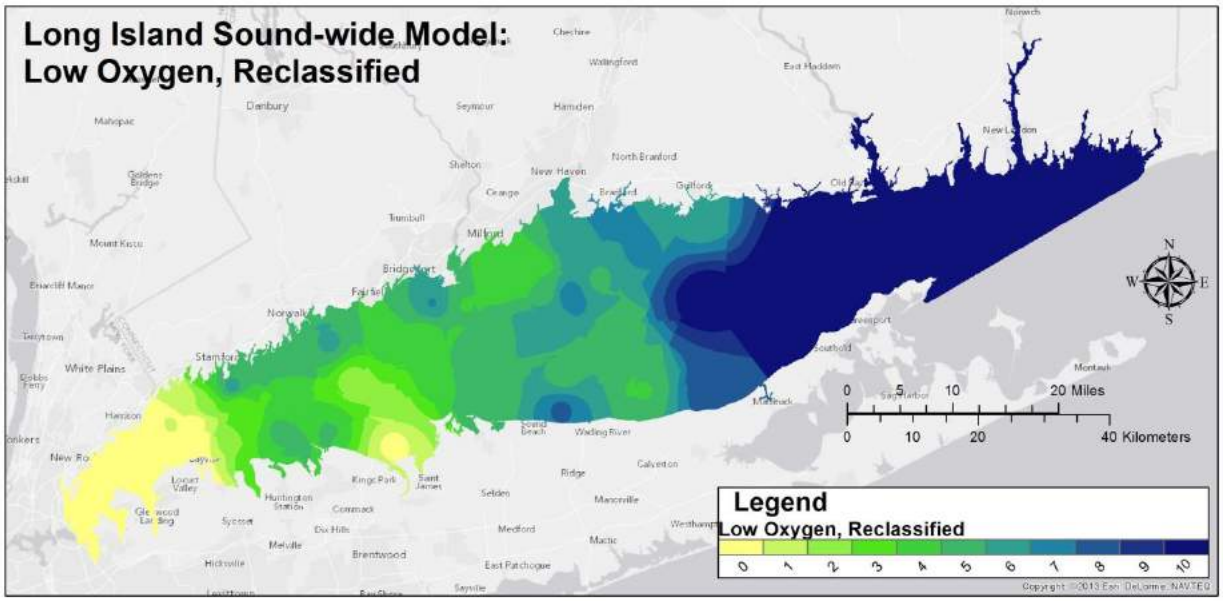


Figure 19: Low Oxygen, Reclassified.
Low Oxygen received a maximum score of 10.

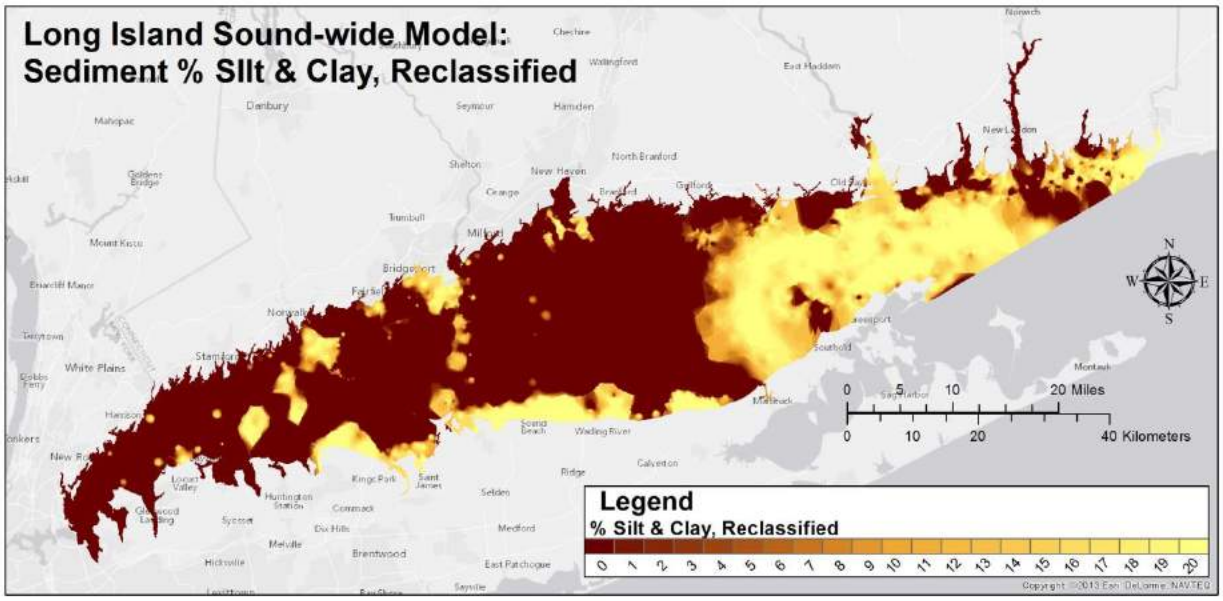


Figure 20: Sediment % Silt & Clay, Reclassified.

The characteristics of the bottom are important to eelgrass being able to grasp the bottom and not be pulled away by the strong tidal currents and wave action nearshore. % Silt and Clay received a maximum score of 20.

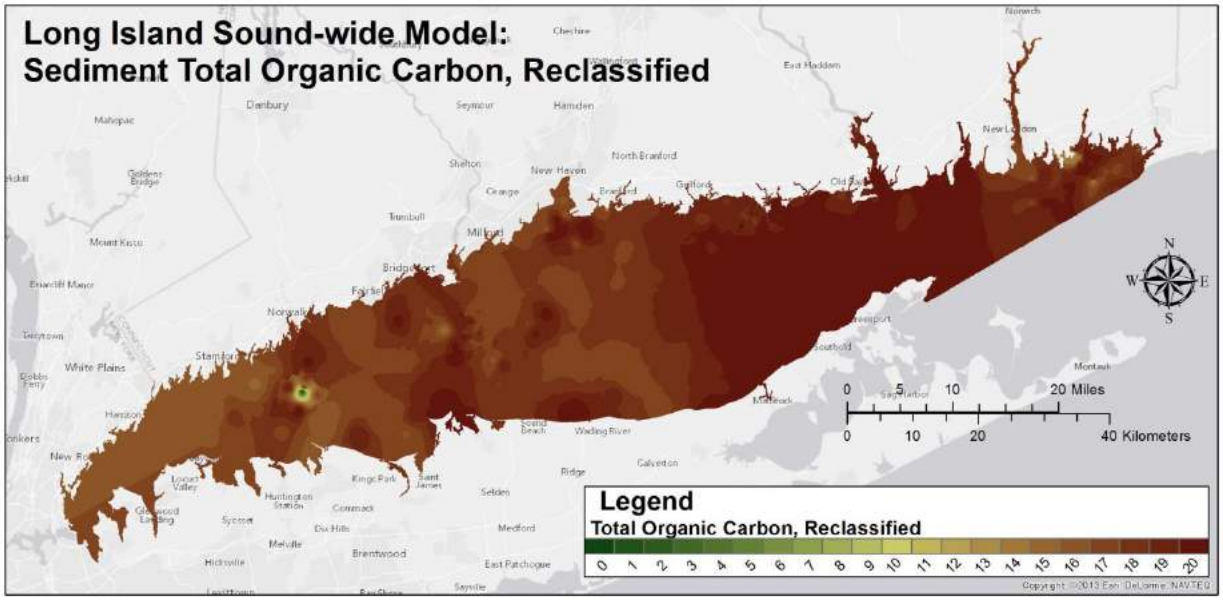


Figure 21: Sediment % Organic Content, Reclassified.

Sediment, % Organic Content received a maximum score of 20.

6.4.5 FINAL RESULTS OF EHSI MODEL

The results of the individual parameter weightings were summed in the *ArcGIS Raster Calculator* and the resulting raster was clipped within the exclusive band (Figure 22). The highest score of the sum of the weighted parameters reached 100, referring to the most ideal habitat for eelgrass survival. The lowest score returned from the sum of the weighted parameters was 28, referring to highly unfavorable areas for eelgrass. The regions with scores of 28 include some areas which received a model score of 0 for one or more of the parameters, for example, the sediment grain size as % silt and clay is unsuitable for eelgrass in many areas of LIS (Figure 20). Theoretically, these areas where one or more parameters appear unsuitable should receive model scores of zero. The model does not operate in this manner (setting the score to 0 if any one of the parameters has a model score of 0) for two distinct reasons which are addressed in the following paragraphs.

One use of the model is to examine what factors are *currently* limiting to eelgrass success in a particular area. For example, in the far western Sound, both grain size (Figure 20) and dissolved oxygen (Figure 19) are unsuitable for eelgrass. Applying a score of 28 to these areas indicates that some of the five parameters of interest appear suitable for eelgrass, allowing managers to identify what might be limiting in a particular area. While a first approximation at what factors may limit eelgrass success in an area can be achieved by examining Figures 17 - 19, the GIS model files allow a user to zoom into a particular area then toggle through the layers of model scores associated with each parameter to better evaluate which parameter is causing the impairment.

A second reason why model scores do not show a minimum of zero has to do with the application of the exclusive band (Section 6.3, page 29). In order to increase computational speed, any areas identified as unlikely to ever support eelgrass were eliminated from the computational model domain (Figure 11). All areas outside of the computational domain actually do have a model score of zero. The fact that the lowest model score is 28, versus something closer to 0, reflects that some parameters are generally conducive to eelgrass success in most of the computational model domain. Temperature (max of 20 points available) and organic content of the sediment (max of 20 points available) both receive high model scores for most of the model domain. The Percent Light to Bottom (max of 30 points available) is typically high in shallow areas and low in deeper areas. Grain size as % silt and clay (max of 20 points available) and dissolved oxygen (max of 10 points available) typically receive low model scores in the western half of Long Island Sound.

It is important to keep in mind that eelgrass can overcome poor conditions in one parameter if other conditions are suitable. So, if the sediment is fine with a large amount of organic matter, high light availability can overcome this impairment and support eelgrass growth. The ranges developed for eelgrass suitability employed in this model reflect the best understanding of what is required for *restoration work* in Long Island Sound.

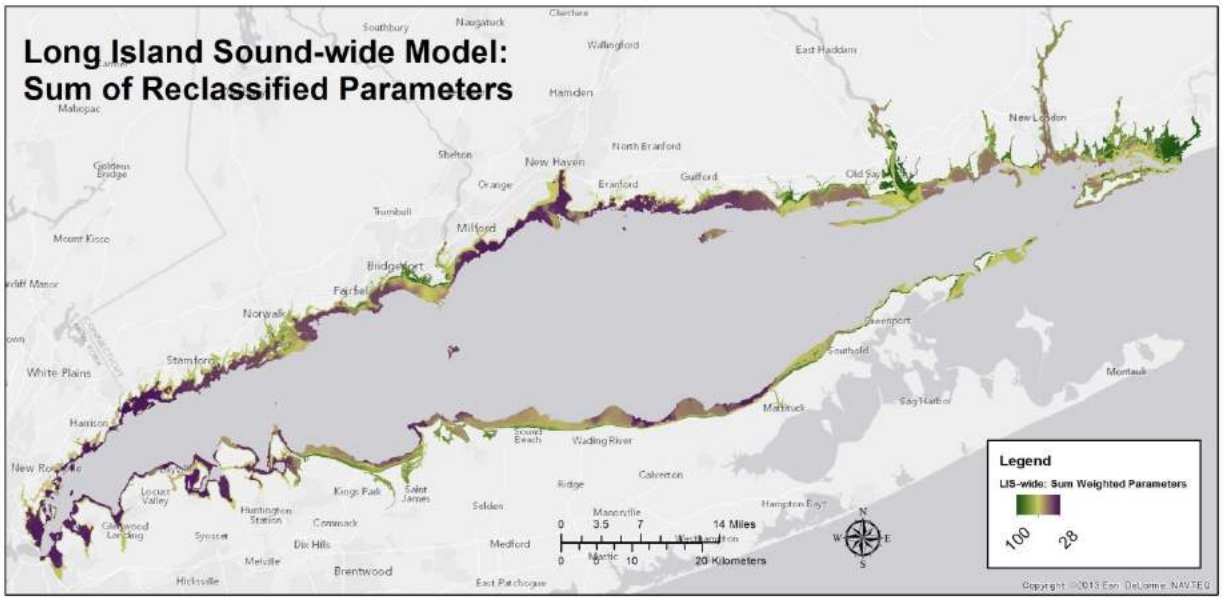


Figure 22: Sum of Ranked Parameters within the Exclusive Band.
The ranking results of the five selected parameters which were weighted and then summed to a maximum score of 100. A score of 100 is considered most ideal for eelgrass and 0 is least ideal. The lowest score within the exclusive band is 28.

6.5 Model Calibration and Skill Assessment

6.5.1 Determining Model Thresholds Indicative of Eelgrass Success

The EHSI Model output was assessed for threshold values of eelgrass site suitability by comparing the model output to areas with eelgrass. For these assessments, only data included in the aerial over flights conducted by the United States Fish and Wildlife Service (USFWS) are included in the assessment (Tiner et al. 2003, 2007, 2010). The 2012 aerial survey was not included in the skill summary because data were not released until late November 2013 (Tiner et al. 2013). This included all points in the model east of longitude -72.546355^{o}.

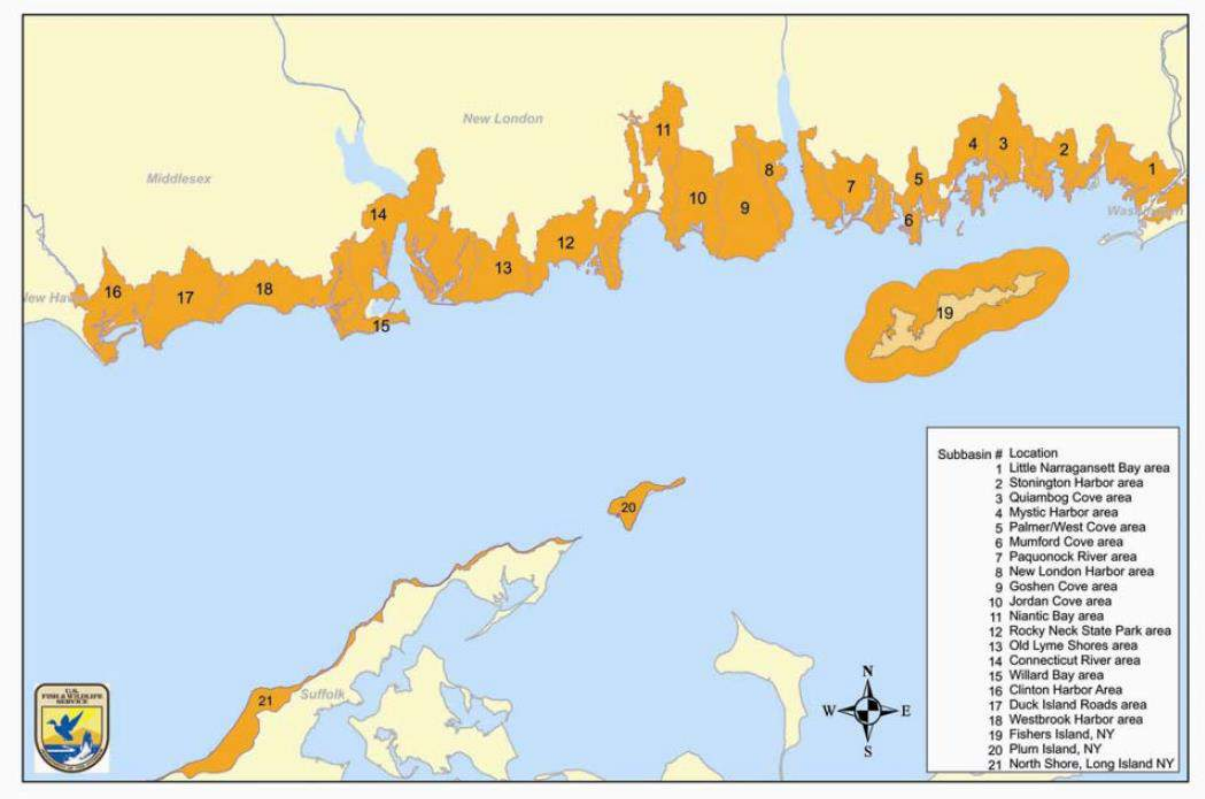


Figure 23: Area included in the aerial eelgrass surveys.
Surveys conducted by the USFWS in 2002, 2006, and 2009 (Tiner et al., 2003, 2007, 2010).

The model output ranges from 28 to 100, with 100 indicating that all model parameters were deemed optimal for eelgrass (Figure 22). An evaluation of only points with eelgrass indicates that model scores above 50 are more likely to have eelgrass than scores lower than this value (Figure 24). The grids with eelgrass and model scores less than 50 were often located along the deep edge of the existing beds (Figure 25).

CCE-SC has planted eelgrass at five restoration sites along the New York and Connecticut shoreline (CT: Little Narragansett Bay, Pine Island, Clinton Harbor; NY: St. Thomas Point, Duck Pond Point). Of the 724,244 grid points included in the model, only 44 of the grid points overlap a restoration planting site. Of the 44 grids, 21 were successful plantings, surviving more than one year. For all successful restoration sites, model scores were greater than 88 (n=44), though some sites with a score greater than 88 failed (n=15) (Figure 26).

This initial evaluation indicates that when choosing restoration sites, model scores should be greater than 88 in some portion of the restoration site, though values above 50 may also be supportive of eelgrass. It is important to note that mature eelgrass beds modify the environment and are more resilient to stressors due to their larger size and dense coverage. A restoration planting is typically conducted in areas considered very well suited to eelgrass because newly planted beds are more sensitive to stressors relative to established beds. This is reflected in the minimum score of 88 for restoration plantings and a minimum score of 50 for established beds. With regard to those sites where

the model score was high and the planting was still unsuccessful this can likely be explained by the influence of parameters such as extreme hydrodynamics (e.g., storm driven waves) or bioturbation (e.g., crab damage) that could not be included in this model given a lack of Sound wide data.

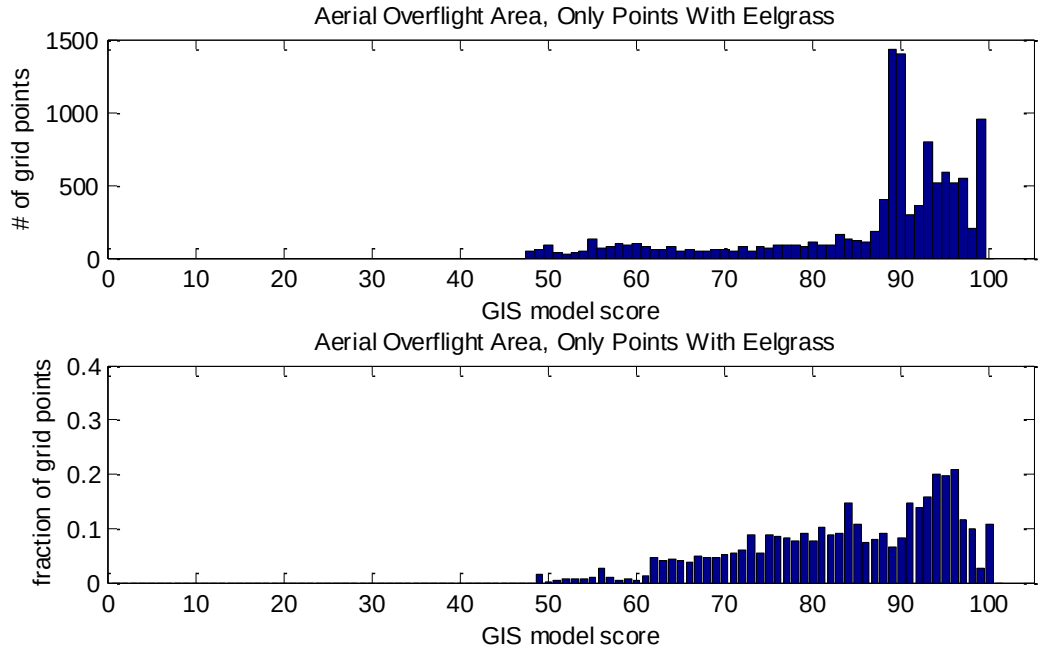


Figure 24: Model output for points with eelgrass, modification 3.
Only cells with eelgrass are included in this analysis. The upper panel is the total number of grid points binned by whole number model score. The lower panel is normalized to the total number of grid points with and without eelgrass occurring within that bin, yielding the fraction of grid points with eelgrass having the indicated model score.

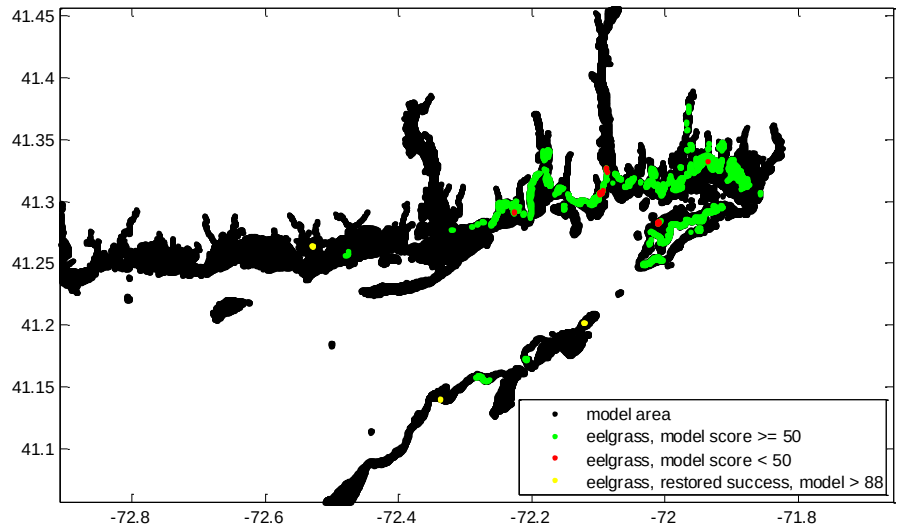


Figure 25: Evaluations of model scores for eelgrass areas, modification 3.
The model area is shown in black. Green points represent eelgrass areas with a model score >= 50. Red areas are model scores <50. The restored eelgrass areas all had model scores > 88.

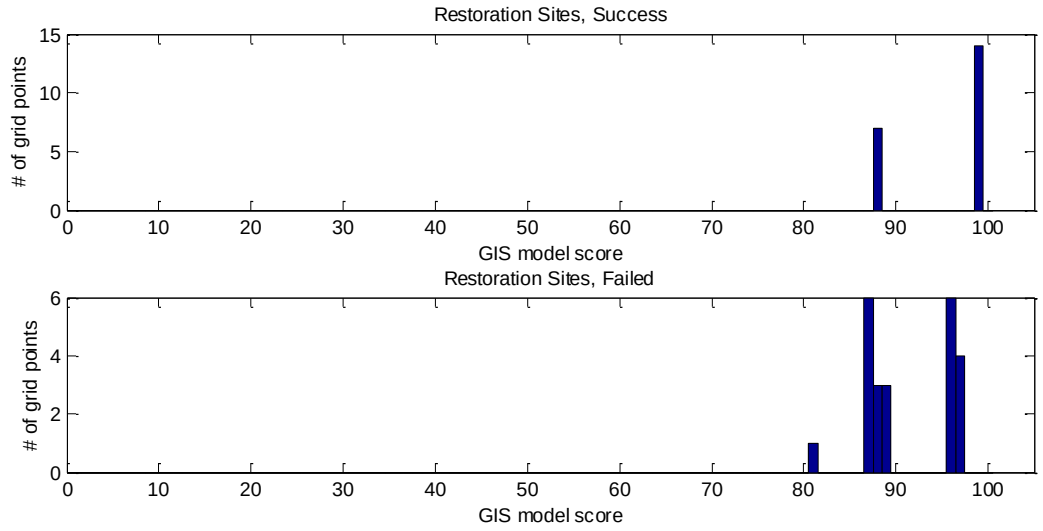


Figure 26: Evaluation of model scores for restoration sites.

6.5.2 MODEL CALIBRATION

The process of model calibration and determination of critical thresholds was an iterative process, though the end results of this process have been presented in the previous sections of this report. An initial "original" weighting scheme (Table 9) was applied to the five parameters and the model was completed, including all skill assessments. These weightings were determined based on expert opinion on what was most likely to influence eelgrass distribution in Long Island Sound. Once the model was complete, the weighting of the five parameters was modified to determine the weighting scheme which yielded the most accurate model output, i.e. the model was calibrated (Table 9).

Table 9: Calibration Scenarios

	original	modification 1	modification 2	modification 3	modification 4
percent light reaching the bottom	50%	20%	40%	30%	20%
surface temperature	20%	20%	30%	20%	10%
low dissolved oxygen	10%	20%	10%	10%	10%
sediment grain size	10%	20%	10%	20%	30%
sediment organic content	10%	20%	10%	20%	30%
for model score > 88, fraction of grids containing eelgrass	10.00%	8.83%	8.69%	10.56%	6.27%
for model score < 89, fraction of grids containing eelgrass	0.72%	1.14%	1.15%	0.54%	1.28%

Based on the results shown in Table 9, modification 3 provides a slightly better fit between model output and the field based maps of eelgrass presence. While the fraction of total grid cells with a model score > 88 containing eelgrass improved only slightly over the original weighting, an evaluation of model output indicates this improvement is sufficient to warrant choosing modification 3. The original weighting scheme (Table 9) yielded a large number of grid points containing eelgrass with scores lower than 50 (Figure 27, lower panel). While modification 3 yields only a slight increase in the fraction of total model grids within the calibration area which contain eelgrass (Table 9), the large number of grid points in the CT aerial over flight region with eelgrass and a score of < 50 under the original weighting scheme were eliminated (Figure 27, upper panel). They were eliminated because the deeper edges of the eelgrass beds which showed lower model scores under the original weighting scheme (Figure 28, lower panel) now have model scores higher than 50 under the final weighting scheme of modification 3 (Figure 28, upper panel).

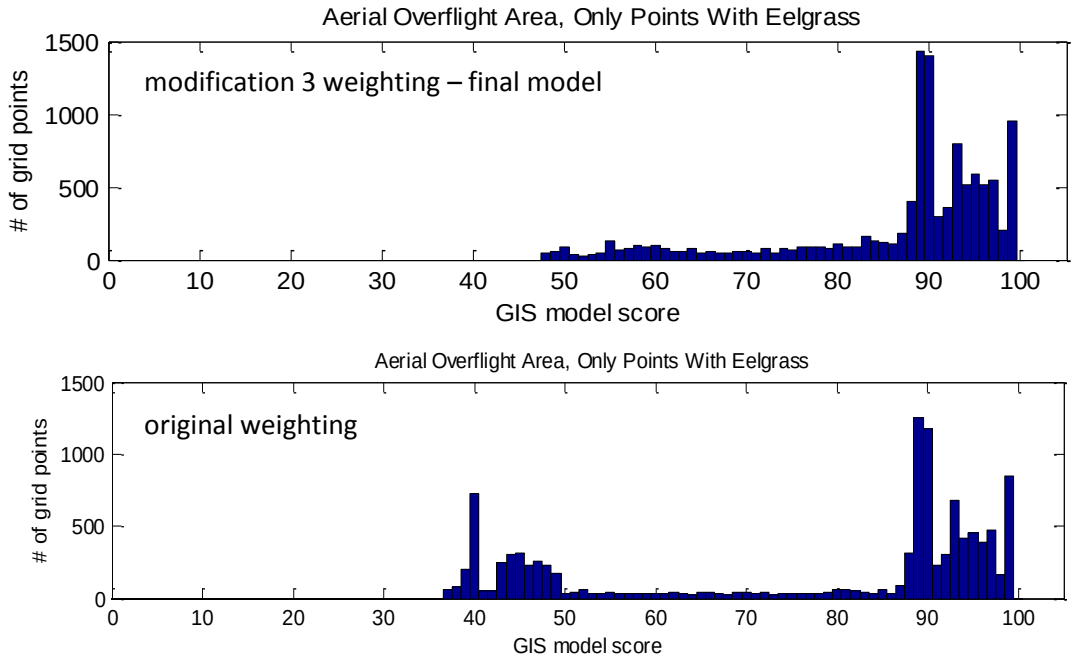


Figure 27: Model output for points with eelgrass.
Only cells with eelgrass are included in this analysis. Both panels show the total number of grid points binned by whole number model score. The upper panel uses model output using modification 3 of the weighting scheme, the final model formulation. The lower panel uses the original model weighting scheme.

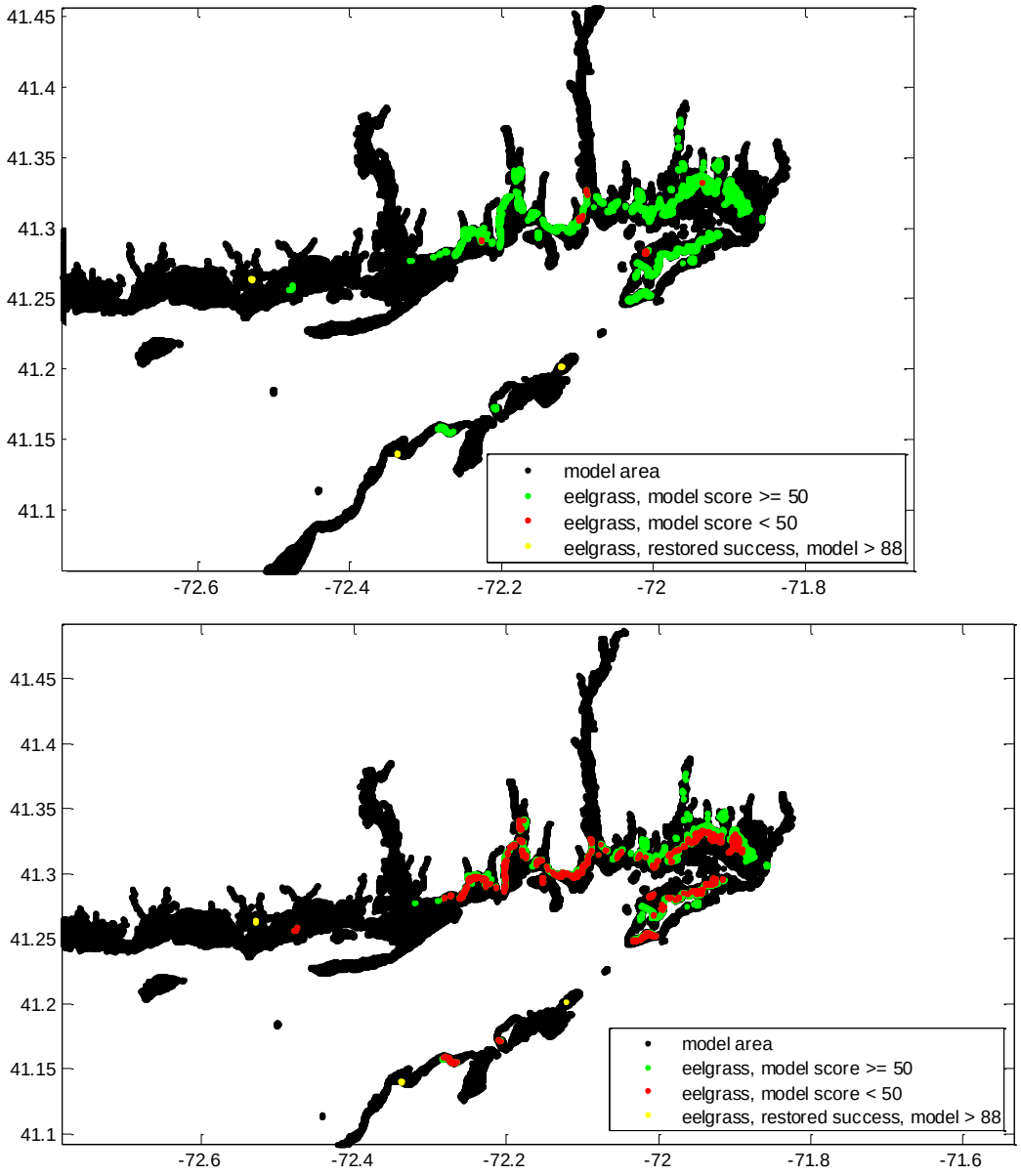


Figure 28: Evaluations of model scores for eelgrass areas.
The model area is shown in black. Green points represent eelgrass areas with a model score >= 50. Red areas are model scores <50. The restored eelgrass areas all had model scores > 88. The upper panel is for model output using modification 3 of the weighting scheme, this is the weighting scheme used in the final version of the model. The lower panel is the original weighting scheme.

6.5.3 SKILL ASSESSMENT OF THE CALIBRATED MODEL

Model skill analysis often involves an index based on the mean squared error (MSE). Because the reference data of eelgrass is "present" or "absent," using skill analysis methods based on MSE is inappropriate.

To evaluate the skill of model output, model score in all areas of the aerial over flight region (Figure 23) were evaluated relative to the presence and absence of eelgrass. The point of this step was to evaluate how well the model performs at predicting suitable eelgrass areas within a broader region. For model scores greater than 88 in the aerial over flight region, 10.56% (n = 7,592) of the 71,886 grid points contained eelgrass (Figure 29). For model scores of 88 and lower, only 0.54% (n = 3,541) of the 652,358 grid points contained eelgrass (Figure 29). Eelgrass is 19.7 times more likely to be located in grids with model scores greater than 88 relative to those grids with scores less than 89. In Section 5.2 (page 22), it was determined that any model prediction which found eelgrass in more than 4.6% of the defined verification area of the aerial surveys would be skilled. This criteria of 4.6% was determined by examining the aerial surveys of eelgrass distribution conducted in 2002, 2006, and 2009 in the eastern end of Long Island Sound (Tiner et al. 2003, 2007, 2010). These surveys illustrate that eelgrass is not present in all locations which are suitable for eelgrass. Excluding depths greater than 9.2 m (where eelgrass is highly unlikely to occur), eelgrass beds are found in only 4.6% of the aerial survey study range. Thus a prediction rate of 10.56% indicated the model is skilled at predicting sites with suitability for eelgrass growth.

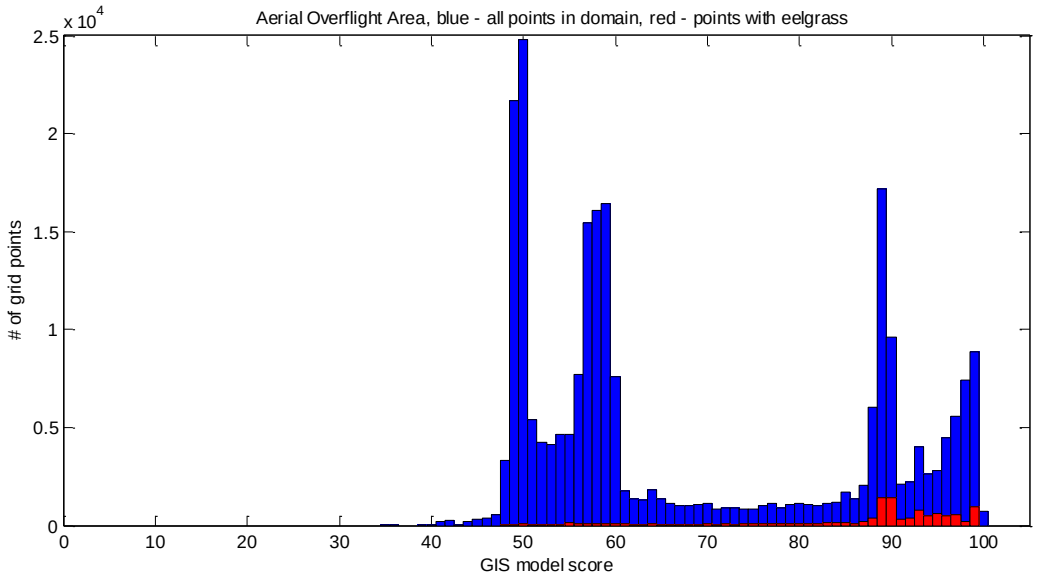


Figure 29: Evaluation of Model Output in Aerial Over Flight Area, modification 3.
Only data in the aerial over flight region are shown. The red bars indicate areas with eelgrass, the blue indicate areas without eelgrass.

6.5.4 EHSI Model Calibration and Skill Summary

A model value of greater than 88 is recommended when choosing restoration sites, though existing eelgrass beds are also found in grids with a model prediction of 50 or greater. The choice of a minimum model score of greater than 88 improves the likelihood of success for the planting of restoration plots.

In grids with a model score of > 88, eelgrass may be expected in approximately 10.56% of the area under current conditions in Long Island Sound. In the eelgrass aerial survey study limits (excluding depths greater than 9.2 m), eelgrass beds are found in only 4.6% of the area. The fact that model scores above 88 contain eelgrass 10.56% of the time indicates the model is skilled at predicting eelgrass presence, as values greater than 4.6% indicate improving accuracy.

The western limit of the area with model scores greater than 88 extends to Mattituck on Long Island and Clinton Harbor along the Connecticut shoreline (Figure 30). The area around Bridgeport (Bridgeport Harbor and Black Rock Harbor) also received scores of greater than 88.

The recommended weighting of parameters for the EHSI Model is as follows:

- percent light reaching the bottom 30%
- surface temperature 20%
- low dissolved oxygen 10%
- sediment grain size 20%
- sediment organic content 20%

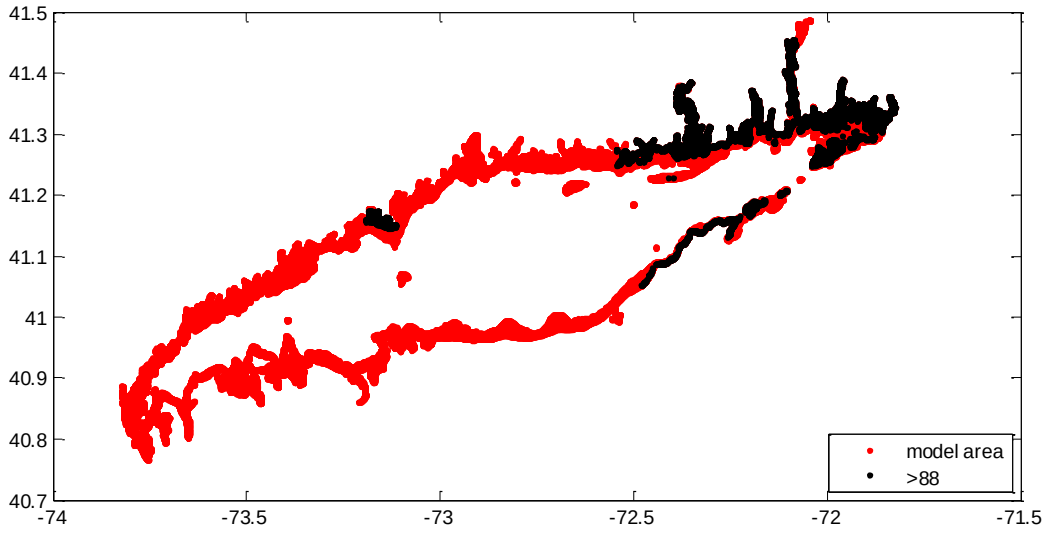


Figure 30: Areas Suitable for Eelgrass Restoration
Model area is shown in red with grids having a model score greater than 88 in black. The western limit of the area with model score greater than 88 extends to Mattituck on Long Island and Clinton Harbor along the Connecticut shoreline. The area around Bridgeport (Bridgeport Harbor and Black Rock Harbor) also received scores of greater than 88.

6.6 Sea Level Rise Analysis

Water depth influences the amount of light reaching the bottom and is important to eelgrass survival because of its high light requirement. Considering sea level rise predictions over the coming years, it was desirable to evaluate the impact sea level rise will have on the extent of the exclusive band.

NOAA provides information on sea level trends based on decades of tide gauge data (http://tidesandcurrents.noaa.gov/sltrends/msltrendstable.htm). The rate of current sea level rise varies across Long Island Sound (LIS), with an average of 2.48 mm/y (Figure 31). Climate Central published a report detailing projected sea level rise (http://slr.s3.amazonaws.com/SurgingSeas.pdf). The projections were based on the NOAA sea level trend data and included the predicted effects of global climate change on sea level trends. These predicted climate influenced sea level changes are roughly three times greater than what we might expect from the current trends in sea level change (Table 10).

While the predicted sea level change varies within LIS, the model runs were conducted using a single average value for change across LIS. The predicted increase in sea level has a large degree of error (+/- 8 to 10 cm), so the use of an average value for LIS is justified given that the individual "best estimate" station predictions are within 2 cm of each other (Table 10). From these predictions, seven estimates for sea level rise were chosen to span the range of predictions (Table 11). Processing was conducted in *ArcGIS Model Builder* which applied projected changes in bathymetry to the Percent Light Reaching the Bottom. The processes were applied only to the study area and did not include an estimate of land which would be inundated. This inundated land may create new suitable areas for eelgrass. However, as stated in Section 6.3.1 (page 11), bathymetry data in shallow areas are not available, so the model domain extends to the shoreline. In addition to the lack of bathymetry data in the shallow areas, available topographic data is coarse for land areas and would have a large amount of error in the results. For these reasons, land areas were not included in the Sea Level Rise results. An additional caveat regarding the migration of eelgrass inland as sea level rises is the limiting effect of hardened shorelines. While eelgrass may migrate inward to a degree, it will likely stop at the current shoreline due the effect of human uses and habitation in the highly urbanized LIS.

Figure 31: Sea Level Rise Predictions for Long Island Sound

NOAA's calculation of average rate of sea level rise, based on more than 30 years of data at each station. These sea level changes include any motion of the land within the measurement. From the NOAA website: "The Center for Operational Oceanographic Products and Services has been measuring sea level for over 150 years, with tide stations of the National Water Level Observation Network operating on all U.S. coasts . Changes in Mean Sea Level (MSL), either a sea level rise or sea level fall, have been computed at 128 long-term water level stations using a minimum span of 30 years of observations at each location. These measurements have been averaged by month to remove the effect of higher frequency phenomena in order to compute an accurate linear sea level trend. The trend analysis has also been extended to a network of global tide stations." (http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml).

Table 10: Predicted Sea Level Rise in Long Island Sound

Estimates for sea level rise in Long Island Sound which include the effects of climate change (Climate Central Predictions, http://slr.s3.amazonaws.com/SurgingSeas.pdf) versus estimates based on the past 30 year trend in sea level rise (NOAA Past Record, http://tidesandcurrents.noaa.gov/sltrends/msltrendstable.htm). The changes are calculated relative to 2008 sea levels.

	by 2030		by 2050	
Climate Central Predictions	Best estimate (cm)	90% range (cm)	Best estimate (cm)	90% range (cm)
New London - Thames River CT	13	5 to 23	30	13 to 56
Bridgeport - Bridgeport Harbor CT	13	5 to 23	30	13 to 56
Montauk - Fort Pond Bay NY	15	5 to 25	33	15 to 58
The Battery - New York Harbor NY	13	5 to 23	33	15 to 58
AVERAGE (not including The Battery)	14	5 to 24	31	14 to 57

	by 2030		by 2050	
NOAA Past Record	Best estimate (cm)	95% range (cm)	Best estimate (cm)	95% range (cm)
New London, CT	5.0	4.8 to 5.1	9.5	9.3 to 9.6
Bridgeport, CT	5.6	5.4 to 5.9	10.8	10.4 to 11.1
Montauk, NY	6.1	6.0 to 6.3	11.7	11.5 to 11.9
Port Jefferson, NY	5.4	5.0 to 5.7	10.2	9.8 to 10.7
Kings Point, NY	5.2	5.1 to 5.3	9.9	9.7 to 10.0
The Battery, NY	6.1	6.1 to 6.1	11.6	11.6 to 11.7
AVERAGE (not including The Battery)	5.4	5.2 to 5.6	10.4	10.1 to 10.7

Table 11: Summary of Sea Level Change Projections and Suggested Model Runs.

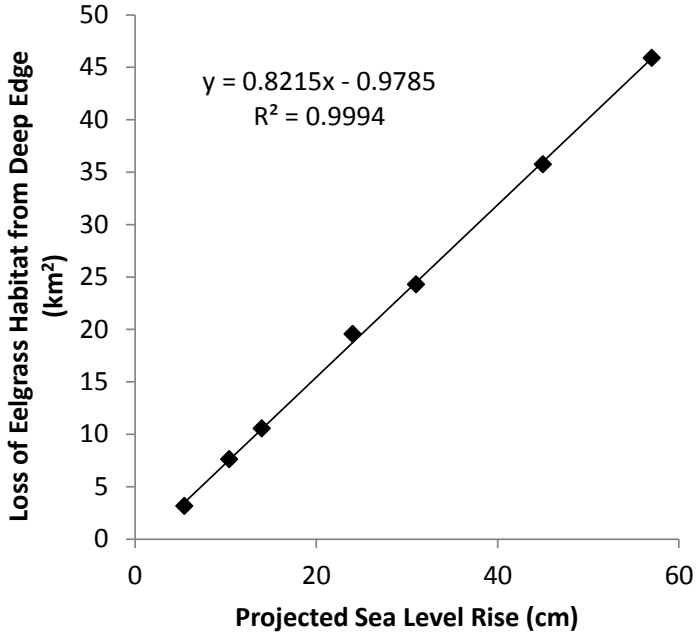
The NOAA and Climate Central (CC) predictions are averages of the data in table 10. Increase in sea level (cm) suggested for use in model runs include the average values from CC and the 90% CI on the estimates for both 2030 and 2050. Only the average of the current sea level rise reported by NOAA is included, not the 95% CI of these values. The model run of 45 cm was included to provide data in the large gap between the 31 and 57 cm model runs. The abbreviation "L-90% CI" refers to the lower 90% confidence interval; "U-90% CI" refers to the upper 90% confidence interval.

	by 2030 (cm)		by 2050 (cm)	
NOAA Past Record	5.4	5.2 to 5.6	10.4	10.1 to 10.7
Climate Central Predictions	14	5 to 24	31	14 to 57

Suggested Model Runs (cm)	
5.4	NOAA 2030 Avg; CC 2030 L-90%CI
10.4	NOAA 2050 Avg
14	CC 2030 Avg; CC 2050 L-90%CI
24	CC 2030 U-90%CI
31	CC 2050 Avg
45	
57	CC 2050 U-90%CI

Results of the model runs with the seven sea level rise estimates exhibited a linear relationship between the loss of habitat at the deep edge of the model domain and the sea level rise by 2030 and 2050 (Figure 32). The EHSI Model predicts that 651.8 km^2 of Long Island Sound is within the depth range appropriate for eelgrass (see Section 6.3 for a discussion of how this was calculated). The model predicts loss of area potentially suitable for eelgrass ranging from 3.3 km^2 to 18.5 km^2 by 2030 and 7.3 km^2 to 45.6 km^2 by 2050 (Table 12). It is important to note that these estimates refer to loss of *potential* habitat, not to the loss of *existing* eelgrass beds. As noted in Section 6.5.3 (page 54), eelgrass is found in only a small fraction of the area where conditions are suitable, thus the losses predicted by the model refer to the potential habitat and not the actual loss of currently existing beds.

Model mapping results indicate a sea level rise of 5.4 cm has essentially no effect on the area of the model domain (Figures 32 & 33). Under a sea level rise of 10.4 cm, some area is lost in the Bridgeport, CT area and Northport, NY. A tiny bit of area is lost along the CT coast between Guilford and Clinton (Figures 32 & 34). Progressively greater sea level rises result in greater loss of area along the deep edge of the model domain (Figures 32 & 35 - 39). The greatest losses of suitable areas are predicted to occur along the deep edge of the areas along the Connecticut coast between Bridgeport and Clinton (Figure 39).



Projected Sea Level Rise (cm)	Loss of Eelgrass Habitat from the Deep Edge (km^2)
5.45	3.1
10.4	7.6
14	10.5
24	19.5
31	24.3
45	35.7
57	45.9

Figure 32: Model Area Affected by Sea Level Rise
The projected sea level rise scenarios are associated with a loss of eelgrass habitat from the deep edge of the model domain (potentially suitable area in the model domain = 651.8 km^2). The loss of area was linear with projected sea level rise, indicating that the area within small depth increments is similar (i.e. the area with depth of 8.8 m to 9.0 m is similar to the area with depth of 7.8 m to 8.0 m). It is important to note that these estimates refer to loss of *potential* habitat, not to the loss of *existing* eelgrass beds.

Table 12: Ranges of Predicted Loss of Eelgrass Habitat with Sea Level Rise in Long Island Sound.
It is important to note that these estimates refer to loss of *potential* habitat, not to the loss of *existing* eelgrass beds.

NOAA Past Record

	by 2030	range	by 2050	range
Sea Level Rise Projection (cm)	5.4	5.2 to 5.6	10.4	10.1 to 10.7
Loss of Seagrass Habitat (km^2)	3.5	3.3 to 3.7	7.6	7.3 to 7.8

Climate Central Predictions

	by 2030	range	by 2050	range
Sea Level Rise Projection (cm)	13.5	5.1 to 23.7	31.3	13.5 to 56.7
Loss of Seagrass Habitat (km^2)	10.2	3.2 to 18.5	24.8	10.2 to 45.6

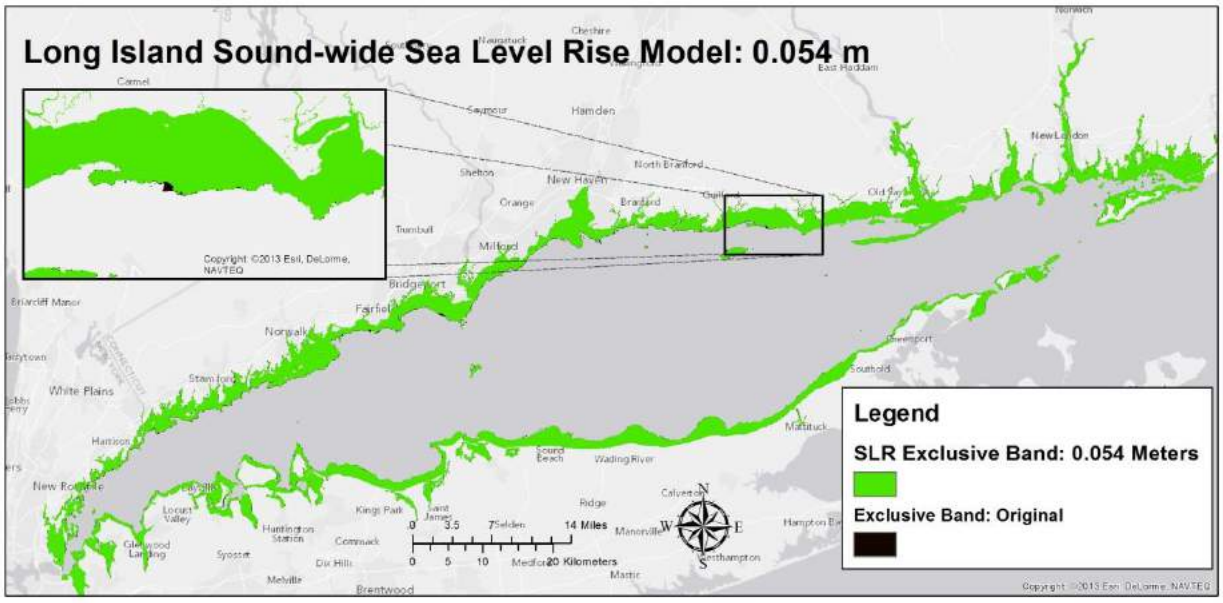


Figure 33: Sea Level Rise, 0.054 m.
The exclusive band has been clipped with respect to the predicted sea level rise value of 0.054 m. Black areas refer to the original exclusive band area that were lost.

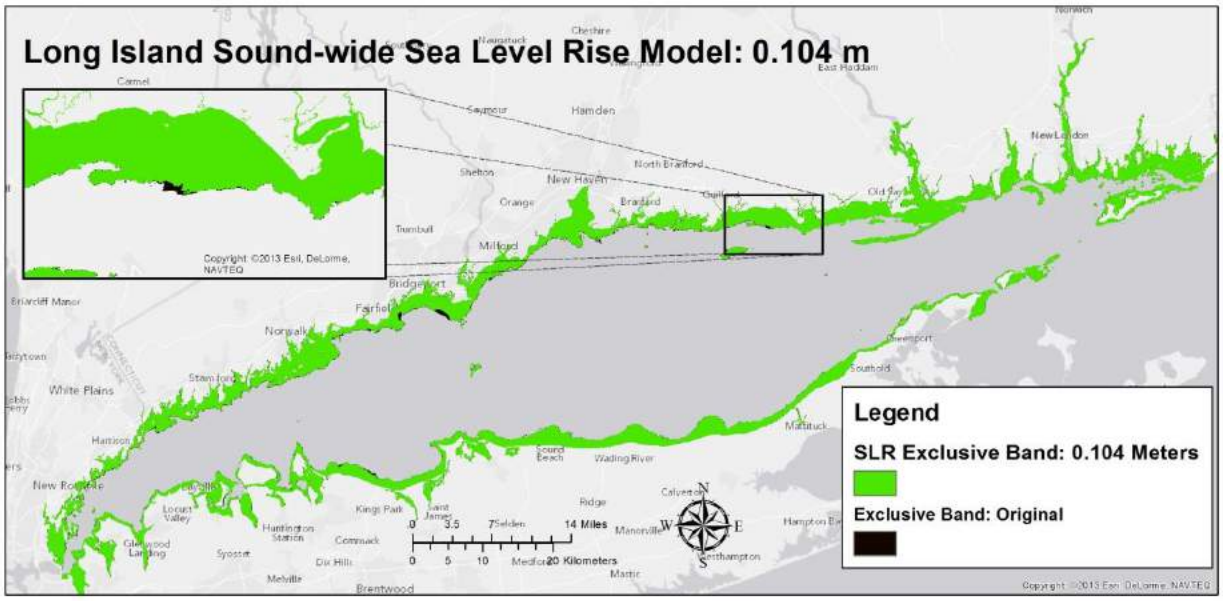


Figure 34: Sea Level Rise, 0.104 m.
The exclusive band has been clipped with respect to the predicted sea level rise value of 0.104 m. Black areas refer to the original exclusive band area that were lost.

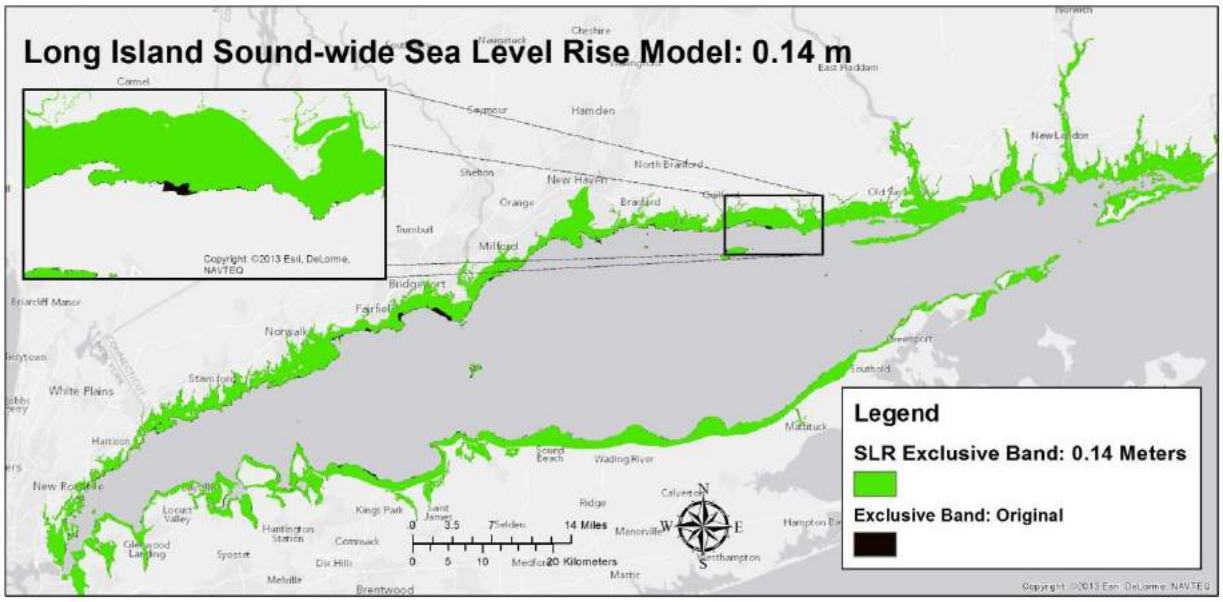


Figure 35: Sea Level Rise, 0.14 m.
The exclusive band has been clipped with respect to the predicted sea level rise value of 0.14 m. Black areas refer to the original exclusive band area that were lost.

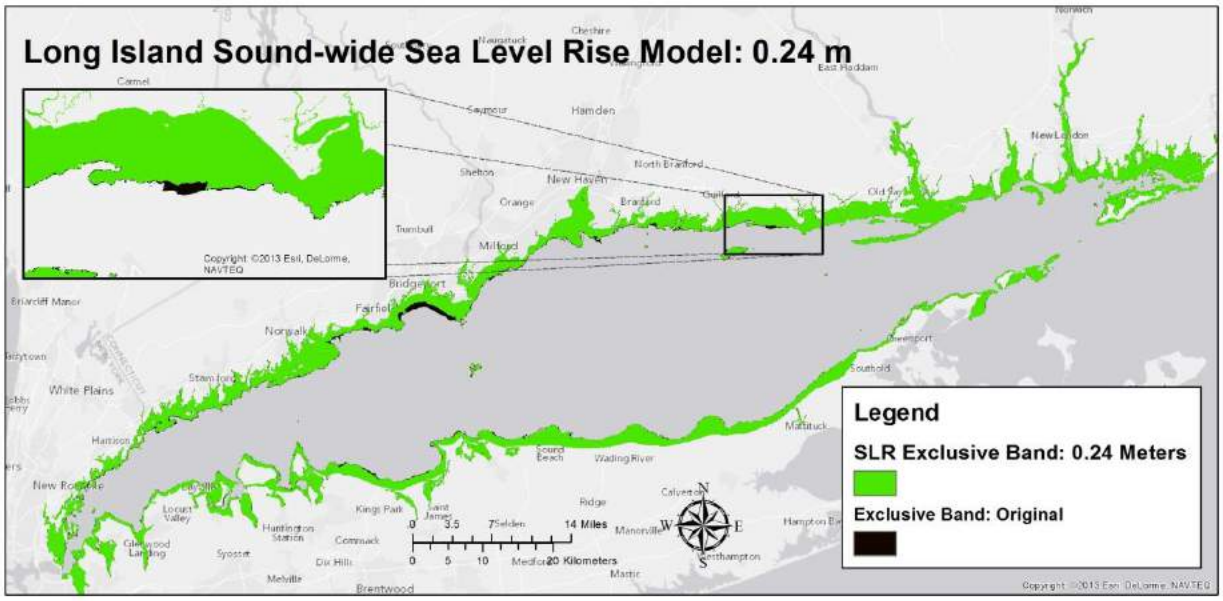


Figure 36: Sea Level Rise, 0.24 m.
The exclusive band has been clipped with respect to the predicted sea level rise value of 0.24 m. Black areas refer to the original exclusive band area that were lost.

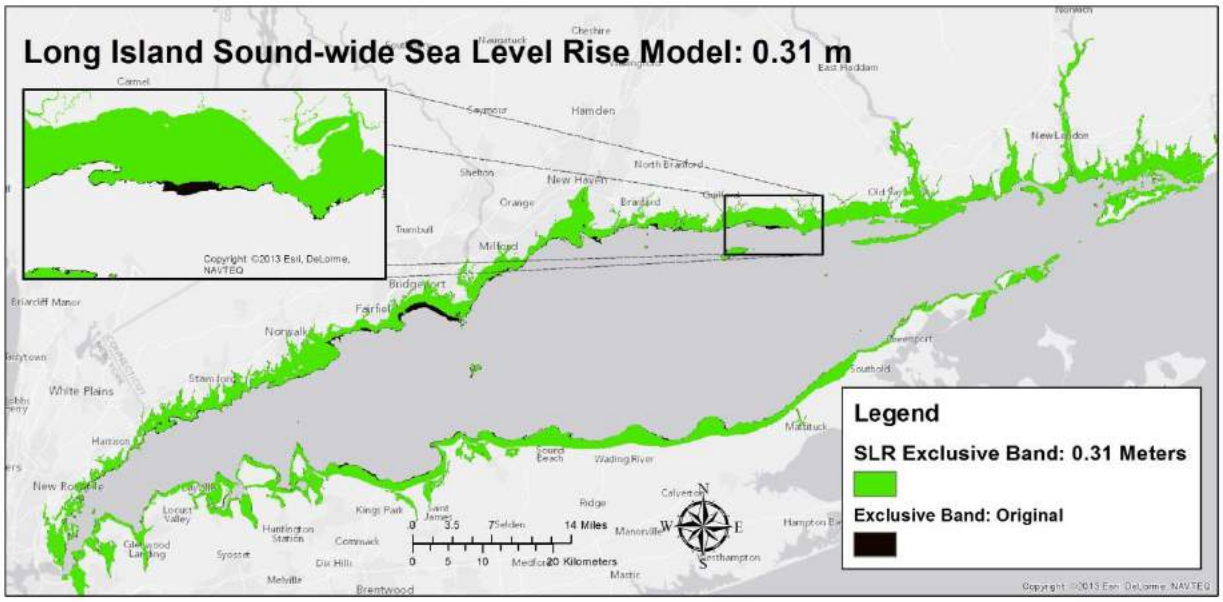


Figure 37: Sea Level Rise, 0.31 m.
The exclusive band has been clipped with respect to the predicted sea level rise value of 0.31 m. Black areas refer to the original exclusive band area that were lost.

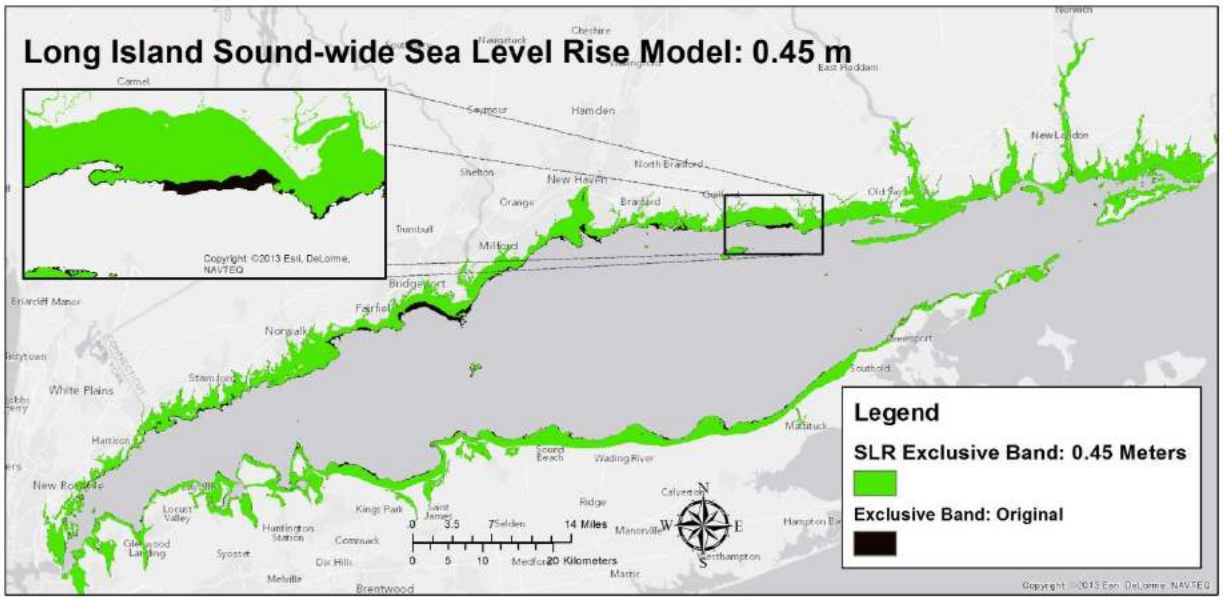


Figure 38: Sea Level Rise, 0.45 m.
The exclusive band has been clipped with respect to the predicted sea level rise value of 0.45 m. Black areas refer to the original exclusive band area that were lost.

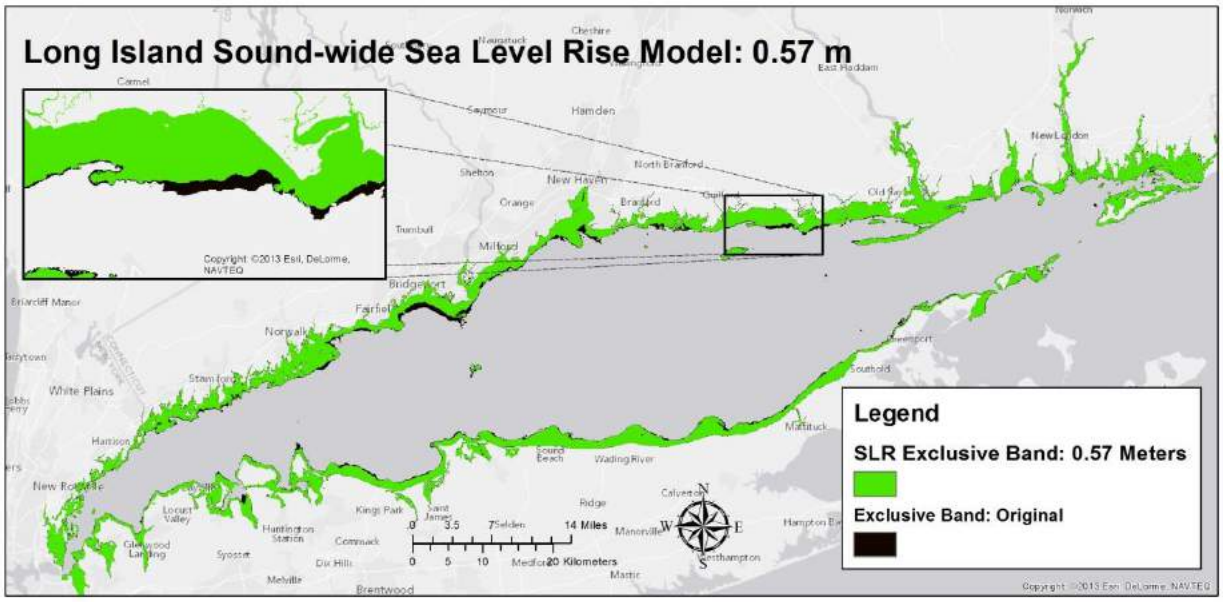


Figure 39: Sea Level Rise 0.57 m.
The exclusive band has been clipped with respect to the predicted sea level rise value of 0.57 m. Black areas refer to the original exclusive band area that were lost.

7 EHSI Sub-Model Development (Case Study Sites)

7.1 Overview

Data on parameters of interest were collected in six case study sites. By collecting supplemental data at a higher spatial resolution, we were able to create model domains within the case study site with a higher resolution. These case study site EHSI Sub-Models were used to evaluate the uncertainty associated with the EHSI Model (Section 8, page 146). A discussion of the field methods and detailed results are provided in Section 7.3 (page 72).

7.2 Case Study Site Selection

Six field sites were chosen to represent a range of conditions in order to validate the model output. Three sites were located in the coastal zone of CT and three in coastal NY (Figure 40). The first step in choosing the case study sites was the development and application of the model for the whole Sound, based on depth and tidal range. Due to changes in the time line of the project, the field work was moved from the summer of 2011 to the summer of 2012. This change allowed for the near-completion of the EHSI Model prior to the onset of field work. Because the initial model results were available, those results in addition to the bathymetry layer were used to identify potentially suitable locations for the six case study sites.

To obtain a range of sites with which to validate the model, one site in each state supported a dense and persistent eelgrass population; a second site must have supported eelgrass within the recent past (~10 years) or have existing beds with high inter-annual variability in coverage; and the third site was eelgrass-free, but identified as physically suitable for eelgrass based on the physical characteristics examined. Sites with known existing scientific research or monitoring data took priority over sites with a sparse data history

The PIs used the model output to identify sites which could potentially support eelgrass beds and were indicated by the model as suitable restoration sites. These choices were guided by our previous knowledge of these sites and the history of research in some systems. Within each site, an area of interest was determined by identifying which sections of the site were potentially suitable based on model output. Portions of the site which were too deep or too shallow were excluded from the area of interest.

For the Connecticut sites, the three sites were chosen in 2011 based on suitable bathymetry. This early decision of the CT sites was necessitated by the need to obtain a Certificate of Permission from CT DEEP and from the Army Corps of Engineers in order to deploy the Nutrient Pollution Indicator (NPI) racks. (see Section 9, page 158).

The following figures provide the model output and the proposed sample area for the six sites. A brief justification for why each site was chosen is provided here:

Niantic Bay, CT (Figures 41 & 42): Has a rich history of research in the area and supports a stable eelgrass population.

Clinton Harbor, CT (Figures 43 & 44): Some data on this site were available. Supports a sparse and variable bed of eelgrass. Two restoration test plots were planted in 2011. These test plots provide a direct test of the model output. One test plot failed, one was successful (see Section 7.7.1, page 138).

Cockenoe Island (Westport), CT (Figures 45 & 46): This western Sound site does not support eelgrass. The site was suggested as water quality appears suitable for eelgrass. We wanted to examine a western site to further investigate the model predictions which indicate some western areas may be suitable for eelgrass.

Petty's Bight, NY (Figures 47 & 48): Has some monitoring data and supports a stable eelgrass population.

St. Thomas Point, NY (Figures 49 & 50): This long-standing restoration site supports a variable, but expanding meadow that was first initiated in 2003. Since that time the grass has expanded considerably and taken on the characteristics of the reference meadow at Petty's Bight.

Duck Pond Point, NY (Figures 51 & 52): This site does not currently support natural eelgrass, but it has characteristics that appear to make it suitable for planting based on CCE-SC's experience with other LIS planting sites. Previous plantings (2010) installed in areas that rank very poorly in the current EHSI Model failed. Plantings conducted recently, but prior to developing the model, happen to fall within the higher ranked areas of our EHSI Model for the site.

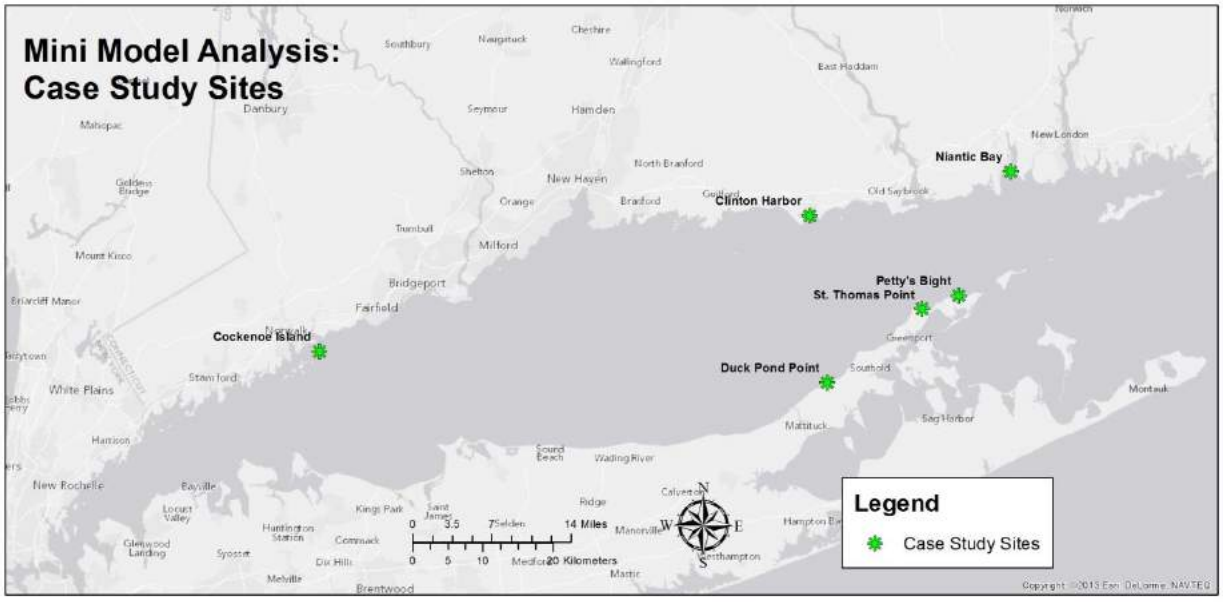


Figure 40: Case Study Site Locations

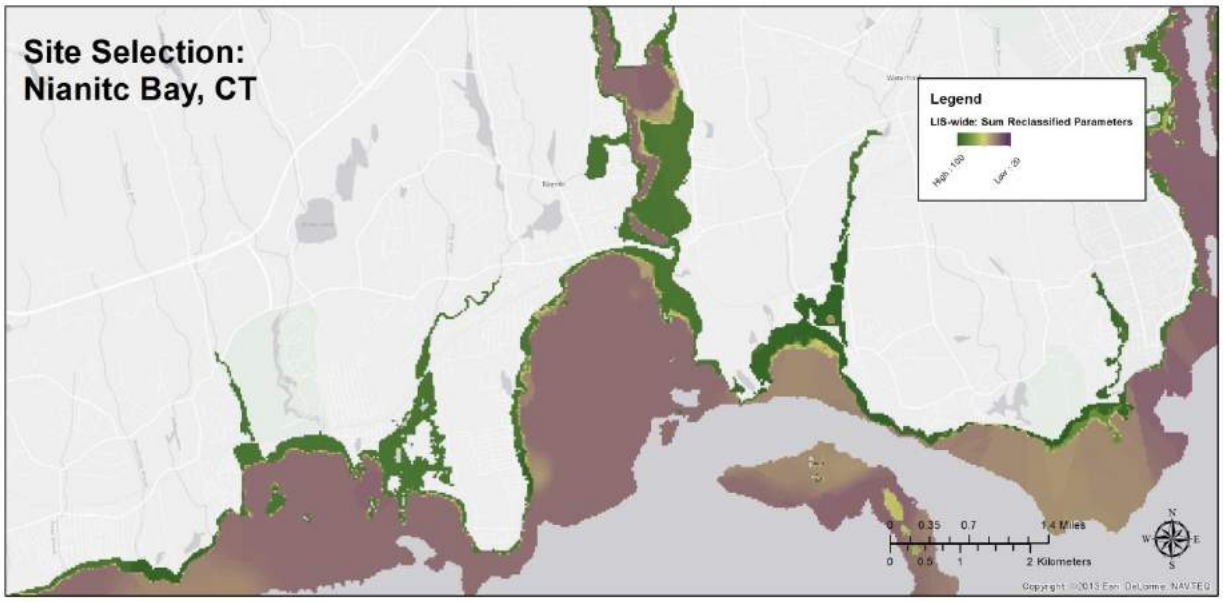


Figure 41: Model Output - CT, Site A, Niantic Bay

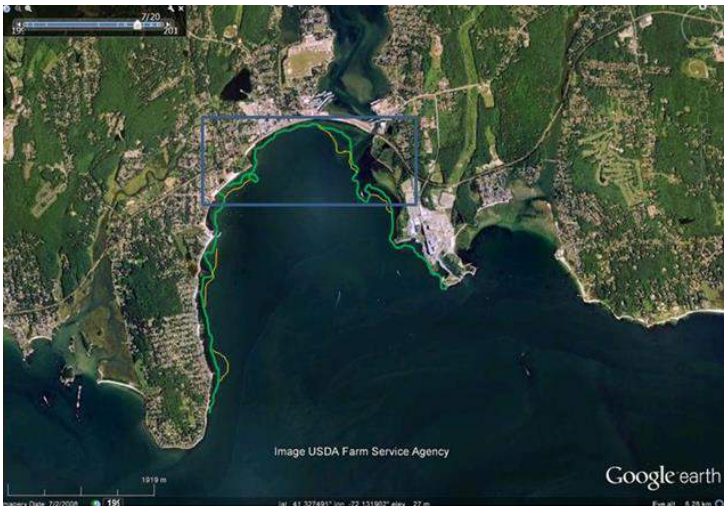


Figure 42: Aerial Photo; Area of Interest, Strata, and Stations - CT, Site A, Niantic Bay
Model output > 50 are on the shore side of the green line. Areas between the yellow and green line have a model output of ~ 50. Blue line encloses area of interest. The area of interest (minus area of land) is ~2.07 km^2, 8 stations will be sampled.

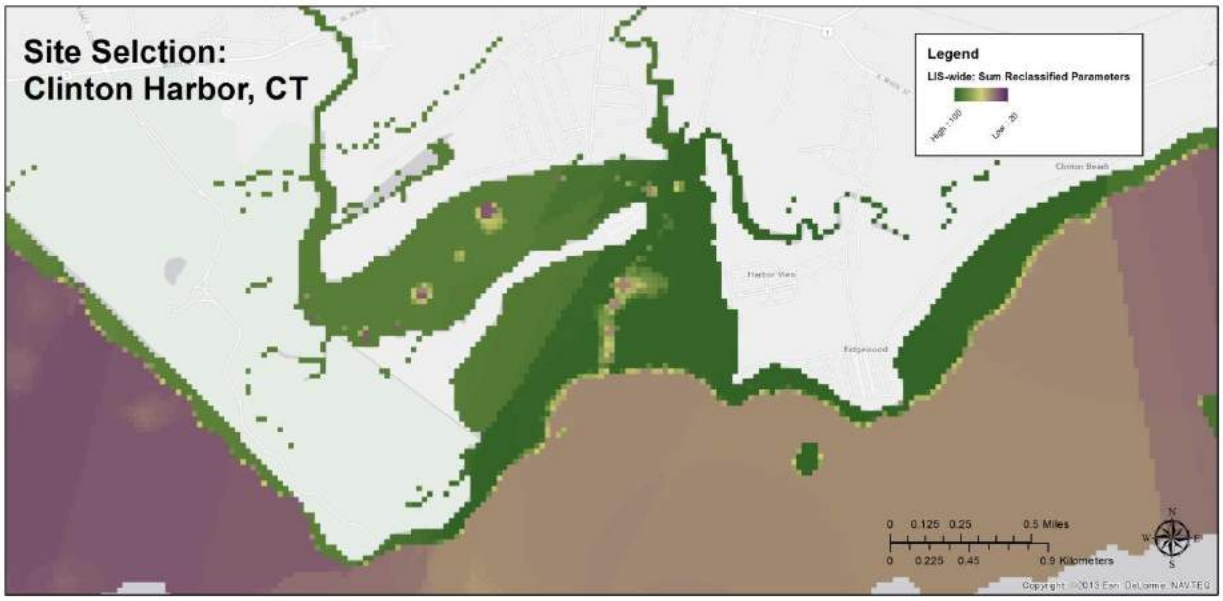


Figure 43: Model Output - CT, Site B, Clinton Harbor

Figure 44: Aerial Photo; Area of Interest, Strata, and Stations - CT, Site B, Clinton Harbor
Model output > 50 are on the shore side of the green line. Green circles with yellow fill are areas where model output < 50. Blue line encloses area of interest. The area of interest (minus area of land) is ~1.51 km^2, 6 stations will be sampled. The location of two restoration attempts are indicated by the white circles with purple fill. The northern-most bed is still successful, the southern bed failed soon after planting.

Figure 45: Model Output - CT, Site C, Cockenoe Island

Figure 46: Aerial Photo; Area of Interest, Strata, and Stations - CT, Site C, Cockenoe Island
Green line encloses areas with model prediction > 50 (0 – 100 scale for suitability, 100 = highest suitability). Blue line encloses area of interest. The area of interest (minus area of land) is ~1.55 km^2, 6 stations will be sampled.

Figure 47: Model Output - NY, Site D, Petty's Bight

Figure 48: Aerial Photo; Area of Interest, Strata, and Stations - NY, Site D, Petty's Bight
Green line encloses areas with model prediction > 50 (0 – 100 scale for suitability, 100 = highest suitability). Blue line encloses area of interest. The area of interest (minus area of land) is ~0.35 km^2, 6 stations will be sampled.

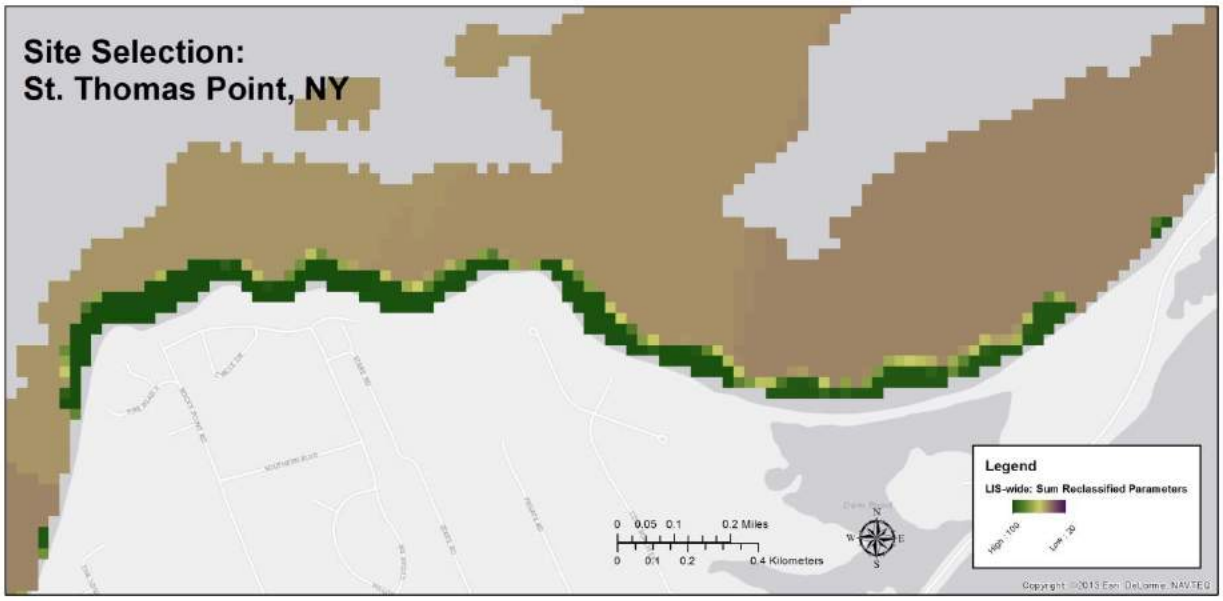


Figure 49: Model Output - NY, Site E, St. Thomas Point

Figure 50: Aerial Photo; Area of Interest, Strata, and Stations - NY, Site E, St. Thomas Point
Green line encloses areas with model prediction > 50 (0 – 100 scale for suitability, 100 = highest suitability). Blue line encloses area of interest. The area of interest (minus area of land) is ~0.3 km^2, 6 stations will be sampled.

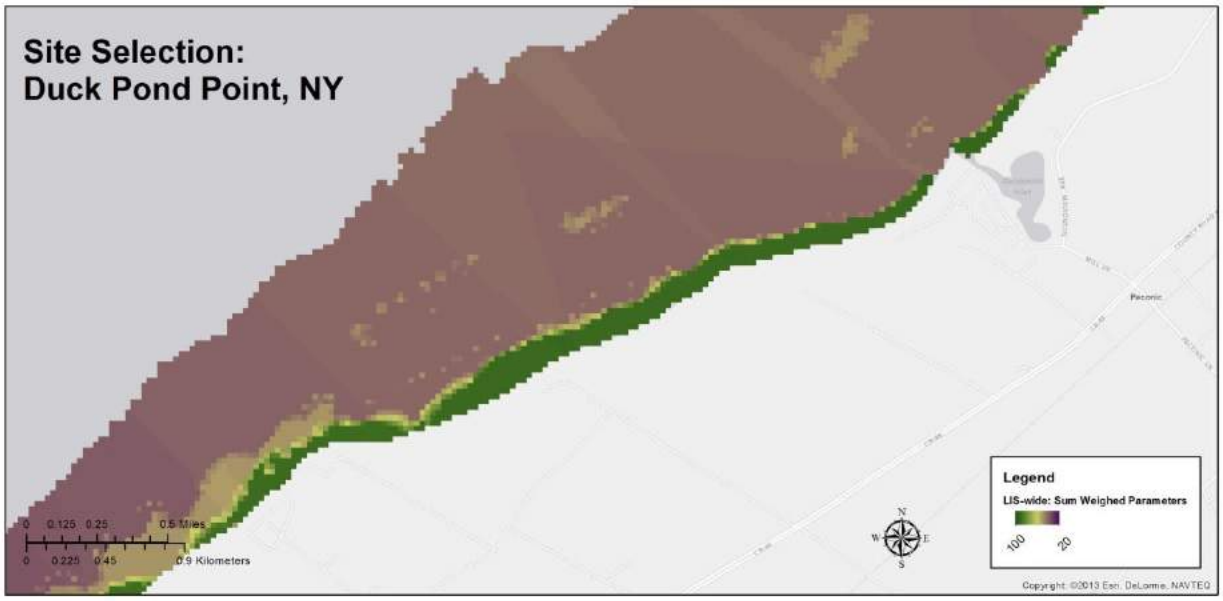


Figure 51: Model Output - NY, Site F, Duck Pond Point

Figure 52: Aerial Photo; Area of Interest, Strata, and Stations - NY, Site F, Duck Pond Point
Green line encloses areas with model prediction > 50 (0 – 100 scale for suitability, 100 = highest suitability). Blue line encloses area of interest. The area of interest (minus area of land) is ~1.2 km^2, 9 stations will be sampled.

7.3 Case Study Site Field Data

7.3.1 INTRODUCTION

The EHSI Model was based on datasets which were available Sound-wide, even though it was recognized *a priori* that these datasets were not ideal as no stations are located in the shallow edges where eelgrass may occur. In order to identify the data gaps and determine which parameters are most indicative of potential restoration success, field work was conducted in the six case study sites. The criteria for the selection of areas for the case studies is reviewed in section 7.2 (page 64).

The data from the case study sites was applied to the EHSI Sub-Models using the same weighting factors as were applied to the EHSI Model. Additional parameters beyond those included in the EHSI Model were sampled in the case study sites and evaluated to determine if the presence of more data would make additional parameters suitable for inclusion in the model.

In developing the thresholds for parameters included in the EHSI Model, previous restoration efforts and reviews of eelgrass suitability criteria in Long Island Sound were considered (Table 13). Many of the parameters listed in Table 13 were sampled as part of the field efforts in the case study sites.

The data presented in this section reviews the field data in the context of parameters included or excluded from the EHSI Model.

Table 13: Recommended habitat requirements for established eelgrass beds in Long Island Sound.
Copied from Vaudrey (2008a), based on work discussed in Vaudrey (2008a, 2008b) and Yarish et al. (2006).

	Suggested Guidelines for LIS	Guideline Type	Analysis Status
Minimum Light Requirement at the leaf surface (%)	> 15 (CB)	primary requirement (must estimate epiphyte biomass)	no data available
Water Column Light Requirement (%)	< 22 (CB)	subtitute for Min. Light Requirement at the Leaf Surface	no data available
Kd (1/m)	< 0.7	provided for reference, use minimum light as the standard	3 case study sites
Chlorophyll-*a* (µg / L)	< 5.5	secondary requirement (diagnostic tool)	3 case study sites
Dissolved Inorganic Nitrogen (mg/L)	< 0.03	secondary requirement (diagnostic tool)	3 case study sites
Dissolved Inorganic Phosphorus (mg/L)	< 0.02 (CB and LIS)	secondary requirement (diagnostic tool)	data not analyzed
Total Suspended Solids (mg/L)	< 15 (CB) < 30 (LIS)	secondary requirement (diagnostic tool)	no data available
Sediment Organics (%)	< 10	habitat constraint	3 case study sites
Vertical Distribution (m)	Zmax = 1m + Zmin	habitat constraint	3 case study sites
Sediment Grain Size	< 20% silt and clay	habitat constraint	no data available
Sediment Sulfide Concentration (µM)	< 400	habitat constraint	no data available
Current Velocity (cm/s)	5 < X < 100	habitat constraint	data not analyzed, case study sites within this range

7.3.2 METHODS

Detailed descriptions of the methods used for field data collection are included in the project QAPP (Pickerell et al. 2011). A summary of field methods is provided here. The QA/QC report is provided in Appendix 3.

The number of stations sampled per study site was determined based on the size of the area of interest. A guideline for determining the number of stations was based on the extensive knowledge of community composition in Niantic River. To adequately capture the range of conditions in the portion of the Niantic River suitable for eelgrass habitat based on depth and tidal range, eight stations are advisable. Based on the area, this yields 1 station per 0.275 km^2. This guideline was applied to a range of areas, providing guidance for the selection of the number of stations (Table 14).The maximum total number of stations sampled within a site are limited by the sampling time allotted for each site.

Station locations were chosen using a probabilistic sampling design, employing expert judgment of the sites to identify the number of stations sampled in each type of benthic habitat. The following steps were followed when determining the location of stations:

1. The locations of stations within an area were constrained by the results of the initial EHSI Model. Approximately half of the stations were located in areas with model output less than 50 and the other half in areas with model output greater than 50.
2. Knowledge of the sites was used to classify the benthic habitat into four strata based on the general community composition of the benthos. These strata consisted of the following community types: eelgrass (sparse to dense eelgrass beds), macroalgae (> 10% areal coverage of any macroalgae), bare sand (coarse grain, < 10% areal coverage of macroalgae), bare mud (fine grain, < 10% areal coverage of macroalgae).
3. Proportional allocation was used “to allocate the samples to the strata so that the proportion of the total sampling units allocated to a stratum is the same as the proportion of sampling units in the population that are classified in that stratum” (from EPA QA/G-5S).
4. The locations of stations within each stratum were determined using simple random sampling as described in EPA QA/G-5S (Guidance for Choosing a Sampling Design for Environmental Data Collection).

For most of the sites, previous site visits and aerial photographs were used to identify the location and area of the four identified strata. When previous knowledge of the sites was lacking, the site was evaluated using satellite images. When applying this approach, it was found that it was difficult to distinguish between bare sand and bare mud; these categories were grouped together into bare sediment. Locations of stations within each case study site are shown on maps included in Section 6.6.

Benthic habitat and water column profiles were assessed at all stations. In these relatively small case study areas, nutrients were not expected to vary a great deal. In open areas along the coast of Long Island, nutrients (and chlorophyll) were analyzed at fewer stations (Table 15). The analysis of water for chlorophyll was not included in the EPA approved QAPP for this project. Though EPA approved methods

were followed, the chlorophyll data is presented as conditional due to a lack of proper review of methods. In the Connecticut sites, the bathymetry of the sites was more complex and the land forms provided input of material and shelter from winds differentially across the study site. All stations in the Connecticut sites were analyzed for nutrients and chlorophyll while approximately half the sites were analyzed for the same parameters in New York.

Table 14: Number of Sampling Stations
A minimum of 5 stations will be sampled per site. Station number is determined using a station density of 1 / 0.275 km^2.

Area of Interest (km^2)	Number of Stations
0.20 to 1.37	5
1.38 to 1.65	6
1.66 to 1.92	7
1.93 to 2.20	8
2.21 to 2.47	9
2.48 to 2.75	10
2.76 to 3.02	11

All sites were sampled within an eight day period in July of 2012. The short sampling time frame reduces the impact of a seasonal signal when comparing among sites. Summertime is a common time for field work, especially in these shallow areas. Data on an annual cycle is often limited. Sampling during the summer for the evaluation of this model coincides with an active time for eelgrass growth and provides a basis for establishing criteria that will be applicable to future summer sampling efforts.

Table 15: Overview of Field Work Schedule

Site	Field Sampling Date	Number of Station for Profiles and Benthic Sampling	Number of Stations for Nutrients and Chlorophyll
Petty's Bight, NY	17 July 2012	6	4
St. Thomas Point, NY	18 July 2012	6	3
Duck Pond Point, NY	24 July 2012	9	3
Niantic Bay, CT	17 July 2012	8	8
Clinton Harbor, CT	19 July 2012	6	6
Cockenoe Island, CT	25 July 2012	6	6

7.3.2.1 Water Column Profiles

A YSI 6600 series sonde (UCONN) or YSI 85 (CCE-SC) was used to record temperature, salinity, and dissolved oxygen in the water column at each station. UCONN's YSI also collected information on pH and turbidity. Data were collected every 10 cm for the first meter, then every 0.25 m until 2.0 m, then every 0.5 m to the bottom.

A Biospherical QSP 2100 PAR sensor (UCONN) or LiCor Underwater Quantum Sensor LI-192 (CCE-SC) was used to evaluate the light attenuation coefficient (K_d) in the water column. The UCONN and CCE-SC instruments were deployed in different configurations, but both yielded an estimate of K_d. UCONN's configuration includes a remote sensor used in a profiling mode referenced to a deck sensor. A minimum of six readings were taken in the vertical and three complete profiles were conducted at each station. CCE-SC's configuration includes two remote sensors fixed at a depth difference of 0.5 m and referenced to a deck sensor. A minimum of six readings were recorded from each sensor.

7.3.2.2 Nutrients

Water samples were collected from two depths in the water column: 0.25 m below the surface and 0.5 m above the bottom. If the station depth was less than 1 m, a single sample was collected from 0.25 m below the surface. Of the 29 stations sampled as part of this project, only two stations had a depth less 1 m.

For inorganic nutrient analysis, samples were filtered through GF/F filters and delivered into acid washed plastic (HDPE) vials. Samples were stored on ice in the field then transferred to a -20^{o}C freezer until the time of analysis. The samples were analyzed on a Westco Smartchem Autoanalyzer at UCONN Avery Point campus following EPA standard methods for ammonium, nitrate, nitrite, and ortho-phosphate. Four replicate vials were collected from each depth. Two replicates were analyzed, with two being reserved in the event that additional analyses were required due to poor agreement between the two field replicates or poor agreement between analytical replicates. Values below the practical detection limit (PDL) of the method employed were flagged by assigning values of -99. The PDL takes into account the method detection limit, the instrument detection limit, and the range of standards used for calibration (the PDL will be whichever value is highest). The PDL values were 1 µM for ammonium, 1.2 µM for nitrate, 1.2 µM for nitrite, and 0.525 µM for phosphate. More details on QA/QC results are provided in Appendix 3.

For chlorophyll analysis, a known volume of sample was filtered through a GF/F filter. Filters were stored in the dark and on ice in the field then transferred to a -20^{o}C freezer until the time of analysis. Filters were analyzed on a Turner Design TD-700 fluorometer at UCONN following EPA standard methods for fluorometric determination of chlorophyll. Two field replicates were analyzed for each depth, analytical replicates are not possible. More details on QA/QC results are provided in Appendix 3.

7.3.2.3 Benthic Characteristics

Benthic characteristics consist of an evaluation of the benthic type, determination of sediment grain size and sediment organic content, and the distribution and biomass of macrophytes.

7.3.2.3.1 General Characterization (camera work)

Camera work was conducted at each station, either by diver (CCE-SC) or by remotely operated video camera (UCONN). Photos were analyzed to determine percent coverage of bare sediment, macroalgae, and eelgrass. More details on QA/QC results are provided in Appendix 3.

Additional photo interpretation yielded the percent coverage by red macroalgae, green macroalgae, and brown macroalgae.

7.3.2.3.2 Sediment

Three separate sediment samples were collected from each station and pooled into a single composite sample. Composite sampling was conducted due to the high heterogeneity found in sediment samples. Samples were collected by a 0.15 cm x 0.15 cm grab (UCONN) or by diver (CCE-SC). The top 1.5 cm of sediment was analyzed for grain size and organic content. For each field sample, triplicate analytical samples were processed.

Sediment organic content was analyzed using the loss-on-ignition method, following the standard approach presented in Heiri et al. (2001). Sediment grain size (% gravel, % sand, % silt & clay, % clay) was analyzed using the gravimetric pipette technique, following the methods of Folk (1980).

7.3.2.3.3 Macrophytes

Macrophytes were isolated from the three grab samples used for sediment collection (UCONN) or three 0.25 m x 0.25 m quadrat were harvested by diver (CCE-SC). Samples were identified to lowest practical taxonomic level, cleaned of epiphytes, rinsed in fresh water, and dried at 50^{o}C to obtain dry weight biomass (g D.W. m^{-2}).

Biomass samples were analyzed for elemental composition once they had been weighed for biomass. As the grabs and quadrats may miss species present in sites, additional algae was collected by rake (UCONN) or diver (CCE-SC) in an attempt to include the major species found at all sites. The elemental analysis of macrophyte samples were conducted on a Perkin-Elmer Series II 2400 CHNS/O Analyzer at the University of Connecticut, Stamford campus.

7.3.3 RESULTS AND DISCUSSION

7.3.3.1 Water Column Profiles

The water column profiles of temperature, salinity, and dissolved oxygen illustrate expected patterns for these sites which range along the length of LIS. Plots of full profiles were included as part of the data analysis process, but are not presented here. To visualize data in a compact format for this report, water column profiles were processed to extract the surface and bottom values for temperature, salinity, and dissolved oxygen (Figure 53). Salinity and temperature data indicate that Petty's Bight and St. Thomas Point were the most heavily stratified sites. Cockenoe Island exhibited a well-mixed water column, verified through evaluation of density profiles of all stations (data not shown).

Temperature and oxygen may vary with the time of day, as the sun affects warming and primary production. Changes in the tidal stage may also affect these two parameters. Most sampling was conducted between 10:00 a.m. and 3:00 p.m. in an effort to minimize the effects of time of day on the data. Diel changes in these values could influence a comparison among stations within a site and among sites. Temperature and oxygen were plotted against time and against salinity to visually evaluate the level to which time of day and tidal stage may have biased the data (date not shown). A linear regression

and Analysis of Variance were conducted for each comparison in *SigmaPlot v. 11.0*. All plots indicated that temperature and dissolved oxygen were not correlated with salinity or time of day, with most R^2 for the regressions below 0.05 and ANOVA p-values for the slope terms of the regression far greater than 0.05 (statistical significance was defined as p-values < 0.05). The exception was the surface and bottom oxygen relative to salinity, which both had p-values less than 0.05 for the slope term in the regression. However, the R^2 value was still low: 0.42 for surface oxygen and 0.47 for the bottom oxygen. The conclusion was that time of day and tidal variation effects on parameters were not discernible from the variability encountered among stations within a site and among sites.

Data illustrate the typical patterns expected in LIS, with higher salinity values in the Western Sound which decrease moving eastward among sites. The three New York sites exhibit greater variability among stations for salinity and to a smaller extent, temperature, relative to the Connecticut sites. Oxygen levels and variability among stations within a site were similar across all sites except for Cockenoe Island, which exhibited lower oxygen values. This pattern is consistent with the Long Island Sound CT DEEP survey data.

The light attenuation coefficient was similar across the six case study sites, with slightly higher values (less light reaching the bottom) at Petty's Bight and St. Thomas Point. The light attenuation coefficient in all sites appears suitable for the support of eelgrass. This was expected based on how these sites were chosen. The five Eastern Sound sites were expected to be suitable eelgrass restoration sites. The parameters included in the EHSI Model indicated that Cockenoe Island should also prove suitable. The Cockenoe Island site was chosen so that the gaps in the model formulations could be identified. The fact that case study sites were chosen in areas where eelgrass was expected means that light in all sites *should* be suitable for eelgrass.

The chlorophyll concentrations were not included in the model because the percent of light reaching the bottom inherently includes the effect of phytoplankton in the water column. Phytoplankton and turbidity are often used as proxies for the light attenuation coefficient, when light data are unavailable. The chlorophyll concentrations were slightly higher in Clinton Harbor when compared to the other case study sites. Cockenoe Island exhibited concentrations similar to Niantic Bay (Figure 54).

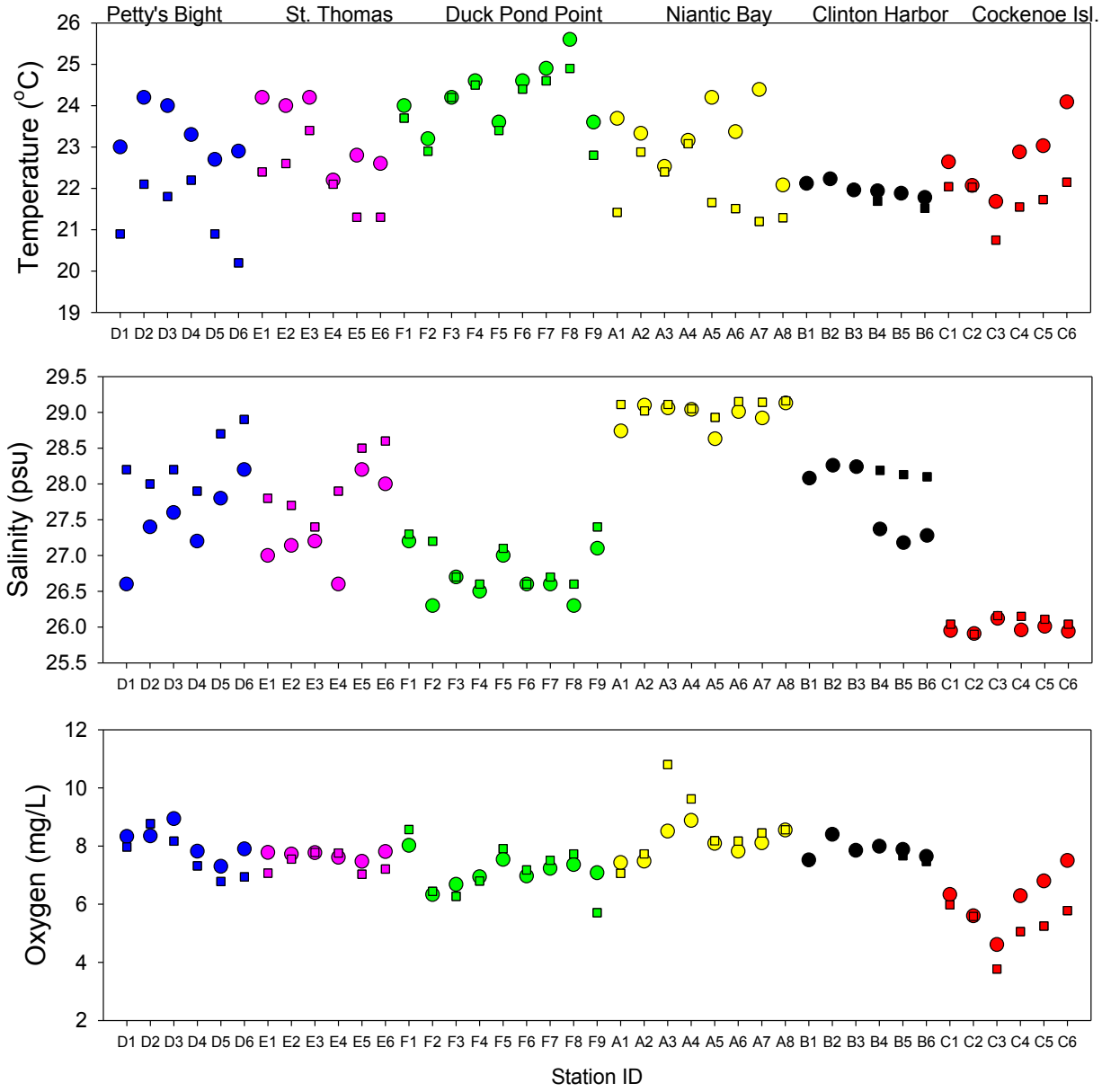


Figure 53: Water Column Profiles: temperature, salinity, dissolved oxygen
Surface (circle) and bottom (square) values extracted from the water column profiles.

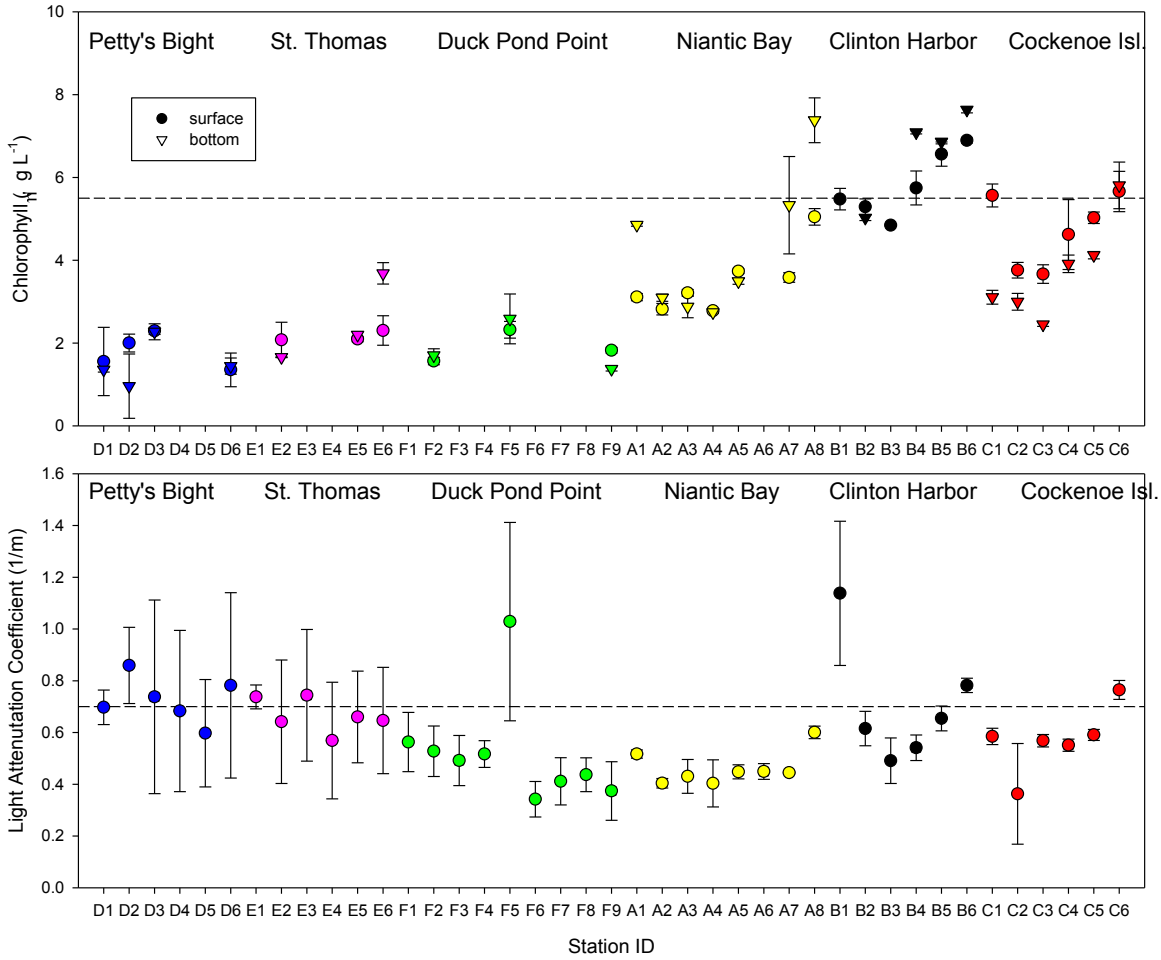


Figure 54: Case Study Sites Field Data: Chlorophyll and Light Attenuation Coefficient
Each case study site is assigned a different color, identified by the list of sites at the head of the figure. Error bars are the standard errors of the field replicates. The dashed line identifies the criteria recommended for the maintenance of existing eelgrass beds in Long Island Sound (Table 13).

7.3.3.2 Nutrients

In the EHSI Model and EHSI Sub-Model, both nutrient concentrations and chlorophyll concentrations were not included as layers in the model.

The nutrient concentrations were excluded because the values did not vary greatly across Long Island Sound, at least not to the extent that the variance in values had an effect on the model score. As an example, the total dissolved nitrogen (TDN) for Long Island Sound is presented in Figure 55. Wazniak et al. (2007) identified an annual average concentration of TDN higher than 0.47 mg/L as detrimental to eelgrass. Based on the recommendations of Wazniak et al. (2007), we applied a criteria for TDN where values above 0.47 mg/L received a model score of 0% of the weight for the TDN parameter, values

between 0.41 mg/L and 0.47 mg/L received a score between 0% and 100% of the weight for the TDN parameter and values less than 0.41 mg/L received 100% of the weight for the TDN parameter. Recall that the rationale when assigning these values is not to scale the range of the weightings to the range of the data, but instead to base the thresholds for ranges on what we understand of seagrass requirements. In this case, TDN throughout Long Island Sound met the criteria associated with successful eelgrass sites (Figure 56).

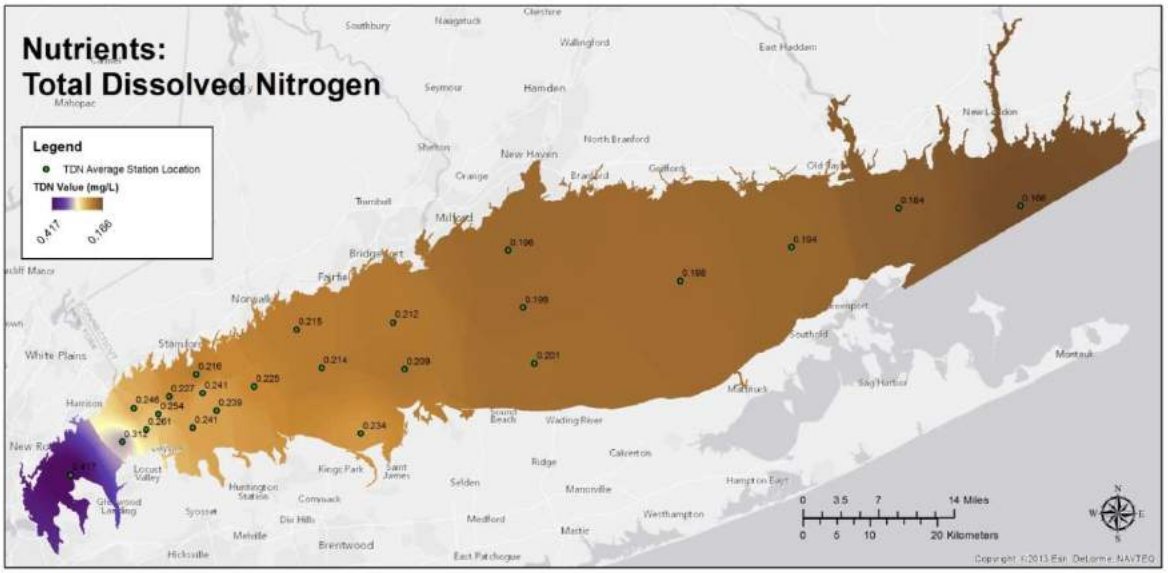


Figure 55: Total Dissolved Nitrogen in Long Island Sound
The annual average of total dissolved nitrogen was plotted from the CT DEEP cruise data using inverse distance weighting for interpolating between points.

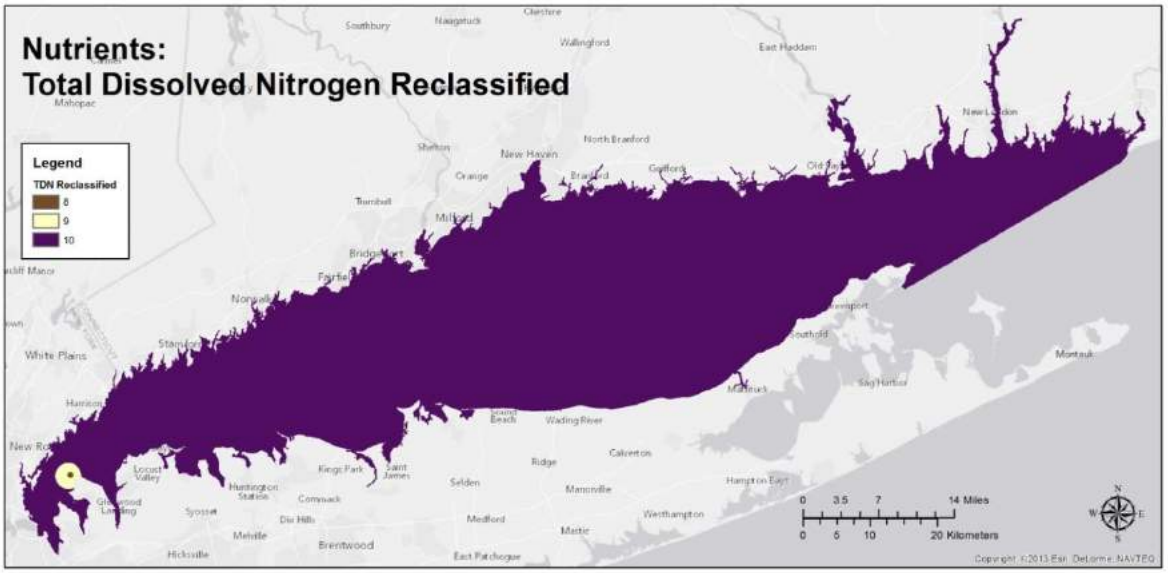


Figure 56: Reclassified Total Dissolved Nitrogen in Long Island Sound
The reclassified annual average of total dissolved nitrogen was plotted from the CT DEEP cruise data using inverse distance weighting for interpolating between points. These weightings were based on data presented in Figure 55

The fact that water column nutrient concentrations are poor indicators of the suitability of a site is well documented (see information in Vaudrey 2008a). Any nutrients delivered to these shallow sites are quickly utilized by primary producers such as macroalgae and phytoplankton. Even sites which have a high nutrient load may show very low concentrations of water column nutrients during the summer due to the presence of a large biomass of algae.

The dissolved inorganic nitrogen (DIN) highlights a second issue with attempting to use nutrient concentrations as an indicator for eelgrass success (Figure 57). The DIN concentrations in Petty's Bight and St. Thomas Point are higher than all other sites, even though these two sites contain eelgrass. Based on the trend in DIN, Clinton Harbor and Cockenoe Island would be implicated as the best sites for eelgrass (Figure 57).

Dissolved inorganic phosphorous (DIP) looks like a possible indicator, with higher values seen in Cockenoe Island, the site considered unsuitable by the Project PIs as a candidate for eelgrass restoration (Figure 58). Duck Pond Point, the site where two restoration attempts have failed, also exhibits DIP concentrations higher than the remaining sites, all of which contain eelgrass. However, an examination of the DIN : DIP ratio indicates that these systems are nitrogen limited (Figure 59). Thus, while DIP appears as a potential indicator, it is more likely that DIP concentrations are indicating a correlation between DIP and eelgrass site suitability that has very little causal relationship between the two.

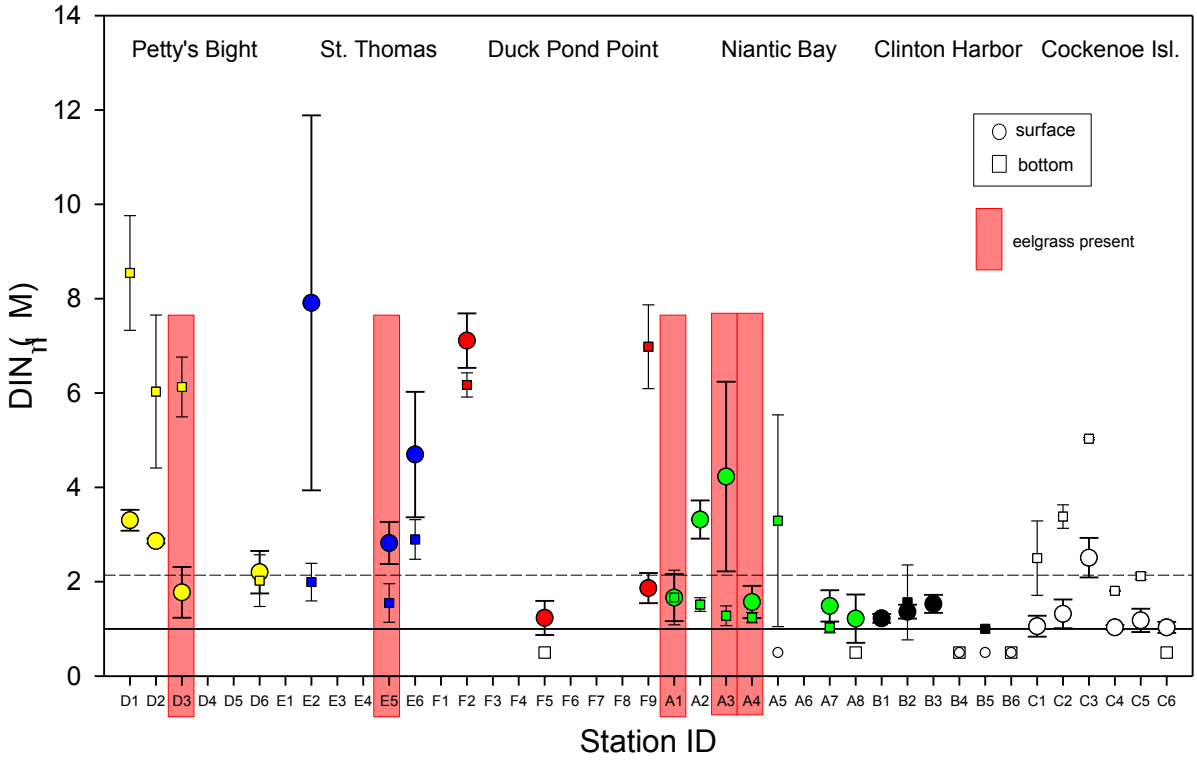


Figure 57: Case Study Sites Field Data: Dissolved Inorganic Nitrogen (DIN)
Dissolved inorganic nitrogen is the sum of ammonium, nitrate, and nitrite. Each case study site is assigned a different color, identified by the list of sites at the head of the figure. Error bars are the standard errors of the field replicates. The solid line identifies the practical detection limit (PDL) of the method. Any values below this limit are shown automatically as 0.5*PDL, allowing for the visual representation of very low concentrations. The dashed line identifies the criteria recommended for the maintenance of existing eelgrass beds in Long Island Sound (Table 13). Stations with eelgrass are identified by the red boxes.

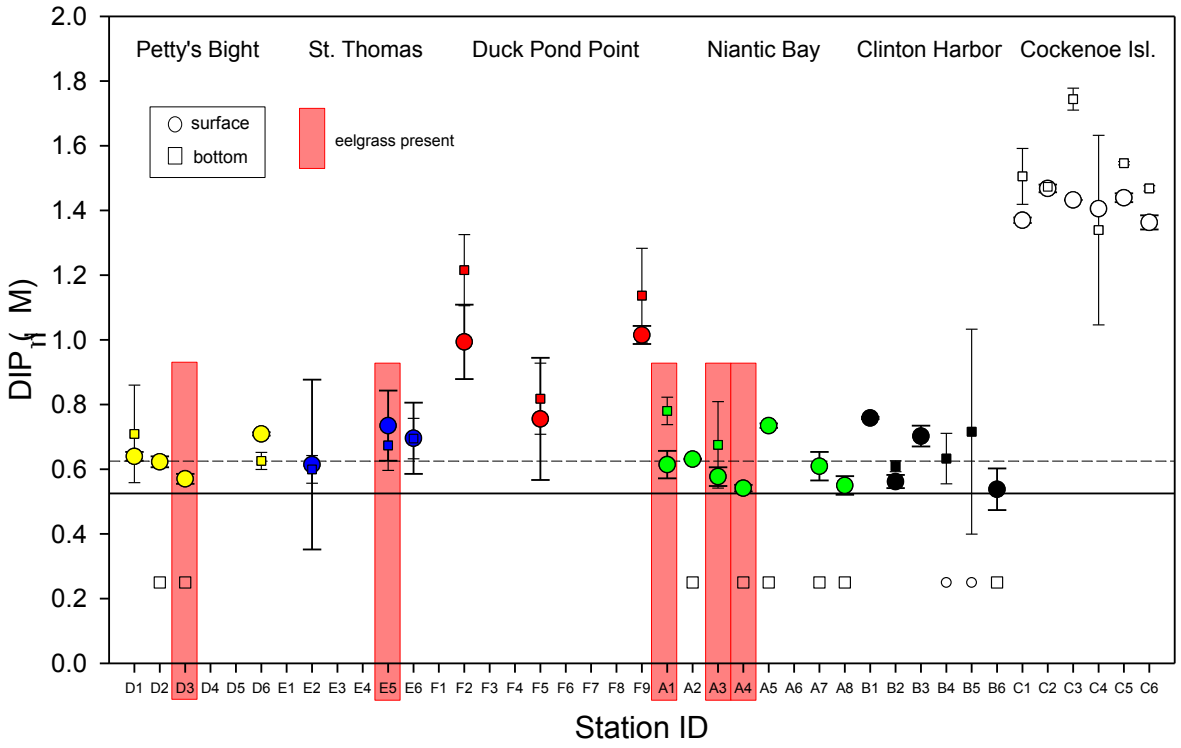


Figure 58: Case Study Sites Field Data: Dissolved Inorganic Phosphorous (DIP)
Each case study site is assigned a different color, identified by the list of sites at the head of the figure. Error bars are the standard errors of the field replicates. The solid line identifies the practical detection limit (PDL) of the method. Any values below this limit are shown automatically as 0.5*PDL, allowing for the visual representation of very low concentrations. The dashed line identifies the criteria recommended for the maintenance of existing eelgrass beds in Long Island Sound (Table 13). Stations with eelgrass are identified by the red boxes.

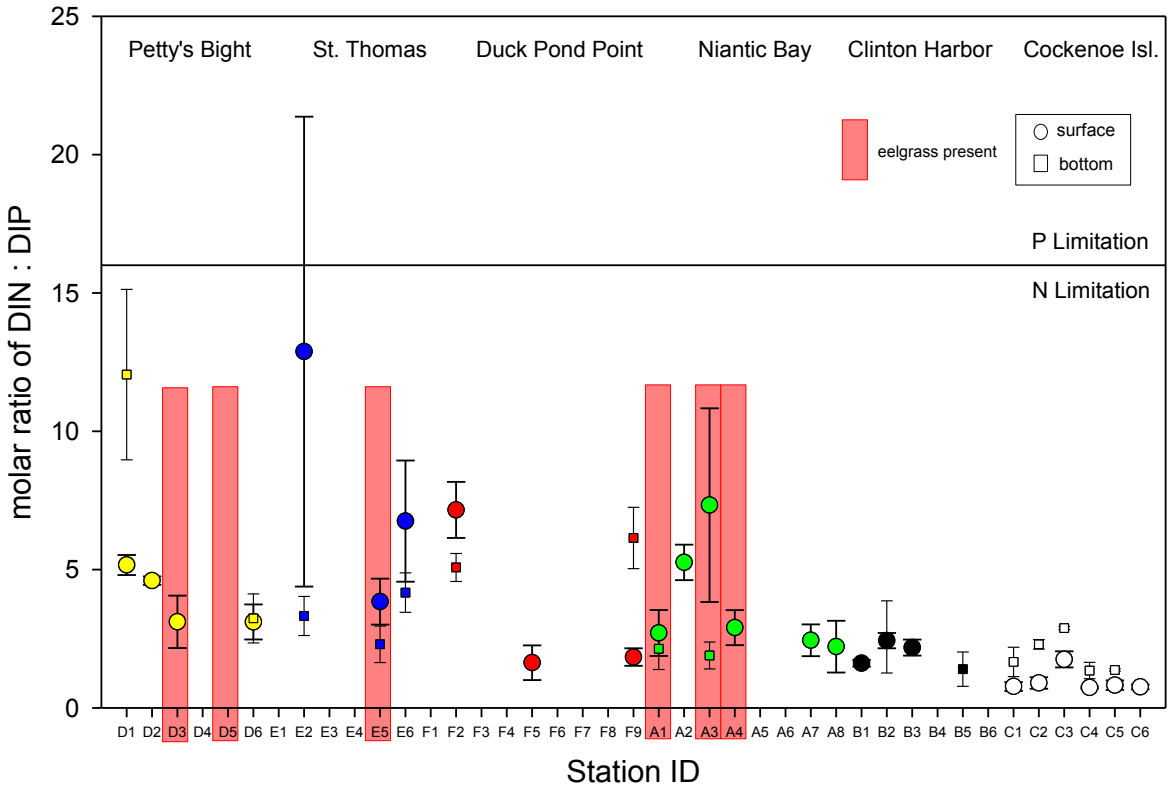


Figure 59: Case Study Sites Field Data: Ratio of DIN:DIP
Each case study site is assigned a different color, identified by the list of sites at the head of the figure. Error bars are the standard errors of the field replicates. The solid line identifies the switch from P limitation to N limitation predicted by the Redfield Ratio of 106 C : 16 N : 1 P for marine systems. Stations with eelgrass are identified by the red boxes.

7.3.3.3 Benthic Characteristics

The benthic characteristics assessed were sediment grain size, sediment organic content, benthic habitat type (bare sediment, macroalgae, eelgrass), macrophyte biomass and macrophyte elemental composition.

7.3.3.3.1 Sediment

During the development of the EHSI Model, sediment grain size and organic content were recognized as important parameters when evaluating a site for eelgrass suitability. Field work in the case study sites supports the inclusion of sediment grain size and sediment organic content as sensitive indicators of site suitability for eelgrass (Figure 85).

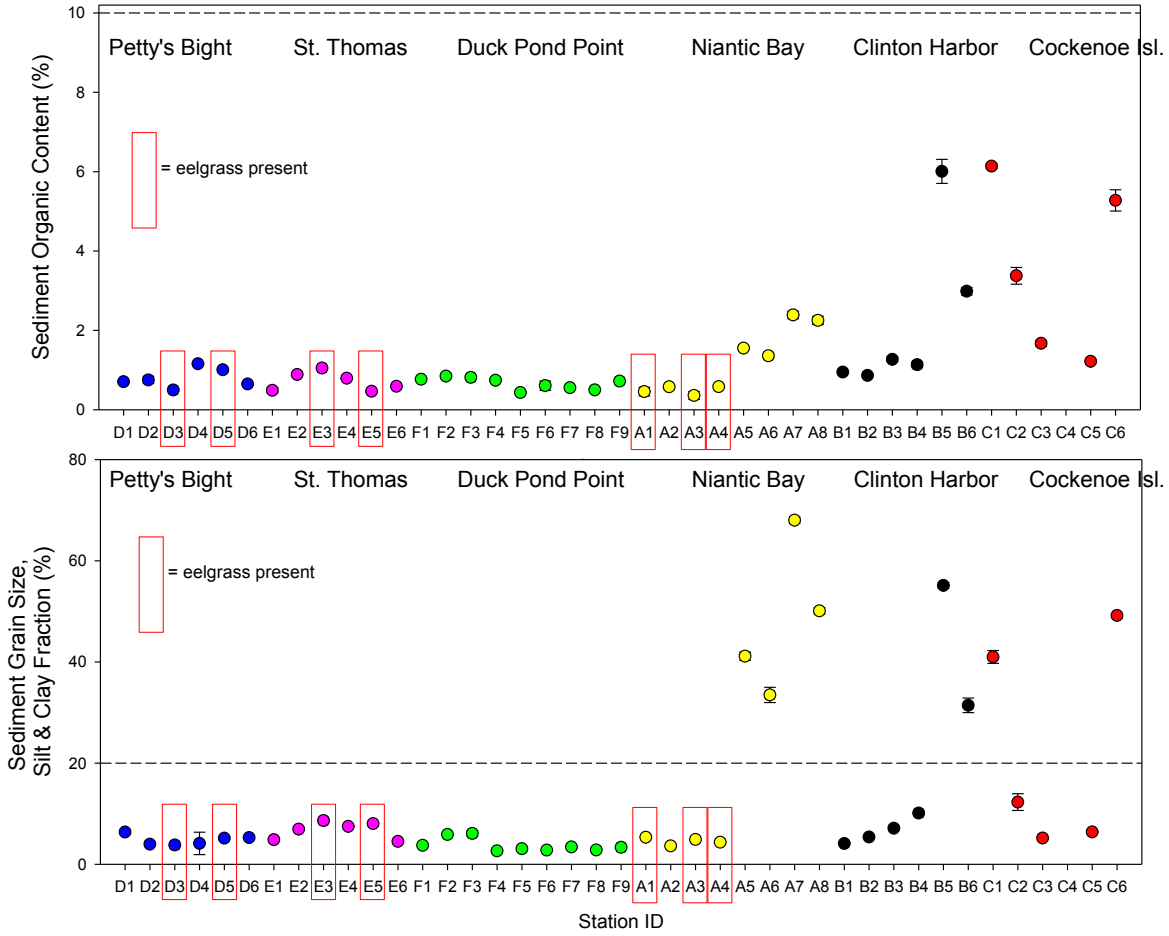


Figure 60: Case Study Sites Field Data: Sediment Organic Content and Grain Size
Each case study site is assigned a different color, identified by the list of sites at the head of the figure. Error bars are the standard errors of the analytical replicates from three composited samples per station. The dashed line identifies the criteria recommended for the maintenance of existing eelgrass beds in Long Island Sound (Table 13). Stations with eelgrass are identified by the red boxes.

7.3.3.3.2 Macrophytes

The macrophyte data proved hard to summarize in such a way as to make a meaningful indicator for the model. The assumption was that sites of poorer quality would support a larger biomass and percent coverage of macroalgae, but the results were not well correlated with the suitability of the sites for eelgrass. The largest macroalgae biomasses were seen at Petty's Bight and St. Thomas Point, the two sites with healthy eelgrass beds (Figure 61). Three grabs or quadrats used to estimate biomass has been recognized as a gross underestimate of the number of grabs required to properly characterize biomass within even small areas. The biomass values are useful for a relative indicator of the amount of primary producers in a system and as a method for gathering samples for elemental composition analysis, but additional information is needed to determine if the grabs are representative of the surrounding community. For this reason, camera work is conducted in the area, allowing for many more evaluations

(typically 9 to 30) of the benthic macrophyte community. The trends in biomass do match the trends in percent coverage by macrophytes (Figure 61).

Photos of the bottom were used to estimate percent coverage. These data were originally intended to provide an estimate of macroalgae coverage which could serve as a parameter in the model. The issue with using macroalgae as a parameter is that some macroalgae are beneficial while others are detrimental. The camera work was reanalyzed and macroalgae were divided into categories: beneficial red, detrimental red, beneficial brown, detrimental brown, detrimental green (there are no beneficial greens in LIS). The sites which support eelgrass (St. Thomas, Petty's Bight, and Niantic Bay) exhibit a greater or similar level for macroalgae percent cover as seen in Cockenoe Island (Figure 61). This trend can be attributed to the difference in physical structure in the environment in the presence and absence of eelgrass. Eelgrass provides a substrate for attachment for certain macroalgae. The structure of the eelgrass blades also trap macroalgae and reduce flow so that macroalgae (which are often detached, for greens and some reds) are not swept clear of the eelgrass beds. Duck Pond Point, Clinton Harbor, and Cockenoe Island do not have eelgrass at the stations sampled, though Clinton Harbor does have a small bed of eelgrass not captured in these sampling events. Clinton Harbor has the lowest macroalgae percent coverage, followed by Duck Pond Point, then Cockenoe Island (Figure 61). The conclusion is that macroalgae may be a good indicator for areas without eelgrass already present in the site, but is not an appropriate indicator for areas already hosting eelgrass.

In an attempt to include the macroalgae in some way, the decision was made to test the effect of adding an estimate of the percent coverage by detrimental green algae into the case study site EHSI Sub-Models. These inclusions were addressed in Section 7.4 (page 92).

The analysis of the macroalgae elemental composition was not as useful as we had hoped. The prediction was that elemental composition in the algae, specifically the %N, would vary among the sites and indicate those sites with a higher N availability (a bad condition for eelgrass). As mentioned above, this lack of differentiation among the sites is likely an artifact of choosing case study sites that were deemed as potentially able to support eelgrass. Thus, a large difference in sites may not be evident in this parameter, though it could prove illustrative in other sites which are more impacted by high nutrient loads. The other issue with the comparison of elemental composition was that the majority of species were found in only one or two of the case study sites. Only one species of green algae (sea lettuce, *Ulva* sp., blade form) was found in four sites. Evaluation of elemental composition of macroalgae across a broader nutrient gradient in embayments of LIS is underway as part of a separate project (Vaudrey and Yarish 2011).

While the elemental composition was not deemed suitable for including as a model parameter, the data do provide some insights into these six case study sites. For any given species, the %C was similar among the sites where data were available, as illustrated by the data for *Ulva* sp., blade form (Figure 62). The variance in molar C : N among sites and stations will be most influenced by %N, as %C is similar among sites. In order to examine differences among species, the %N was plotted by species for green, brown, and red macroalgae (Figures 63, 64, 65).

The %N of *Ulva* sp., blade form, a green alga, was higher at Cockenoe Island relative to the other sites, possibly indicating greater N availability at this site (Figure 63). Values of %N in *Ulva* sp., blade form for the remaining three sites, all of which host eelgrass, were similar. The other green alga sampled was *Codium fragile*, found at only two stations (Figure 63). The *C. fragile* %N data are similar in Duck Pond Point and Cockenoe Island. The presence of this algae in these two sites and its' absence from the other sites may indicate that *C. fragile* is an indicator of a poor quality environment for eelgrass, though data are too limited to make this assertion.

The presence of the brown perennial algae *Saccharina latissima* in Petty's Bight and St. Thomas is considered by restoration experts as an indicator of good habitat quality for eelgrass (Figure 64).

While the green algae shown in Figure 63 are considered detrimental species and the brown algae shown in Figure 64 is considered beneficial, the red category includes both beneficial algae (*Chondrus crispus*) and detrimental algae (*Gracilaria* sp., *Neosiphonia* sp.). The %N in *Gracilaria* sp. and *C. crispus* were similar among sites (Figure 65). The %N in *Grinnellia americana* was higher in Cockenoe Island than Duck Pond Point. The remaining reds were found at only one station, so there is no basis for comparison. The species present (beneficial vs. detrimental) provides an additional parameter to assess when determining where to locate a restoration site.

While interpretation of the macrophyte data was complicated, it was determined that detrimental greens can be included in the EHSI Sub-Model to evaluate how this additional data may change model predictions. While the %N did not show a large gradient among the six case study sites, slight differences indicate it may be a good indicator of nutrient load when examined in the context of a broader gradient. And finally, the species present in a site reflect the suitability of the site for eelgrass.

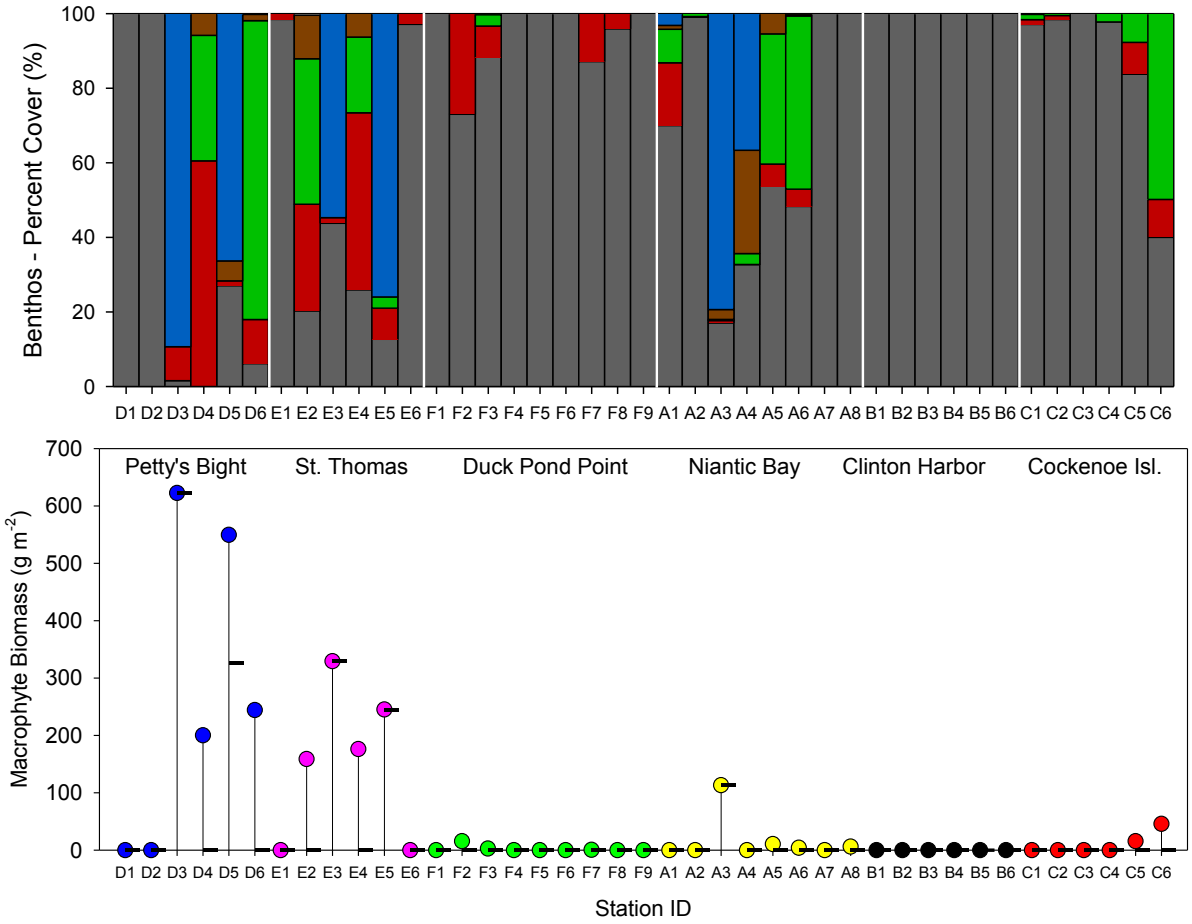


Figure 61: Case Study Sites Field Data: Macrophyte Coverage and Biomass

In the upper panel, the percent cover of the benthos is shown for each station. The five categories are: grey = bare sediment, red = red macroalgae, green = green macroalgae, brown = brown macroalgae, blue = eelgrass. The lower panel presents the total macrophyte biomass for each station. Each case study site is assigned a different color, identified by the list of sites at the head of the figure. The horizontal tick mark indicates the biomass due to eelgrass (e.g., at station D5, eelgrass (*Z. marina*) was 326 g m^{-2} and brown algae (*S. latissima*) was 223 g m^{-2}.

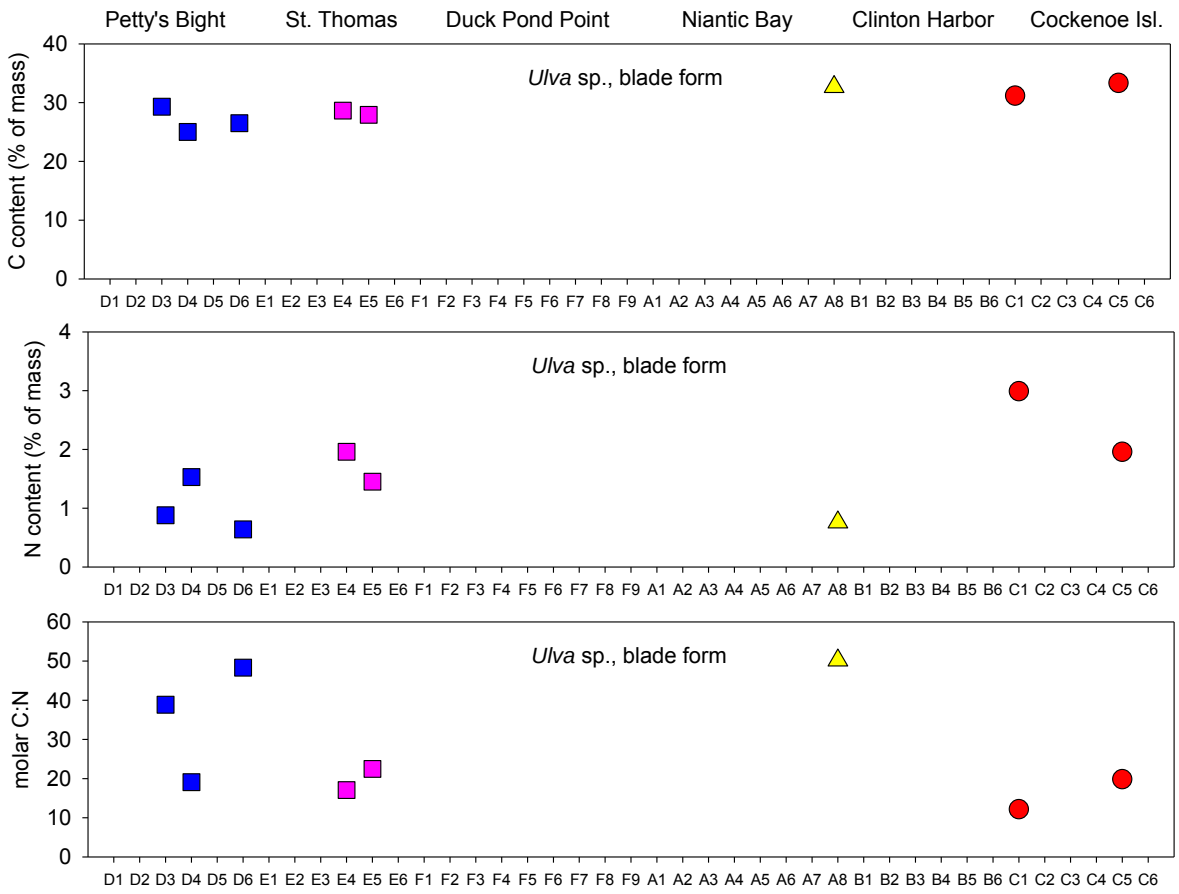


Figure 62: Case Study Sites Field Data: Macrophyte Elemental Composition, *Ulva* sp., blade form
The percent carbon and percent nitrogen in *Ulva* sp., blade form is presented for all stations where the macroalgae was encountered. Each case study site is assigned a different color, identified by the list of sites at the head of the figure. The bottom panel presents the elemental ratio of C:N.

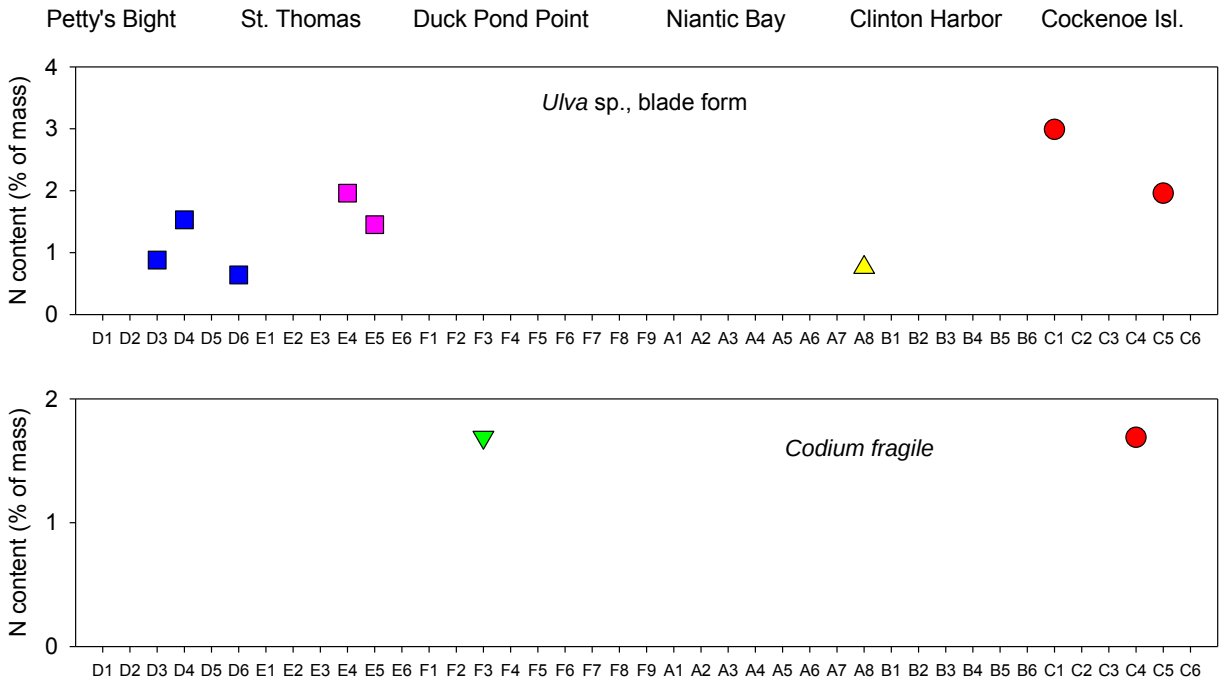


Figure 63: Case Study Sites Field Data: Macrophyte Nitrogen Content in Green Macroalgae
The elemental nitrogen content in all algae green macroalgae samples collected from case study sites is presented by station. Each case study site is assigned a different color, identified by the list of sites at the head of the figure.

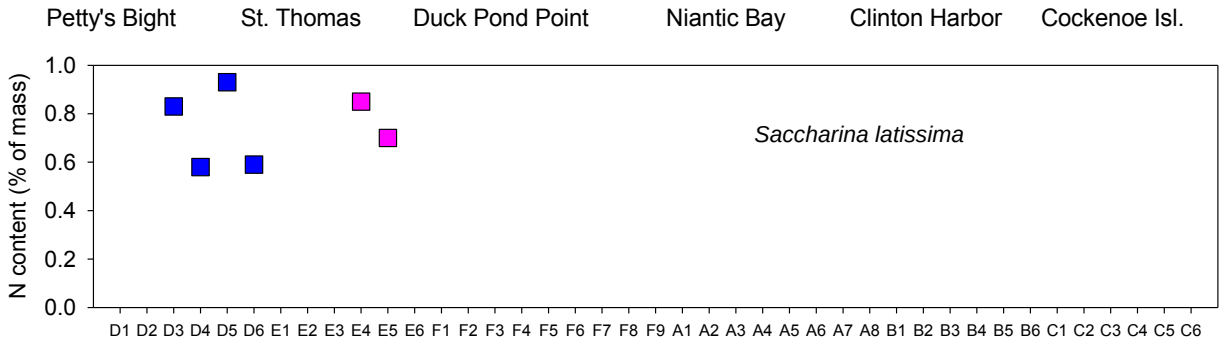


Figure 64: Case Study Sites Field Data: Macrophyte Nitrogen Content in Brown Macroalgae
The elemental nitrogen content in all algae brown macroalgae samples collected from case study sites is presented by station. Each case study site is assigned a different color, identified by the list of sites at the head of the figure.

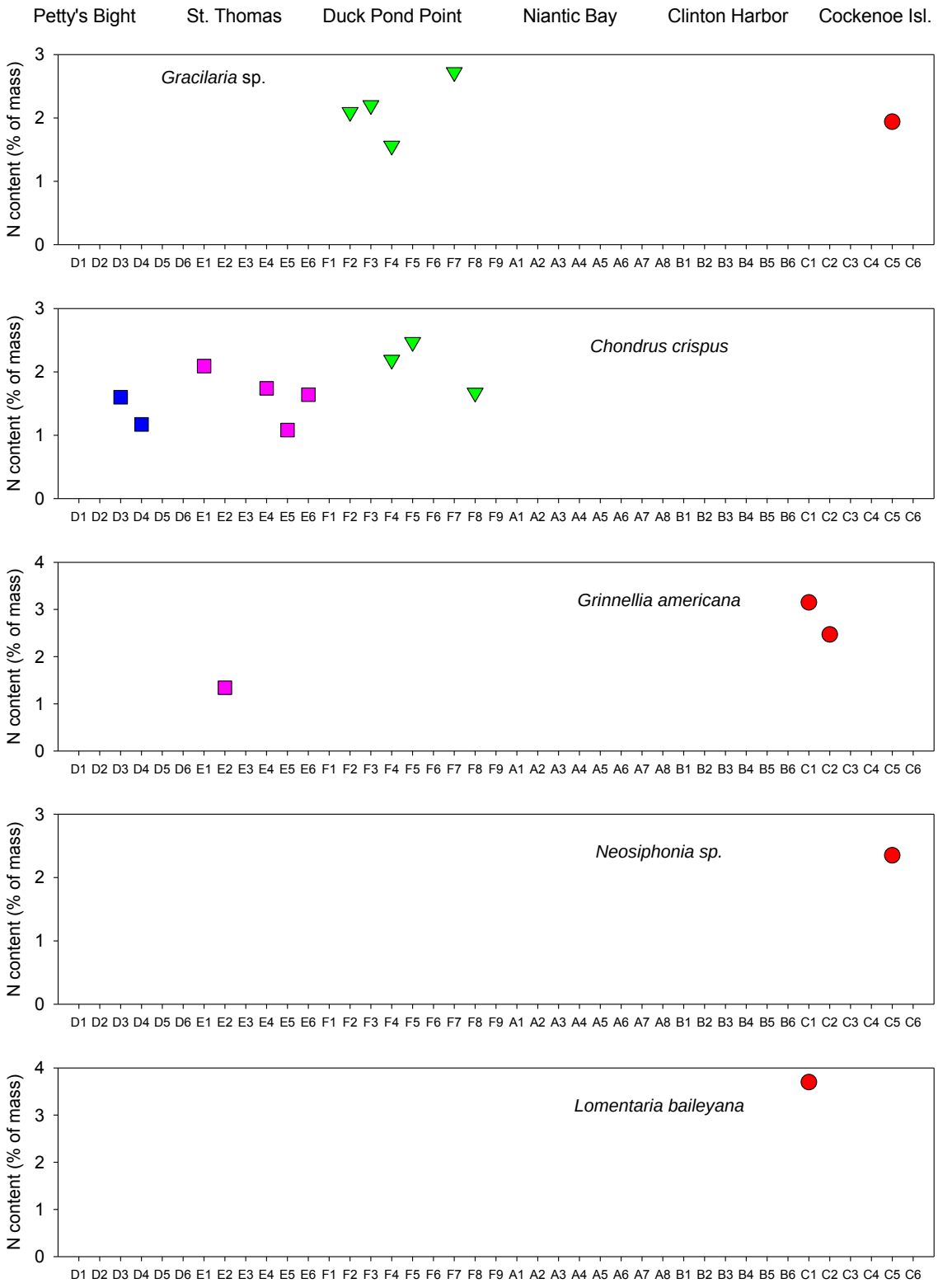


Figure 65: Case Study Sites Field Data: Macrophyte Nitrogen Content in Red Macroalgae
The elemental nitrogen content in all algae red macroalgae samples collected from case study sites is presented by station. Each case study site is assigned a different color, identified by the list of sites at the head of the figure.

7.3.4 SUMMARY

The field data collected in the case study sites were used to drive the case study EHSI Sub-Models and used to illustrate how data collected within a site versus interpolated from stations in the main stem of LIS can improve model accuracy (Section 6.6). The field data also provide support for the choice of parameters included in the EHSI Model and the EHSI Sub-Models. The five parameters included in the EHSI Model (% light to bottom, minimum summer dissolved oxygen, high summer temperatures, sediment grain size, sediment organic content) were chosen based on an evaluation of the data available from CT DEEP's LIS surveys. The field data from the case study sites supports the inclusion of these parameters and the exclusion of other parameters (nutrient concentrations, chlorophyll).

7.4 Case Study Site EHSI Sub-Model Parameter Selection

The EHSI Sub-Model case study sites were conducted entirely within the broad exclusive band generated in the Long Island Sound-wide Model so an exclusive analysis was not necessary for this part of the project. More dense data in these smaller case study sites allowed for results with a higher spatial resolution. The model grid cell size of all EHSI Sub-Model processes was set to 7.62 m x 7.62 m (25 ft x 25 ft) for all surface processing. This means each raster cell in the surface grid contained a calculated value.

The EHSI Sub-Model analysis was similar to the processing in the EHSI Model ranking analysis (see Section 6.4) for data collected in the summer of 2012 at the six case study sites. The major difference was that the site specific field data were used as input for the EHSI Sub-Models, versus the approach for the EHSI Model where data were extrapolated to these areas from distant stations (Section 6.4.2).

Parameters sampled in the case study sites included the same parameters as used in the EHSI Model as well as a number of other parameters deemed to be relevant to eelgrass survival (Table 16). Specifically, the introduction of a macroalgae parameter into the model was evaluated: percent cover of detrimental green macroalgae. The choice of this parameter to represent macroalgae is discussed fully in the section on field data (Section 7.3.3.3.2, page 85). Of the macrophyte data collected, the percent of detrimental green algae cover was included in the model because it can have the greatest detrimental impact on a restoration site (Pickerell, *pers. comm.*).

Table 16: Parameters Collected During Summer 2012.

Parameter	Parameter Used in Models?
% Light Reaching the Bottom	Yes
Bottom Temperature	Yes
Bottom Oxygen	Yes
Sediment % Silt & Clay	Yes
Sediment % Organic Content	Yes
% Detrimental Green Algae Cover	Yes
% Detrimental Brown Algae Cover	No
% Beneficial Brown Algae Cover	No
% Detrimental Red Algae Cover	No
% Beneficial Red Algae Cover	No
% Unknown Algae Cover	No
% Eelgrass Cover	No
% Macroalgae Cover	No
% Bare Cover	No
Macroalgae Biomass	No

7.5 Case Study Sites EHSI Sub-Model Data Interpolation

Stations within each case study site were set at a density of 1 station per 0.275 km^2 (see Section 7.3.2). Data were collected during a single visit to each site in July 2012. The data points were imported to *ArcGIS* and interpolated, estimating values for the entire area of each case study. A number of interpolation tools were tested and considered for processing the data. While Inverse Distance Weighting (IDW) was used for the EHSI Model, the greater density of data in the case study sites allowed for the use of alternate interpolation techniques. The spline technique was chosen because it provides a realistic distribution of values between and around stations, based on the opinion of the PIs who are familiar with these sites. In addition, the spline technique in *ArcGIS* allows for the inclusion of barriers, which are breaks in the interpolation. In other words, values cannot be interpolated through land masses.

The results of the data interpolation for the six parameters within each of the six case study sites are provided in Sections 7.5.1 through 7.5.6. Interpolation was extended to the edge of the EHSI Sub-Model domain in each case study site. In most sites, the edge of the model domain was less than 200 m from a sampling station. The exception was in Petty's Bight, where the eastern edge of the model domain was 300 m from the nearest station (Section 7.5.5, page 106). The distribution of stations within St. Thomas Point look as biased to the west of the domain as seen in Petty's Bight, but the smaller size of the site means that the edges of the domain are at most 140 m from the nearest station. When evaluating the possible bias introduced at the edges of the model domain due to interpolation, it is important to note the legend for distance in the figure in Section 7.5. In many cases, the values interpolated to the edges of the model domain have no effect on the model score because they are above or below the critical

range and thus receive a score indicating perfectly suitable or perfectly unsuitable. Even though a score may be considered "perfectly unsuitable", these area are not given a score of 0. This is a purposeful choice in model parameterization which reflects the possibility that our estimates of the value have an error associated with them and that eelgrass is able to handle conditions outside the optimum range of one parameter if all others are acceptable. An evaluation of the error introduced by extrapolating model scores to the edge of the model domain is provided in Section 7.7.3 (page 142).

7.5.1 CLINTON HARBOR INTERPOLATIONS

Data collected during the summer 2012 in Clinton Harbor, CT were interpolated between points and extrapolated to shorelines for full coverage of the geoprocessing boundary using the spline with barrier interpolation scheme. A full description of field data techniques, results, and interpretation of trends is provided in Section 7.3. The following maps present the data used for the EHSI Sub-Model.

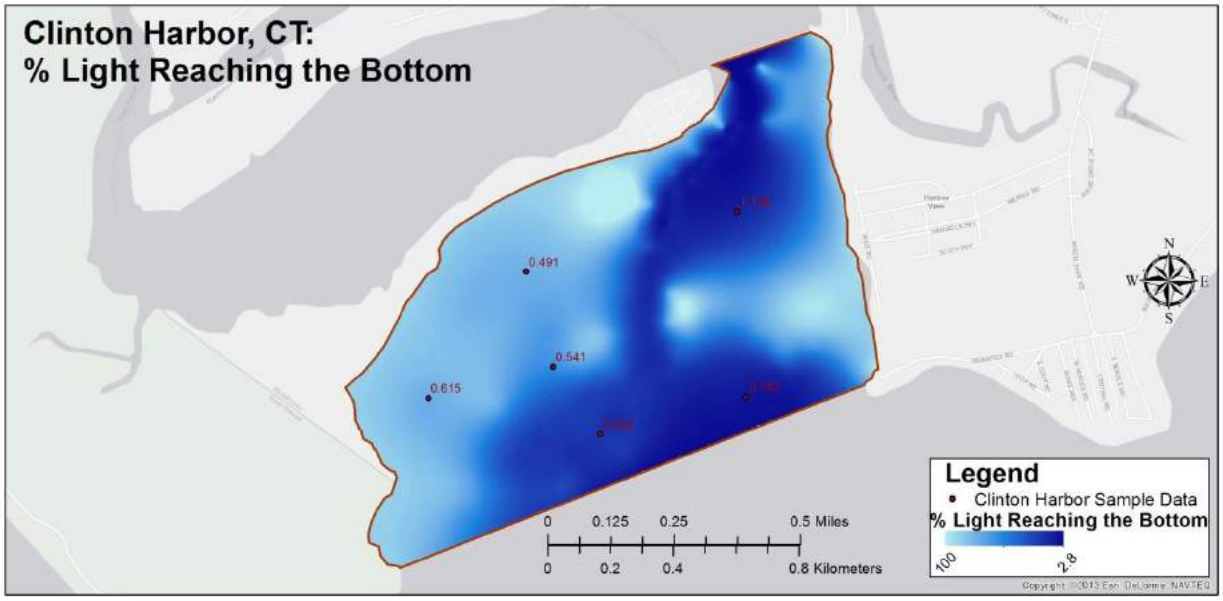


Figure 66: Clinton Harbor, % Light Reaching the Bottom.
The values listed in the plot are for light extinction coefficient (Kd) in units of m^{-1}. The percent of surface light reaching the bottom is calculated using the Kd and depth (see Equation 1, page 32).

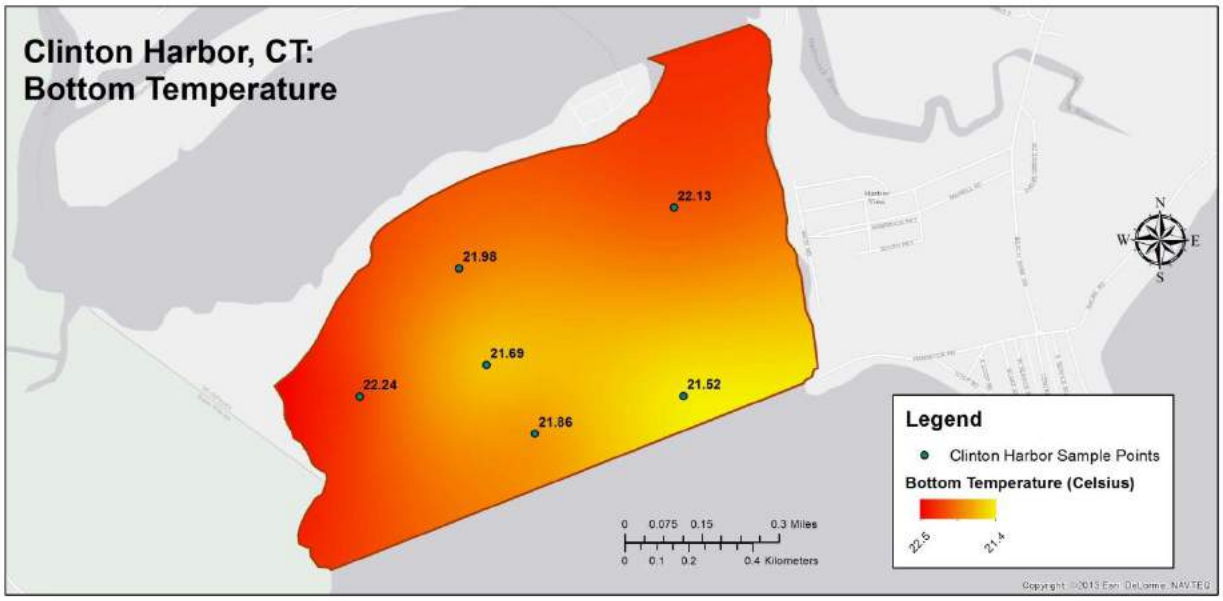


Figure 67: Clinton Harbor: Bottom Temperature.

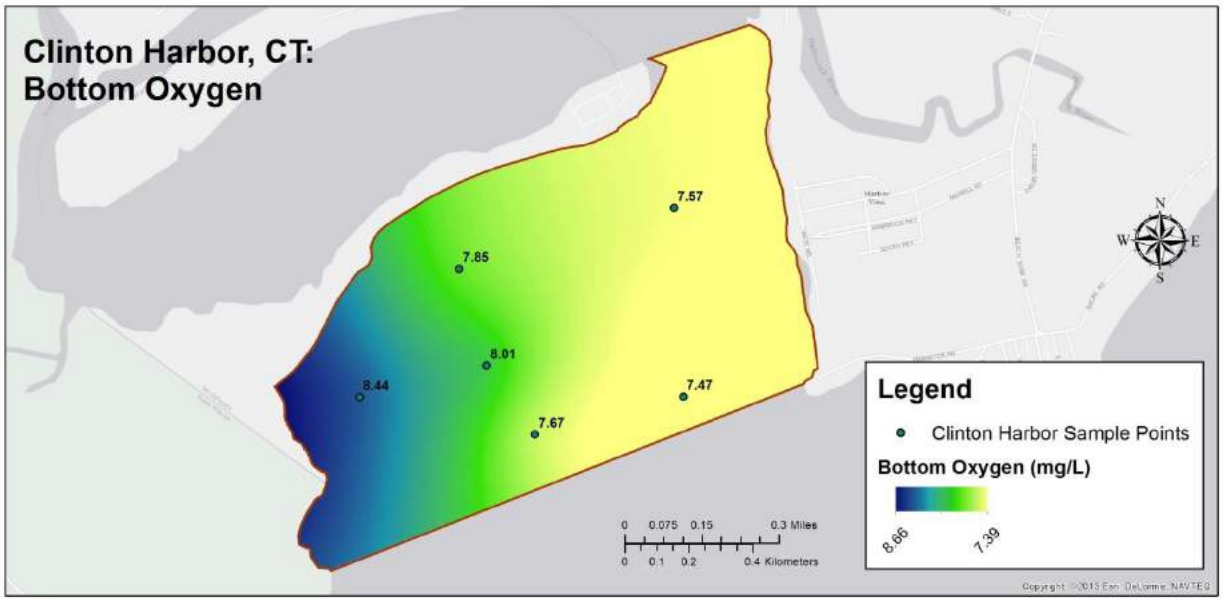


Figure 68: Clinton Harbor, Bottom Oxygen.

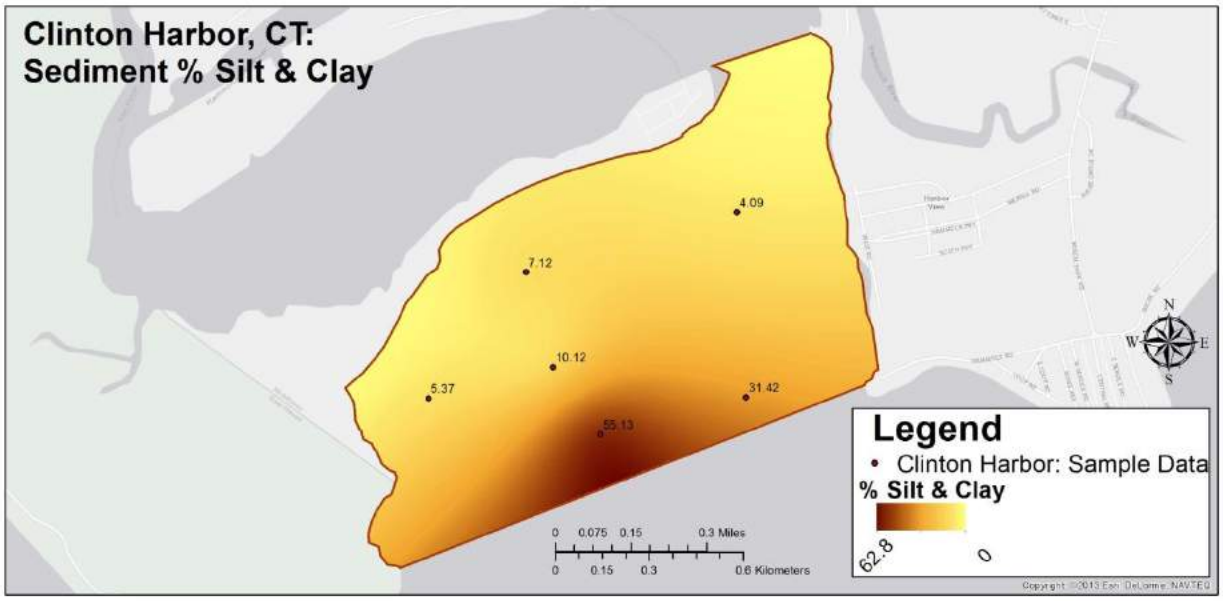


Figure 69: Clinton Harbor, Sediment % Silt & Clay.

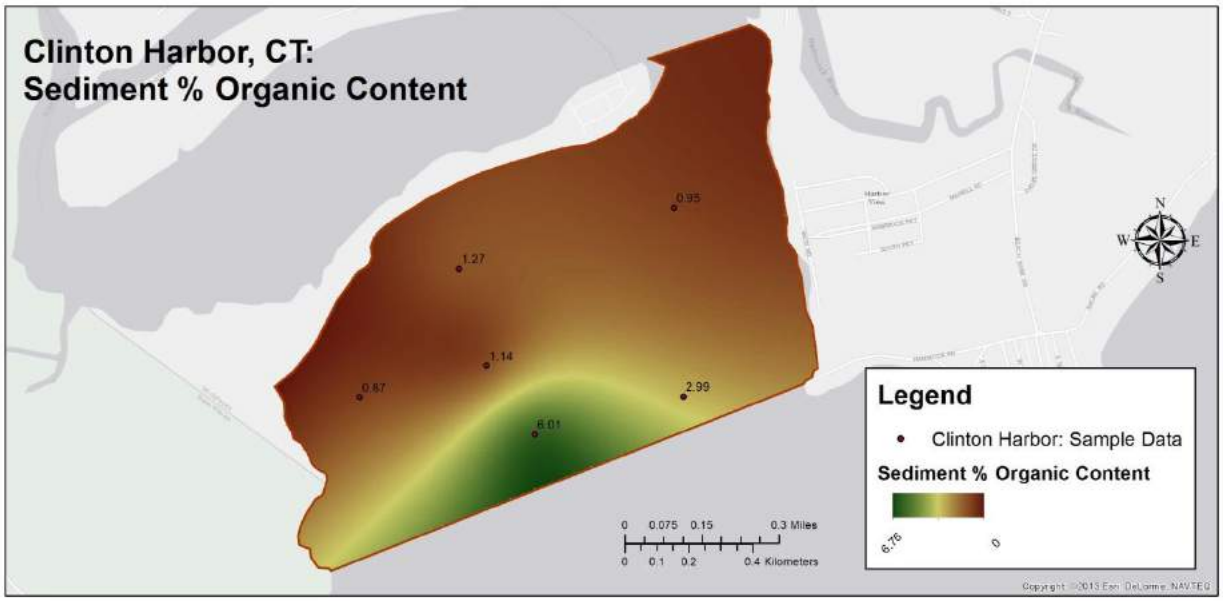


Figure 70: Clinton Harbor, Sediment % Organic Content.

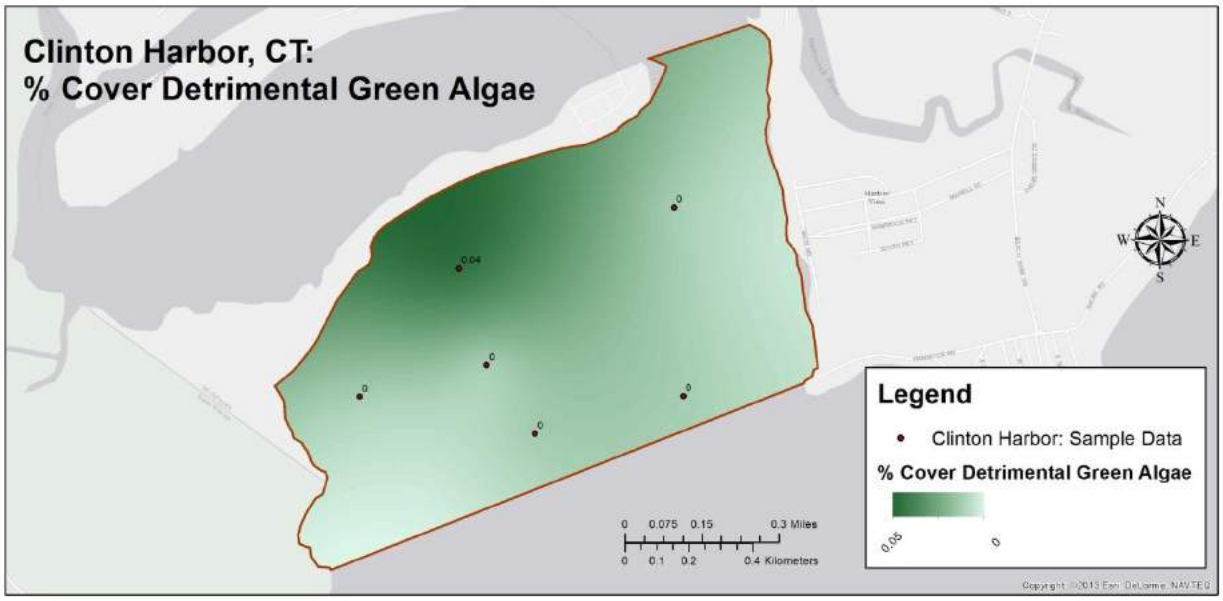


Figure 71: Clinton Harbor, Detrimental Green Algae Cover.

7.5.2 COCKENOE ISLAND INTERPOLATIONS

Data collected during the summer 2012 at Cockenoe Island, CT were interpolated between points and extrapolated to shorelines for full coverage of the geoprocessing boundary using the spline with barrier interpolation scheme. A full description of field data techniques, results, and interpretation of trends is provided in Section 7.3. The following maps present the data used for the EHSI Sub-Model.

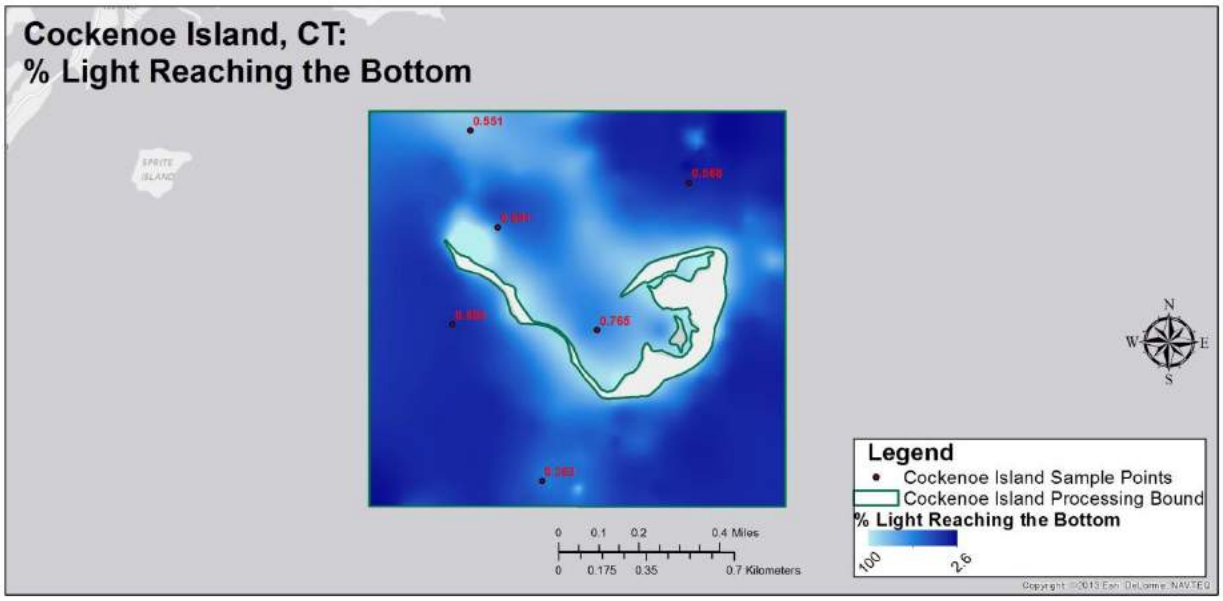


Figure 72: Cockenoe Island, % Light Reaching the Bottom.
The values listed in the plot are for light extinction coefficient (Kd) in units of m^{-1}. The percent of surface light reaching the bottom is calculated using the Kd and depth (see Equation 1, page 32).

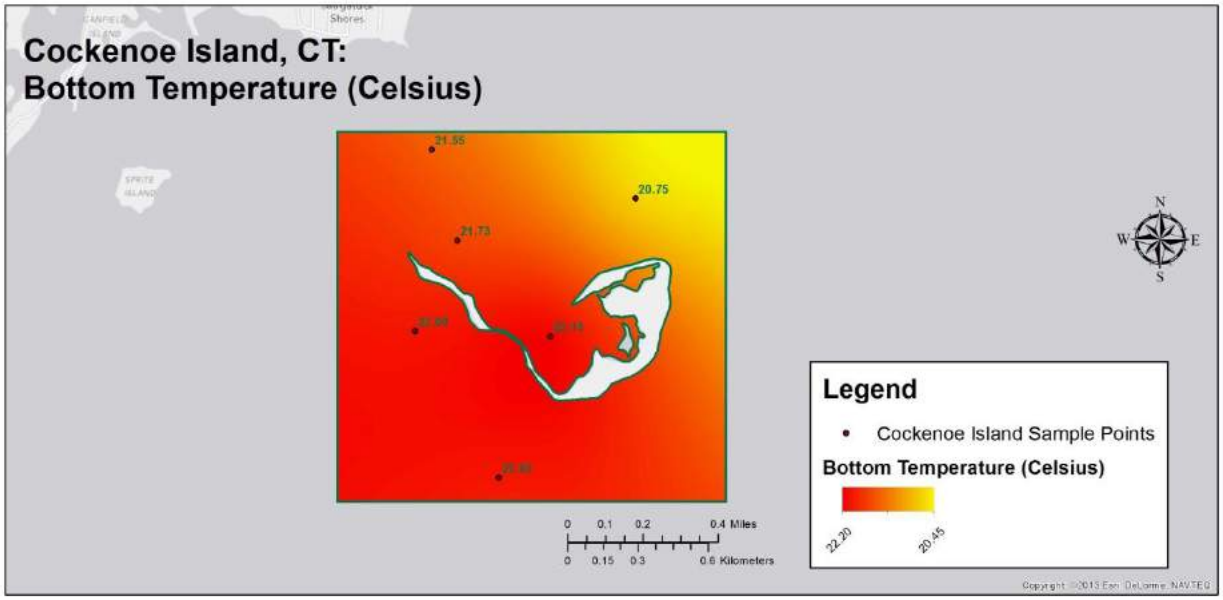


Figure 73: Cockenoe Island, Bottom Temperature.

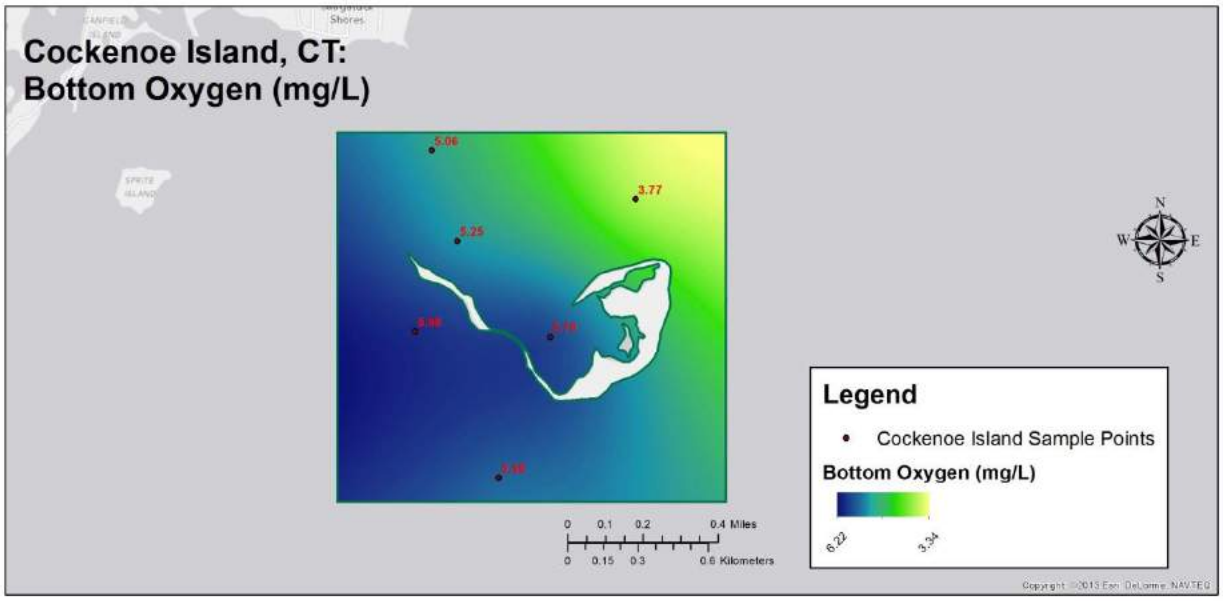


Figure 74: Cockenoe Island, Bottom Oxygen.

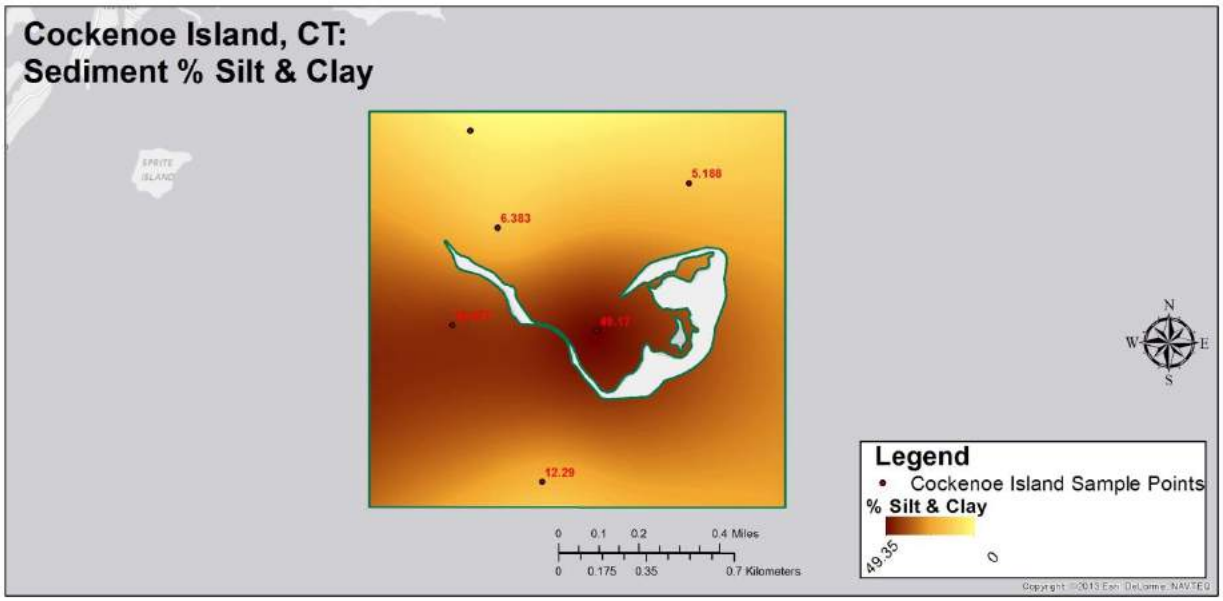


Figure 75: Cockenoe Island, Sediment % Silt & Clay.

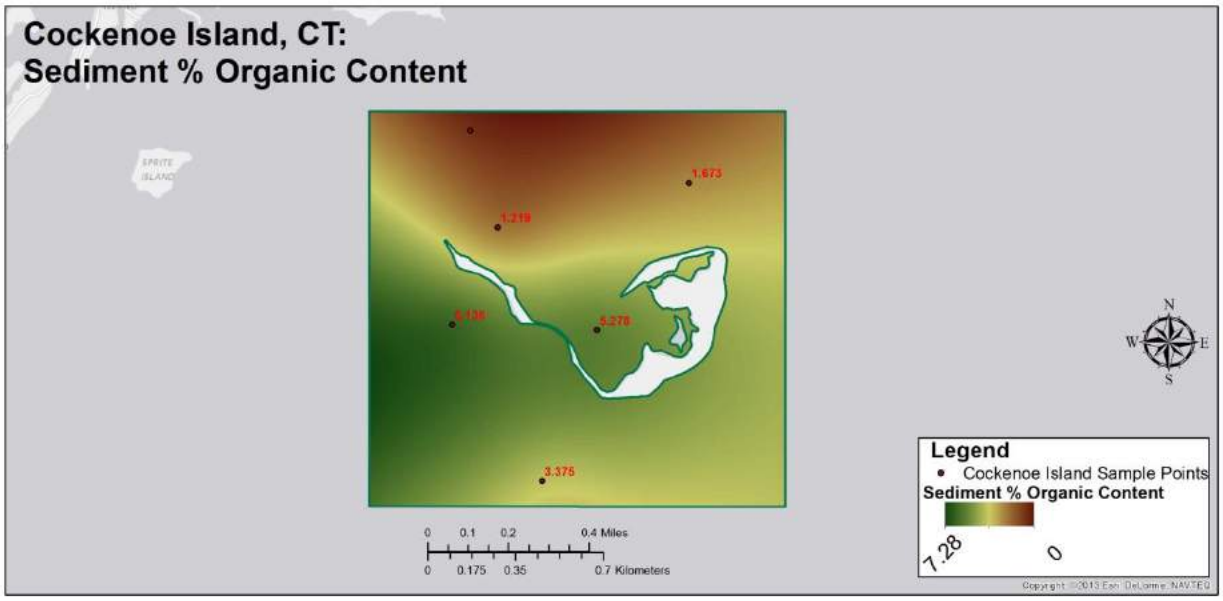


Figure 76: Cockenoe Island, Sediment % Organic Content.

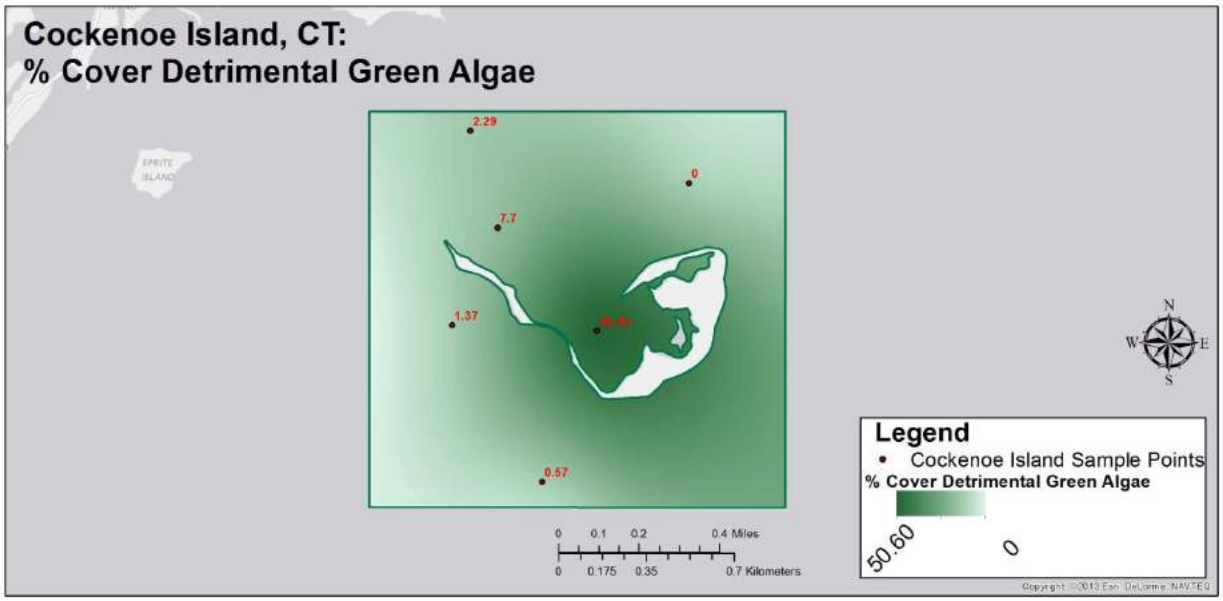


Figure 77: Cockenoe Island, % Detrimental Green Algae Cover.

7.5.3 DUCK POND POINT INTERPOLATIONS

Data collected during the summer 2012 at Duck Pond Point, NY were interpolated between points and extrapolated to shorelines for full coverage of the geoprocessing boundary using the spline with barrier interpolation scheme. A full description of field data techniques, results, and interpretation of trends is provided in Section 7.3. The following maps present the data used for the EHSI Sub-Model.

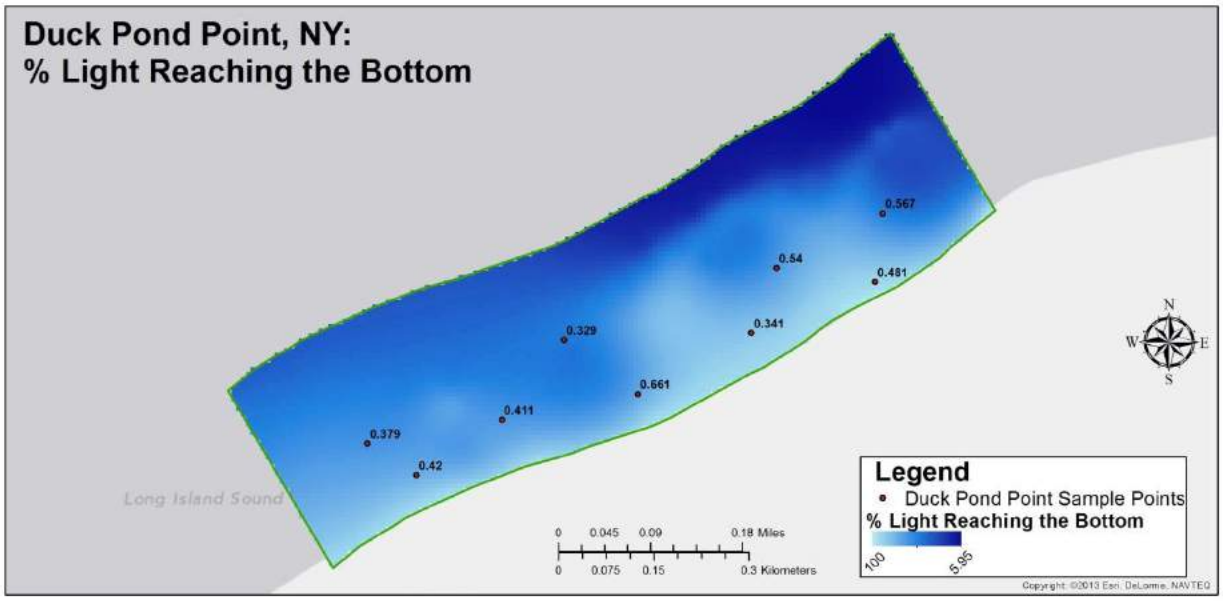


Figure 78: Duck Pond Point, % Light Reaching the Bottom.
The values listed in the plot are for light extinction coefficient (Kd) in units of m^{-1}. The percent of surface light reaching the bottom is calculated using the Kd and depth (see Equation 1, page 32).

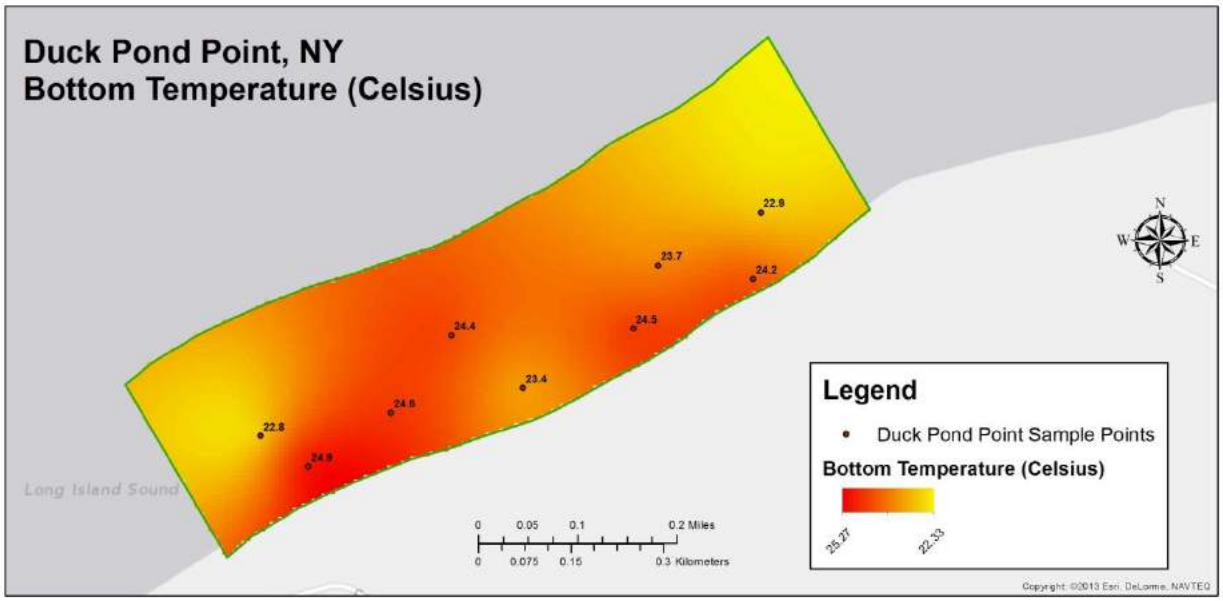


Figure 79: Duck Pond Point, Bottom Temperature.

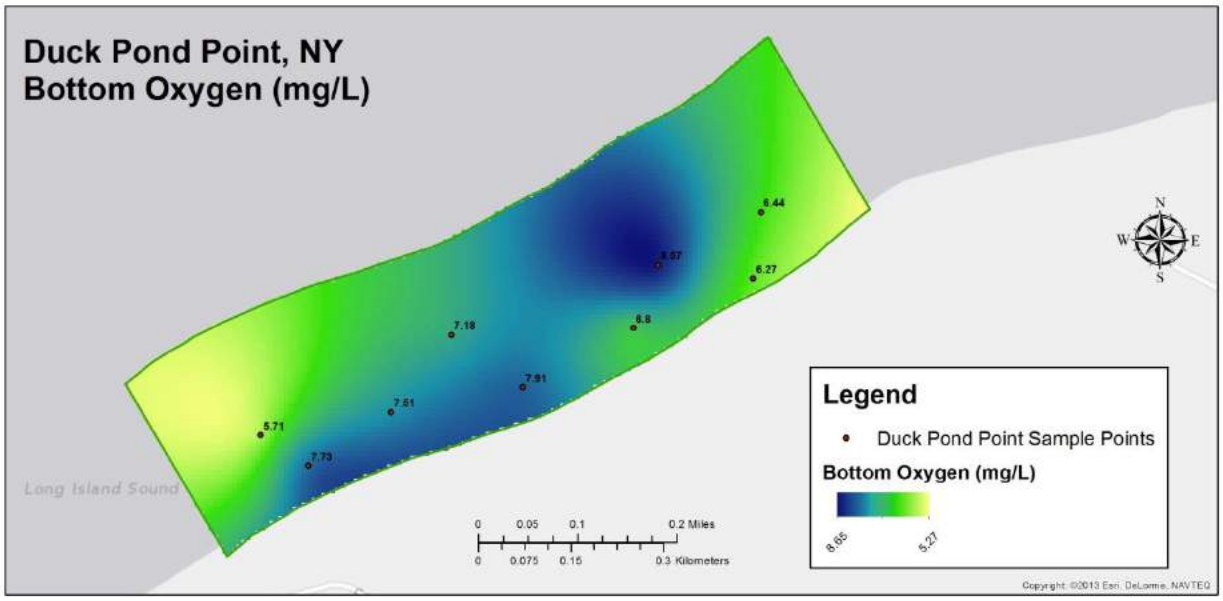


Figure 80: Duck Pond Point, Bottom Oxygen.

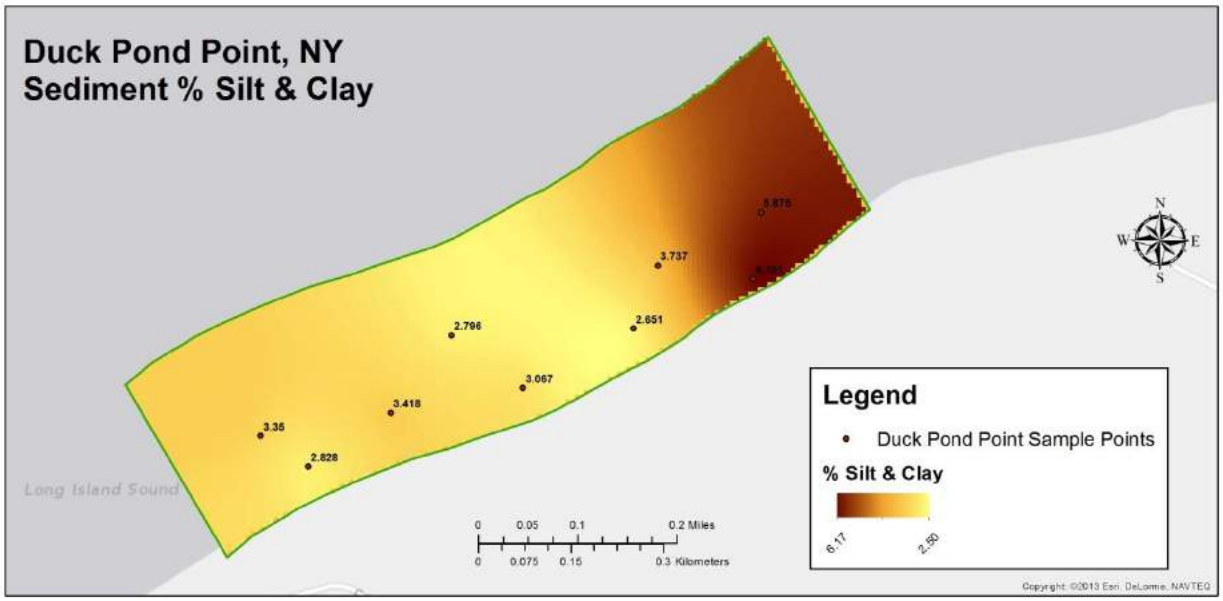


Figure 81: Duck Pond Point, Sediment % Silt & Clay.

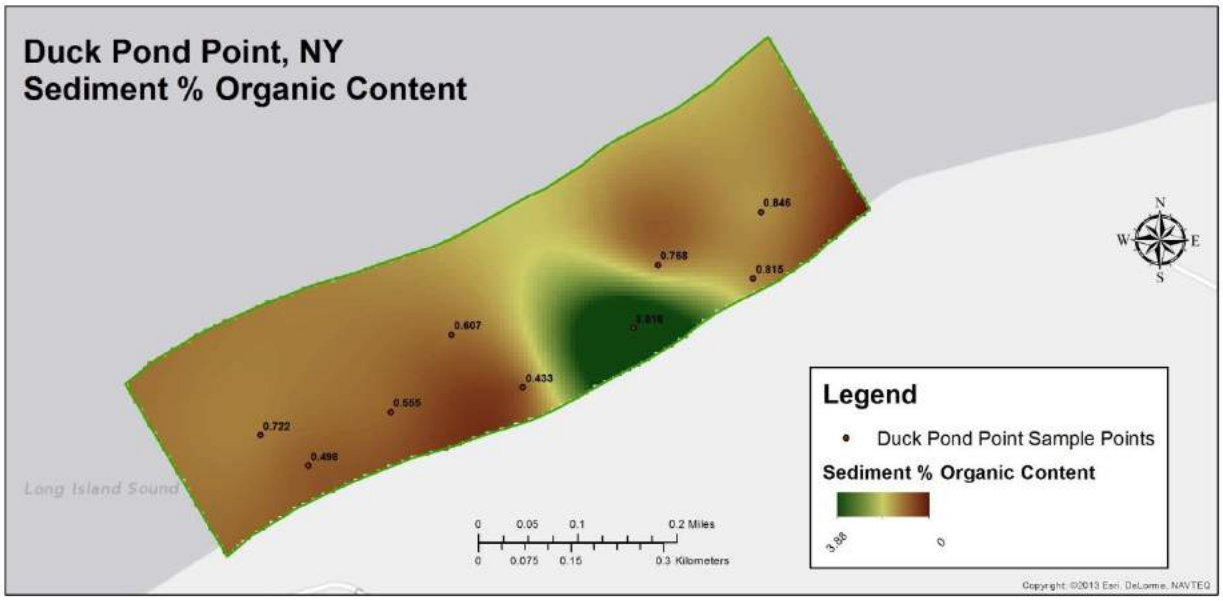


Figure 82: Duck Pond Point, Sediment % Organic Content.

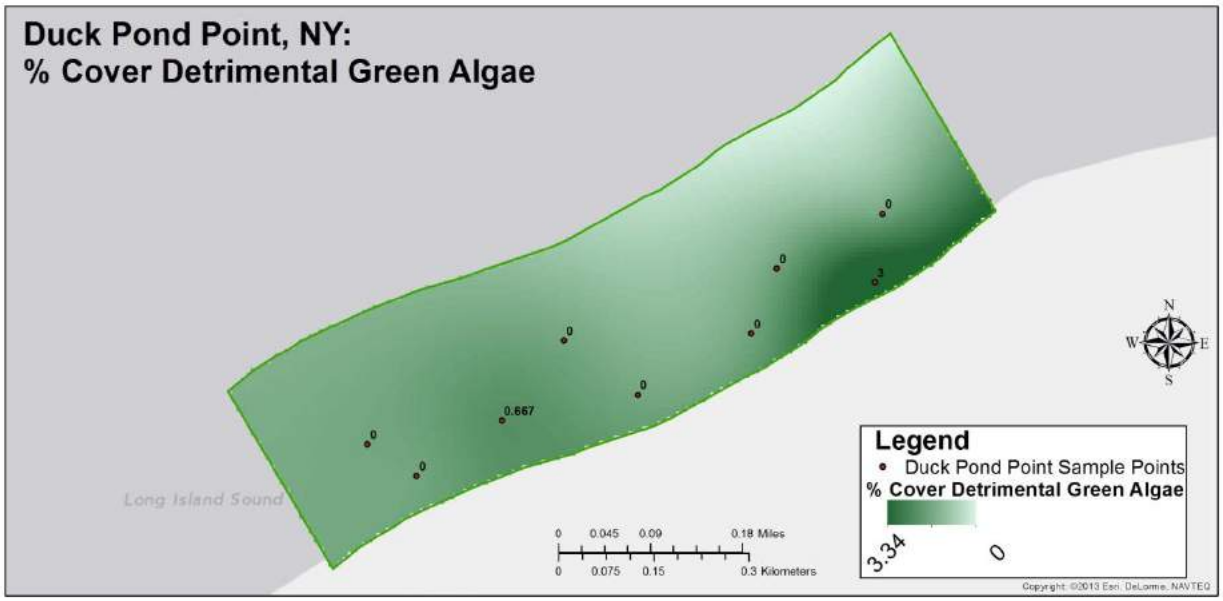


Figure 83: Duck Pond Point, % Detrimental Green Algae Cover.

7.5.4 NIANTIC BAY INTERPOLATIONS

Data collected during the summer 2012 in Niantic Bay, CT were interpolated between points and extrapolated to shorelines for full coverage of the geoprocessing boundary using the spline with barrier interpolation scheme. A full description of field data techniques, results, and interpretation of trends is provided in Section 7.3. The following maps present the data used for the EHSI Sub-Model.

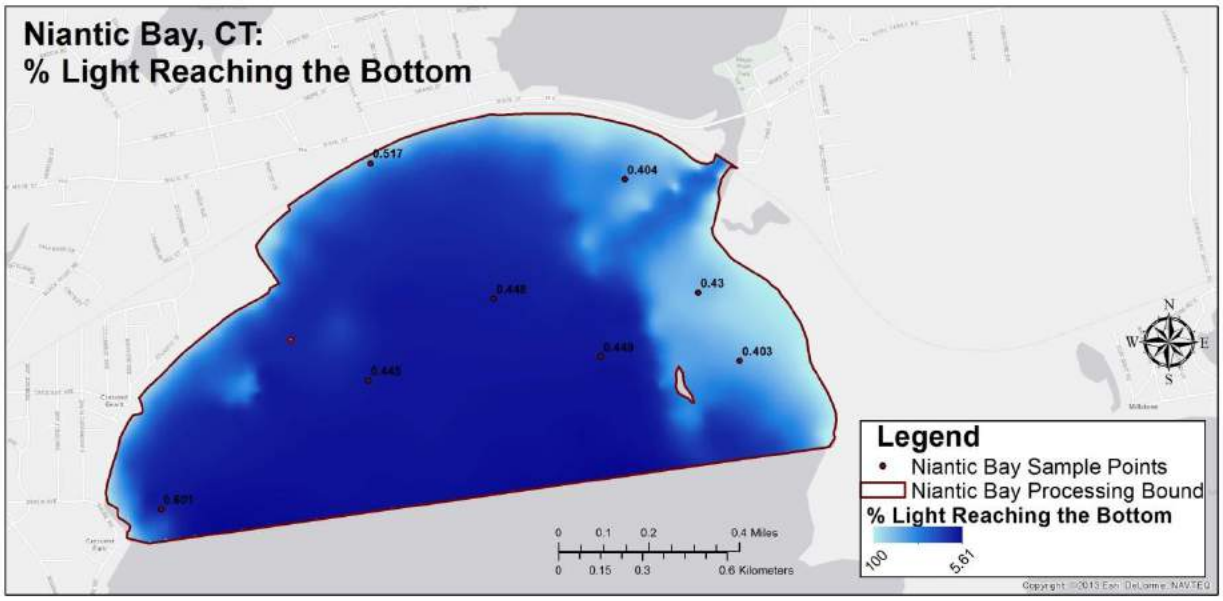


Figure 84: Niantic Bay, % Light Reaching the Bottom

The values listed in the plot are for light extinction coefficient (Kd) in units of m^{-1}. The percent of surface light reaching the bottom is calculated using the Kd and depth (see Equation 1, page 32).

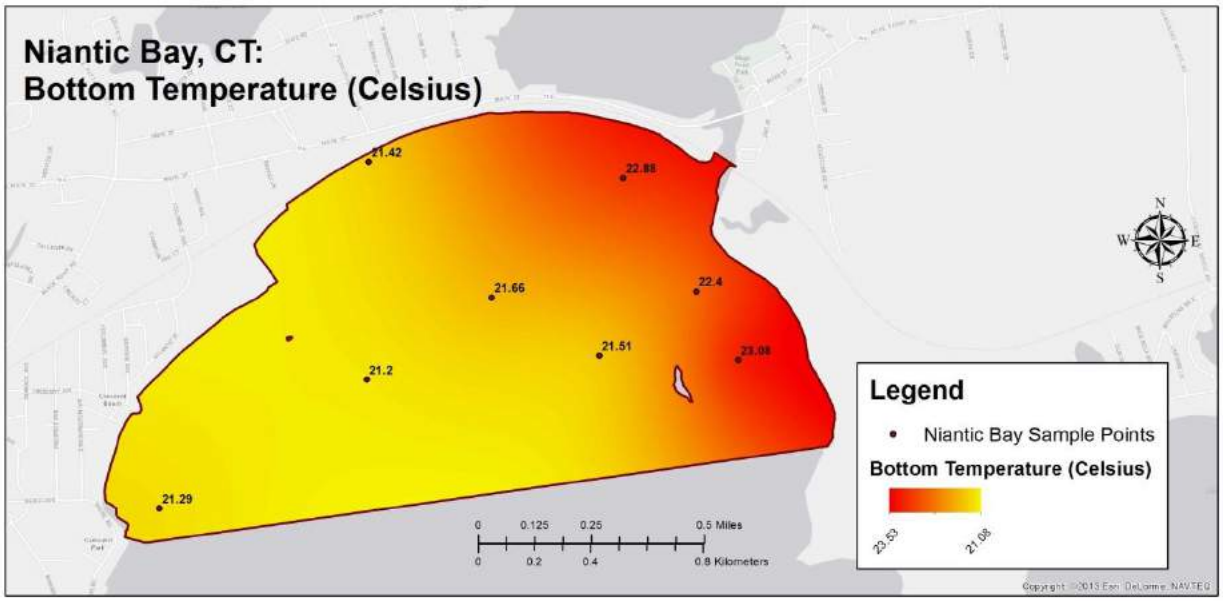


Figure 85: Niantic Bay, Bottom Temperature.

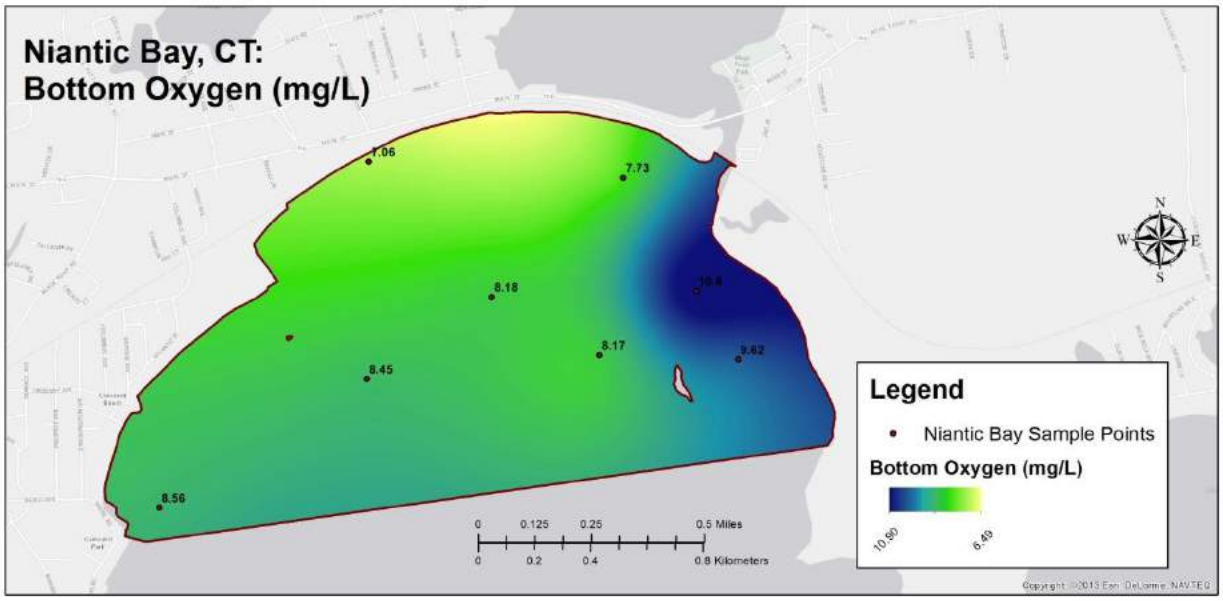


Figure 86: Niantic Bay, Bottom Oxygen.

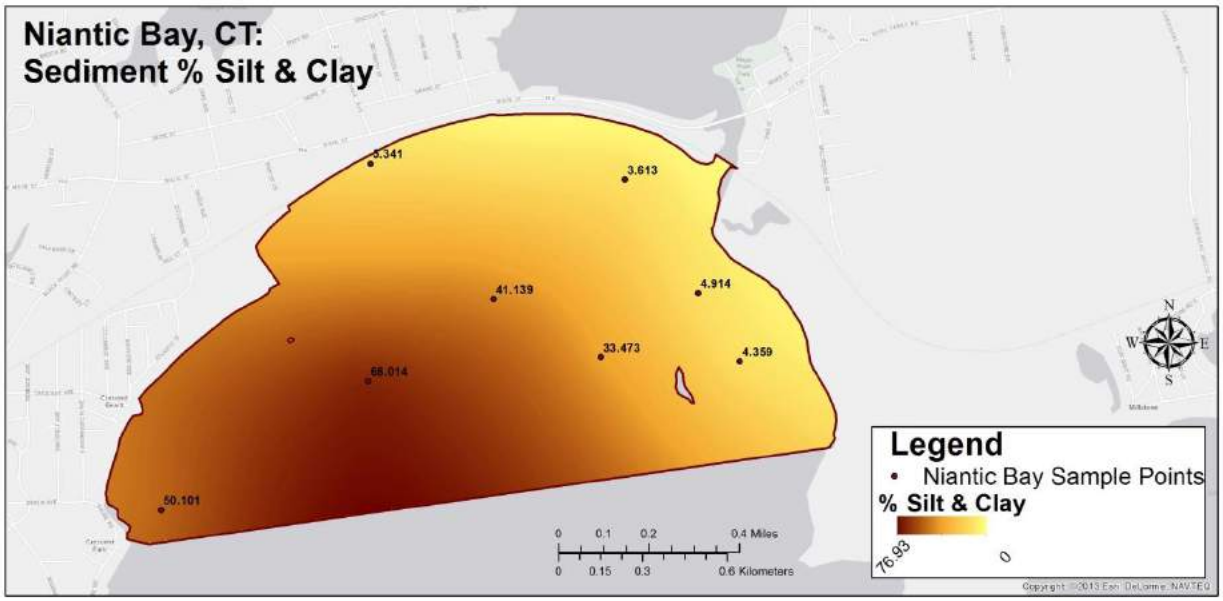


Figure 87: Niantic Bay, Sediment % Silt & Clay.

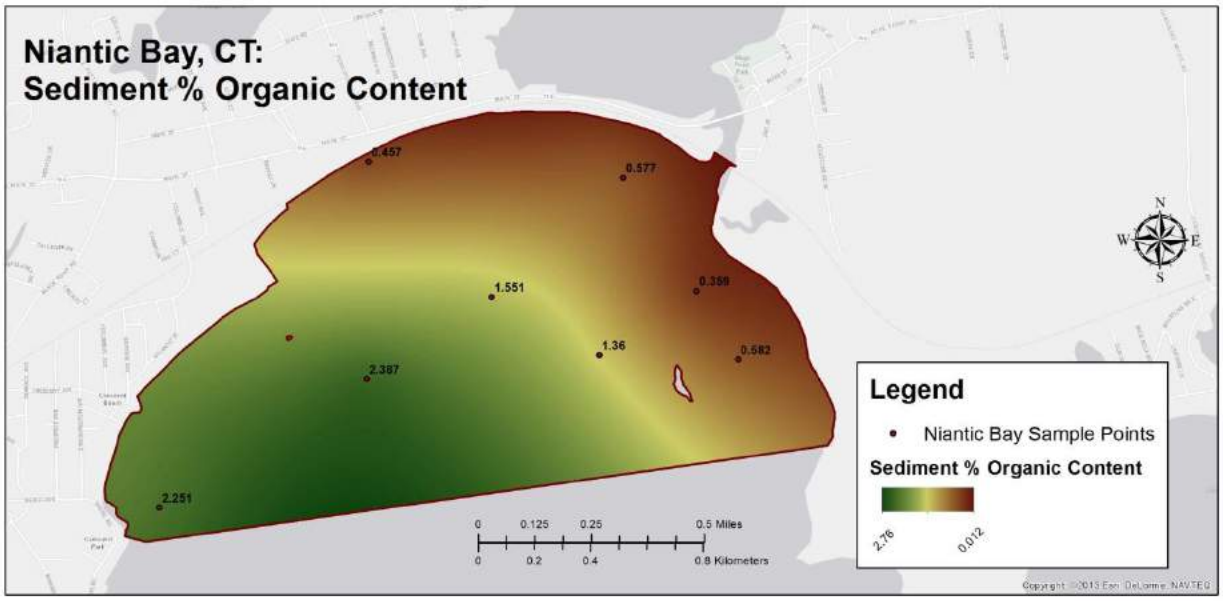


Figure 88: Niantic Bay, Sediment % Organic Content.

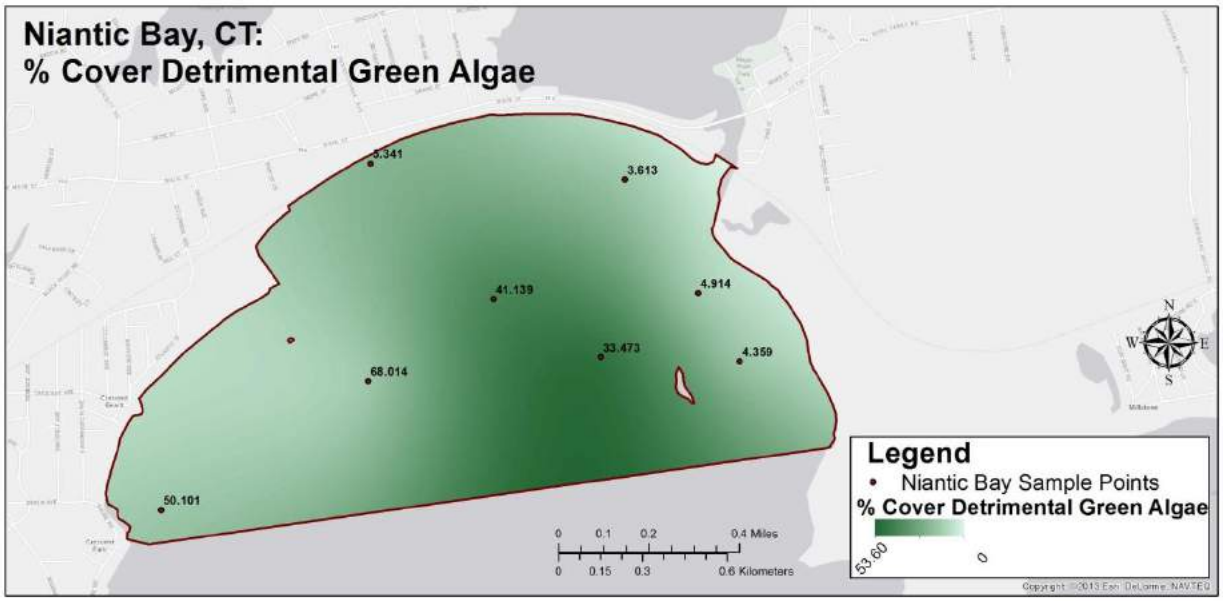


Figure 89: Niantic Bay, % Detrimental Green Algae Cover.

7.5.5 PETTY'S BIGHT INTERPOLATIONS

Data collected during the summer 2012 at Petty's Bight, NY were interpolated between points and extrapolated to shorelines for full coverage of the geoprocessing boundary using the spline with barrier interpolation scheme. A full description of field data techniques, results, and interpretation of trends is provided in Section 7.3. The following maps present the data used for the EHSI Sub-Model.

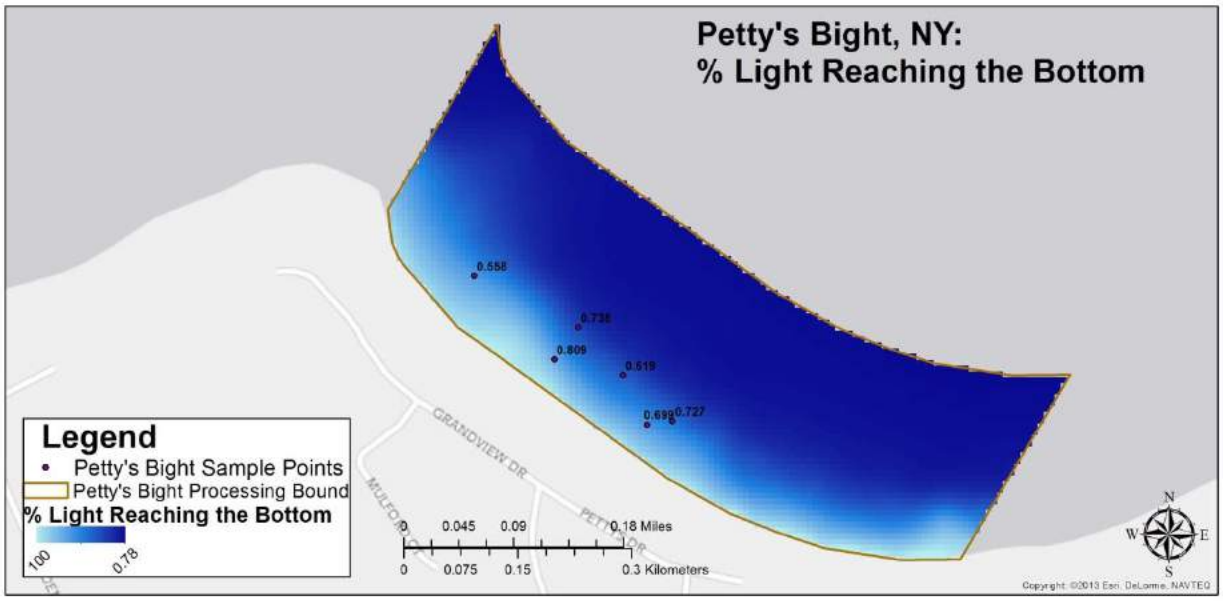


Figure 90: Petty's Bight, % Light Reaching the Bottom.
The values listed in the plot are for light extinction coefficient (Kd) in units of m^{-1}. The percent of surface light reaching the bottom is calculated using the Kd and depth (see Equation 1, page 32).

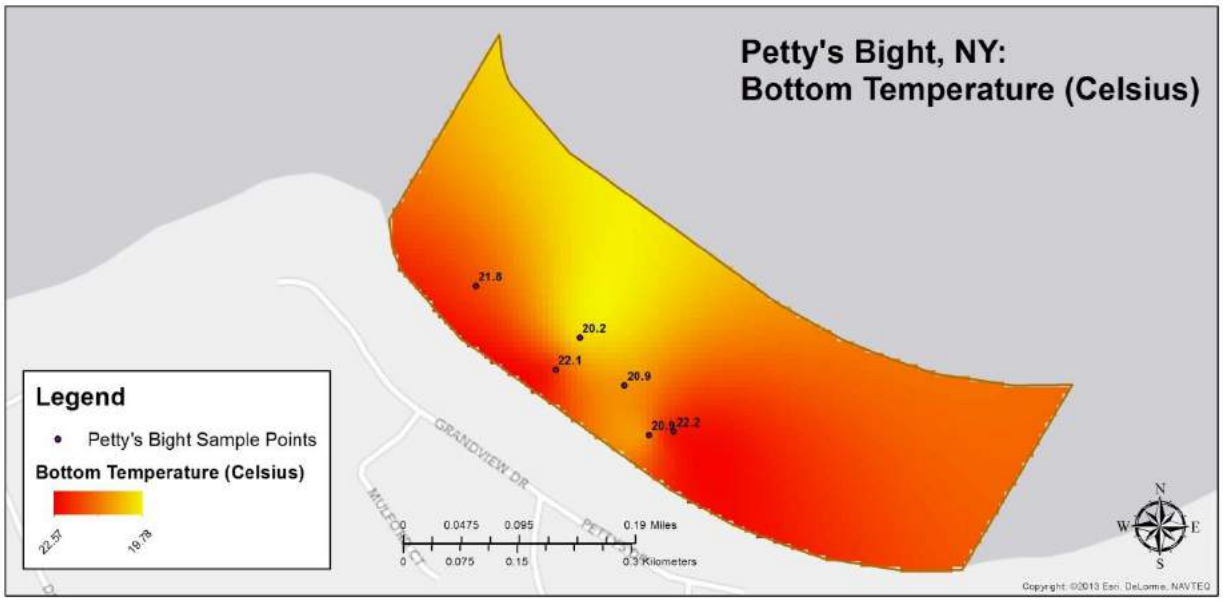


Figure 91: Petty's Bight, Bottom Temperature.

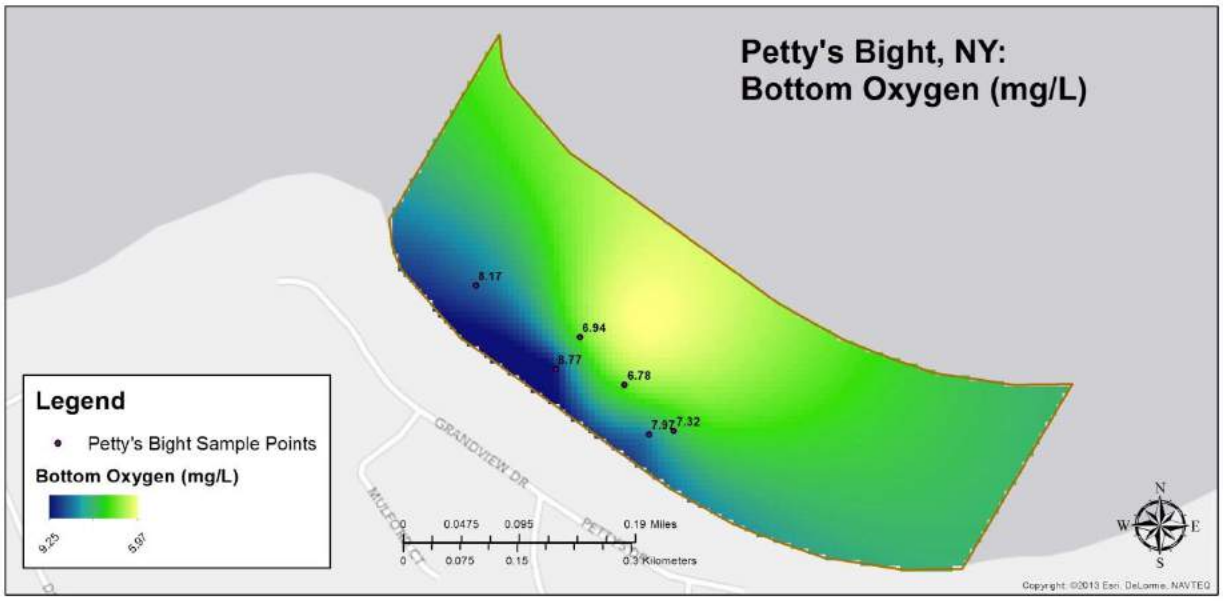


Figure 92: Petty's Bight, Bottom Oxygen.

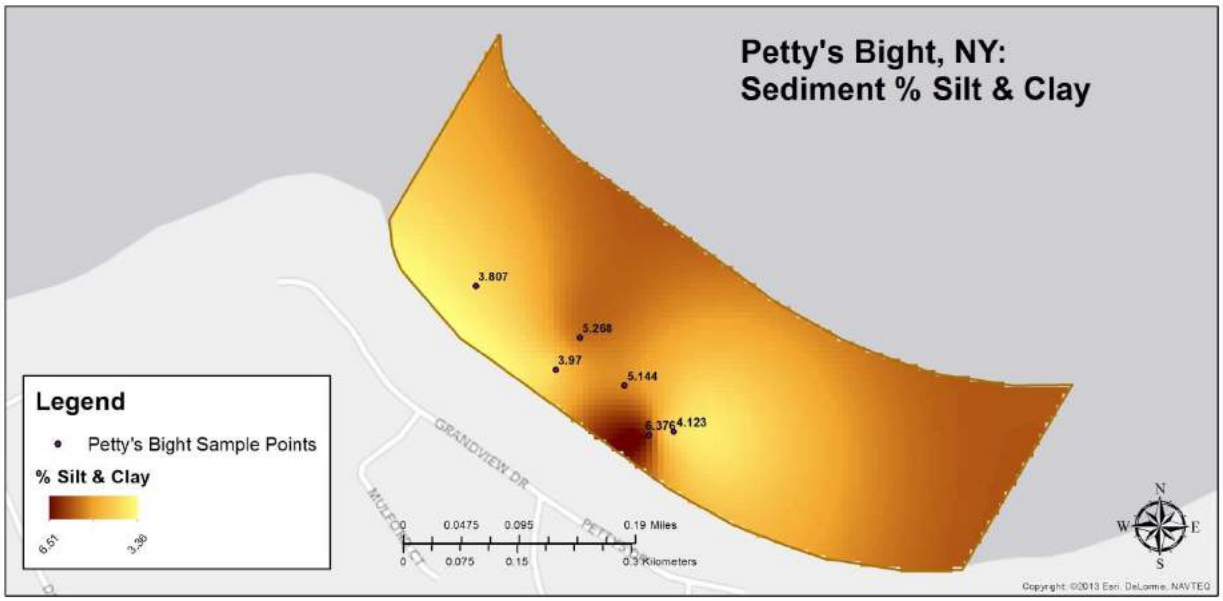


Figure 93: Petty's Bight, Sediment % Silt & Clay.

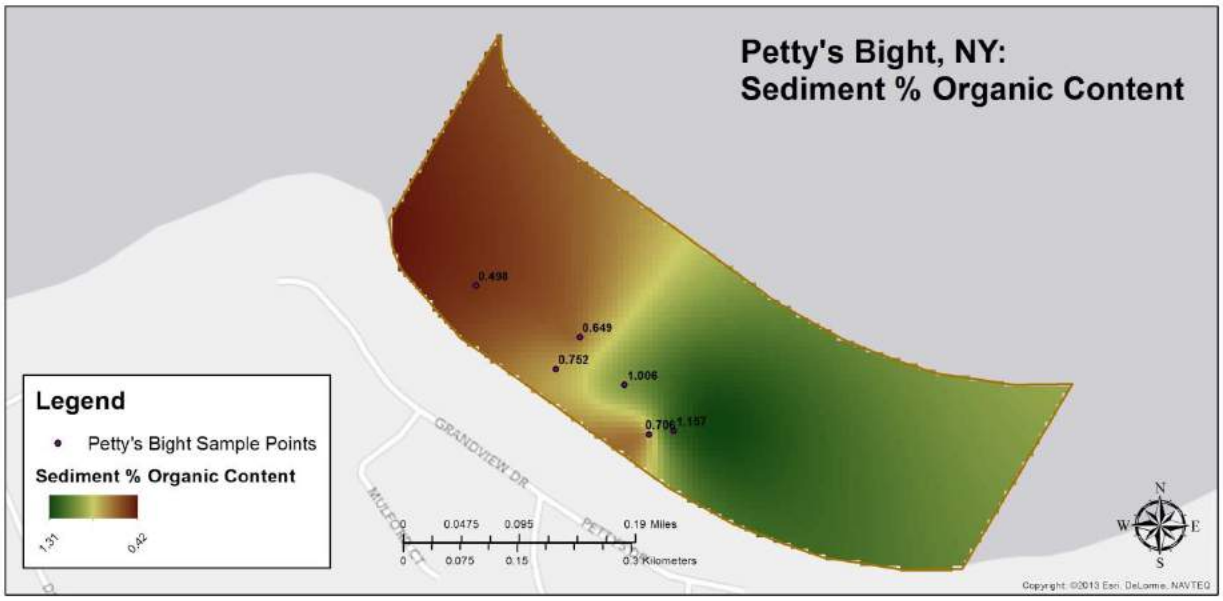


Figure 94: Petty's Bight, Sediment % Organic Content.

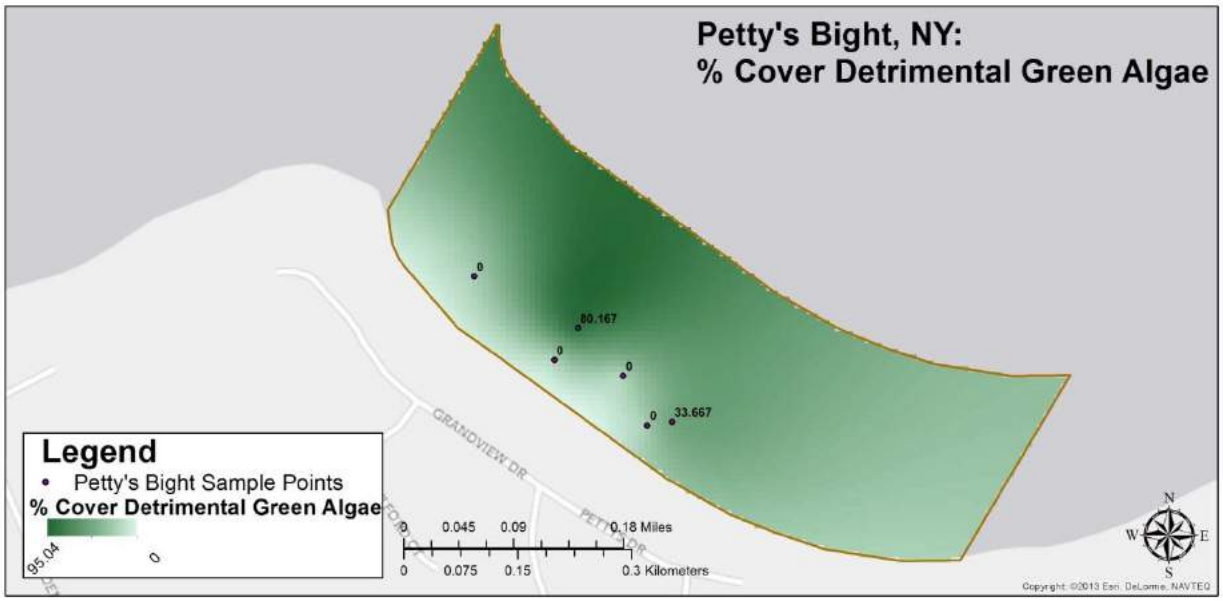


Figure 95: Petty's Bight, % Detrimental Green Algae Cover.

7.5.6 ST. THOMAS POINT INTERPOLATIONS

Data collected during the summer 2012 at St. Thomas Point, NY were interpolated between points and extrapolated to shorelines for full coverage of the geoprocessing boundary using the spline with barrier interpolation scheme. A full description of field data techniques, results, and interpretation of trends is provided in Section 7.3. The following maps present the data used for the EHSI Sub-Model.

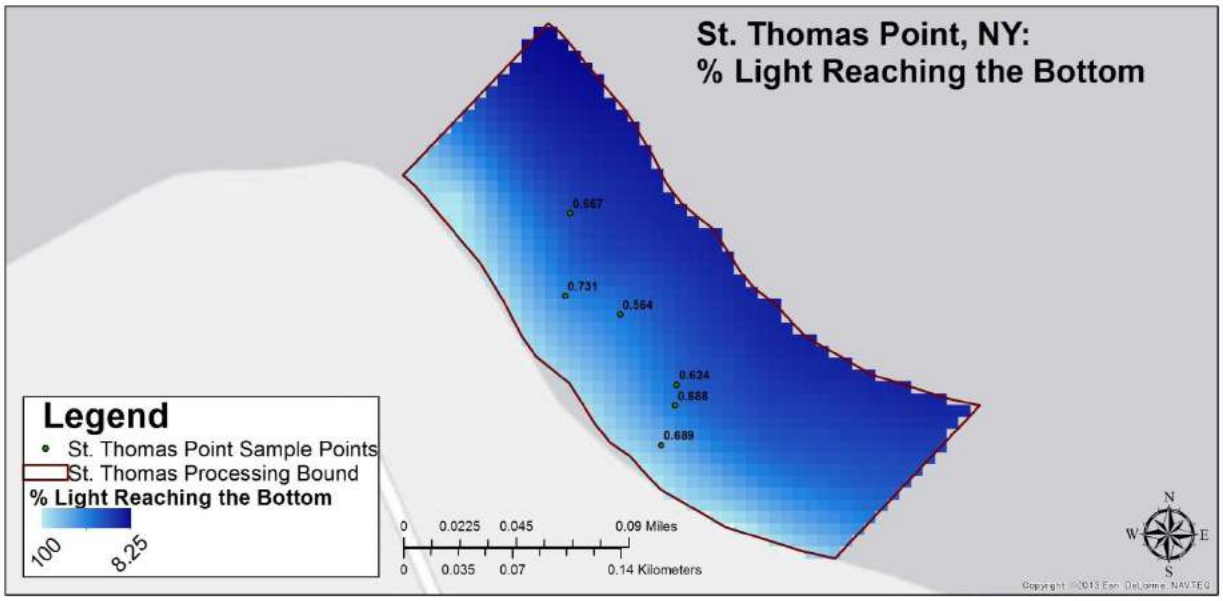


Figure 96: St. Thomas Point, % Light Reaching the Bottom.
The values listed in the plot are for light extinction coefficient (Kd) in units of m^{-1}. The percent of surface light reaching the bottom is calculated using the Kd and depth (see Equation 1, page 32).

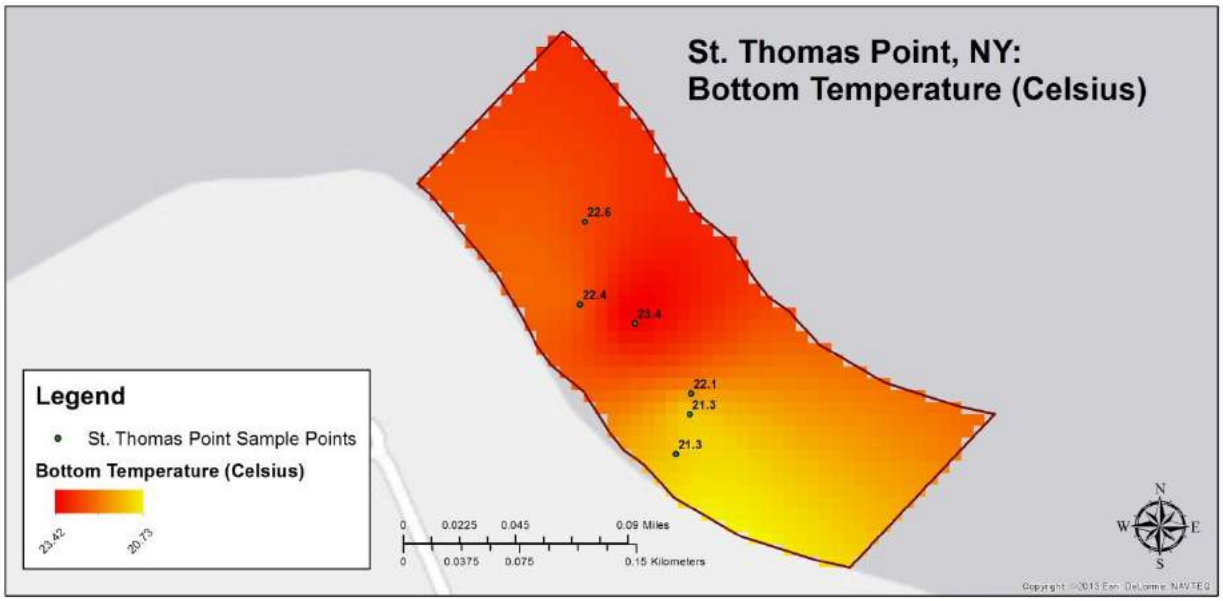


Figure 97: St. Thomas Point, Bottom Temperature.

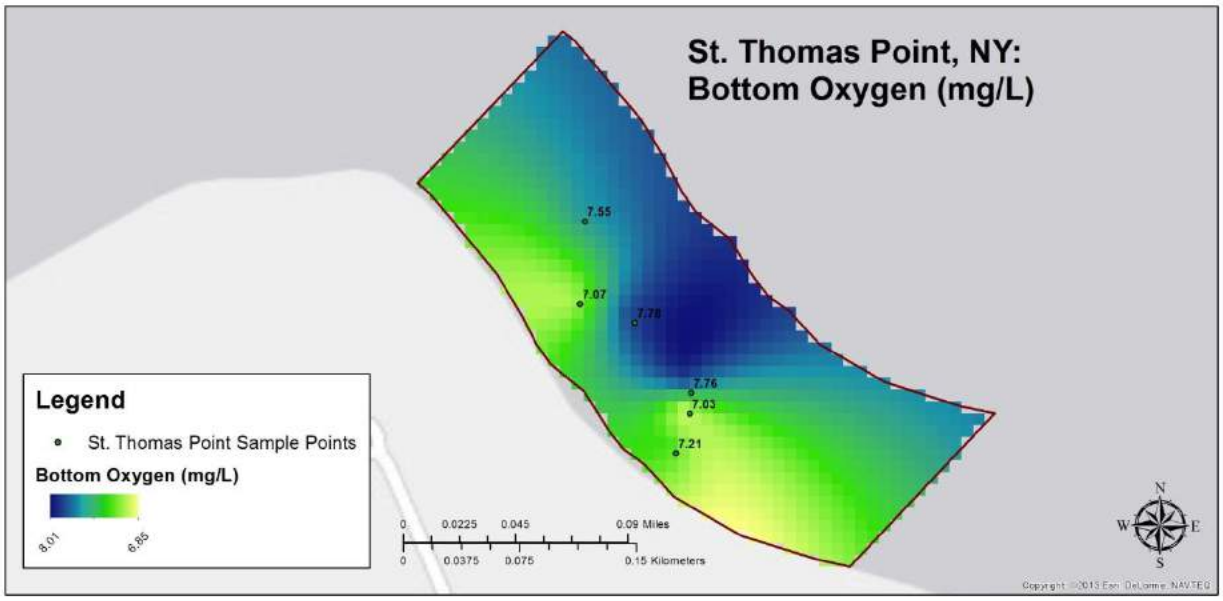


Figure 98: St. Thomas Point, Bottom Oxygen.

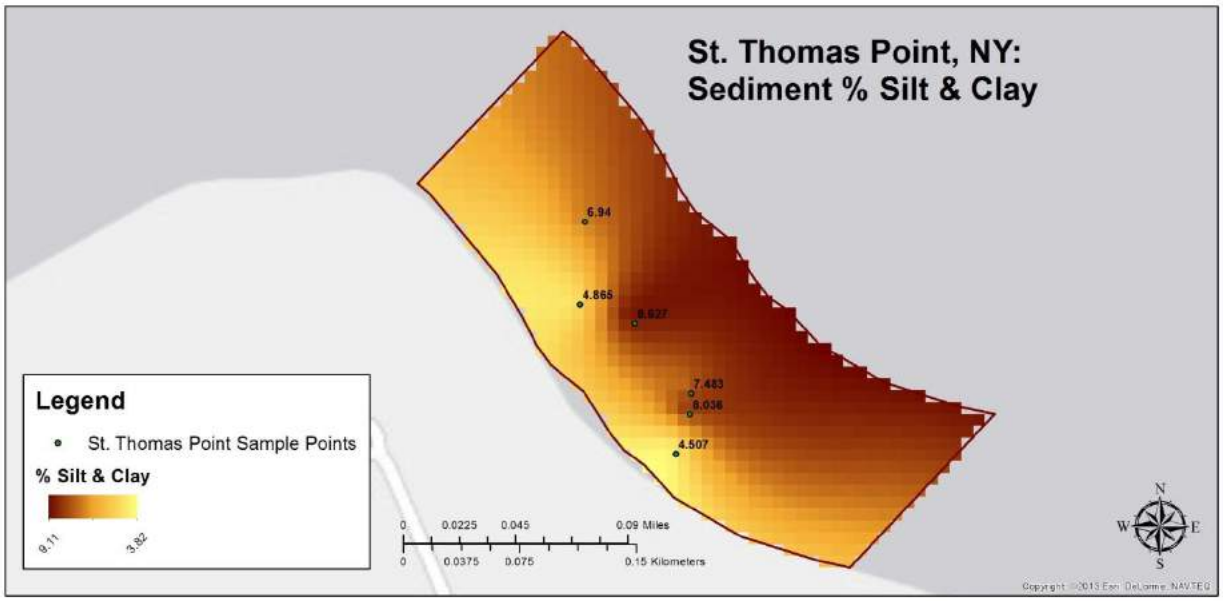


Figure 99: St. Thomas Point, Sediment % Silt & Clay.

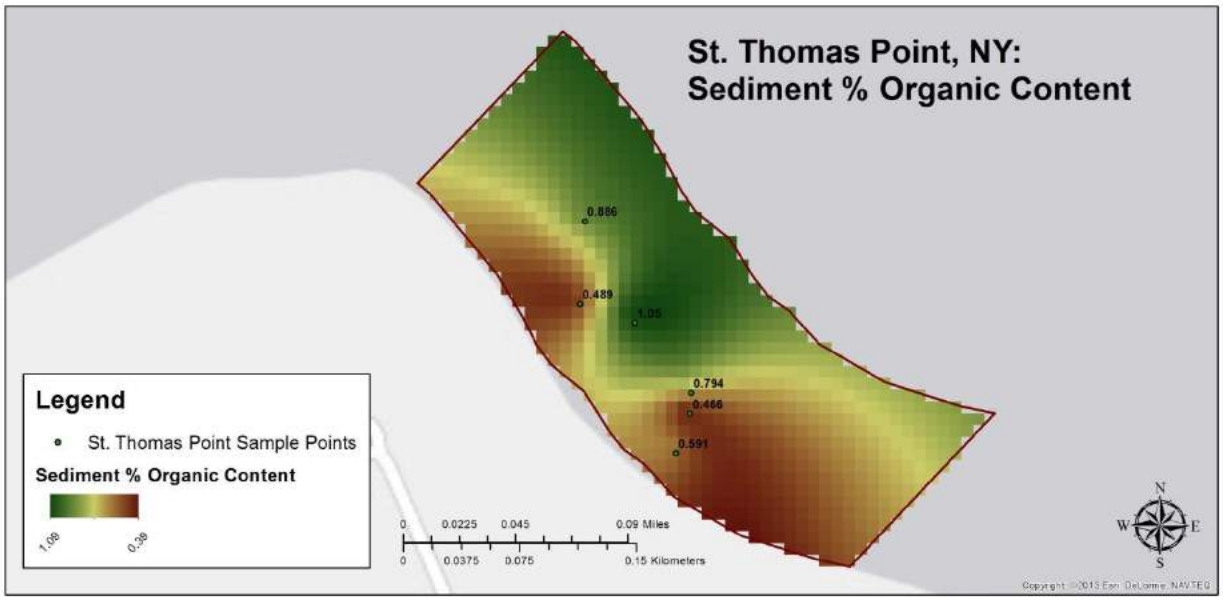


Figure 100: St. Thomas Point, Sediment % Organic Content.

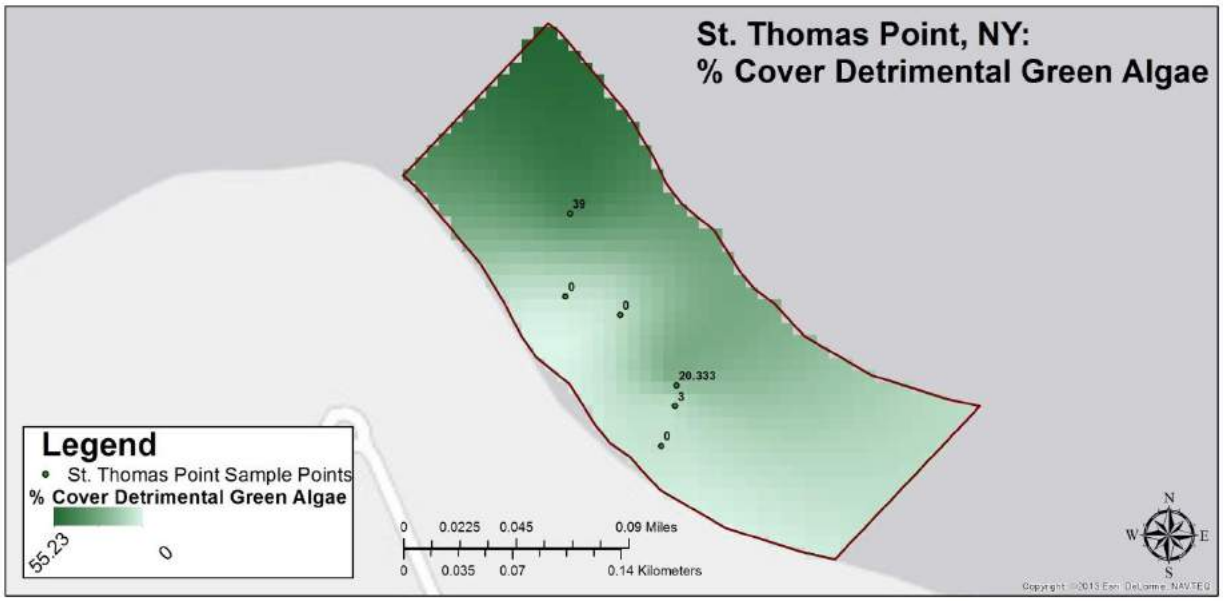


Figure 101: St. Thomas Point, % Detrimental Green Algae Cover.

7.6 Case Study Site EHSI Sub-Model Weightings and Results

The six selected parameters were reclassified within the range defined as critical for eelgrass site suitability, using the same ranges as were applied in the EHSI Model (Table 17).

The model for the case study sites was evaluated using the same weighting scheme for the five parameters as used in the EHSI Model (Table 18, "EHSI Model"). This weighting scheme for the model did not include the effect of detrimental green macroalgae. To include the detrimental green macroalgae, three adjustments to the weighting scheme were compared.

The results shown below for model output are from the "best model" which proved to be Adjustment 2 (see Section 7.7 for a description of the calibration and skill assessment). The results of the *ArcGIS Model Builder* for each case study site returned model site suitability scores as high as 97 in Clinton Harbor (Section 7.6.1) and as low as 32 at Cockenoe Island and in Niantic Bay (Sections 7.6.2 and 7.6.4). Review of each of the six case study site model outputs can lead to identification within a site of the location with the highest likelihood of success.

Table 17: EHSI Sub-Model Reclassification of Parameters.
Parameters were reclassified within the ranges shown. The actual model score varies with the weighting assigned to each parameter (Table 18).

Parameter	Range	Minimum Score (0)	Maximum Score
% Light Reaching the Bottom	25-50%	< 25 %	> 50 %
Temperature	21-25°C	> 25°C	< 21°C
Bottom Oxygen	3-6 mg/L	< 3 mg/L	> 6 mg/L
Sediment: % Silt & Clay	2-20%	> 20 %	< 2 %
Sediment: % Organic Content	0.5-10%	> 10 %	< 0.5 %
% Detrimental Green Algae	10-50%	> 50 %	< 10 %

Table 18: EHSI Sub-Model Structure
Weighted parameters from the LIS-wide calibrated model and adjustments including green macroalgae.

Parameter	EHSI Model	Adj1	Adj2	Adj3
% Light Reaching the Bottom	30	30	30	30
Bottom Temperature	20	14	15	18
Bottom Oxygen	10	9	10	8
Sediment % Silt & Clay	20	13	15	18
Sediment % Organic Content	20	14	15	18
% Detrimental Green Algae Cover	0	20	15	8

7.6.1 CLINTON HARBOR RESULTS

Each interpolated parameter from Clinton Harbor, CT was reclassified into a weighted ranking. The range for reclassification and the structure of the model rankings are provided in Section 7.6. The model score for each parameter was summed to yield the model score for the case study site. Figures shown are for the model weighting scheme "Adjustment 2" (see Table 18, Section 7.6), which includes the detrimental green algae. The model output from the case study sites using the LIS-wide weighting scheme (no macroalgae) is compared to the EHSI Model output in Section 8 (page 146).

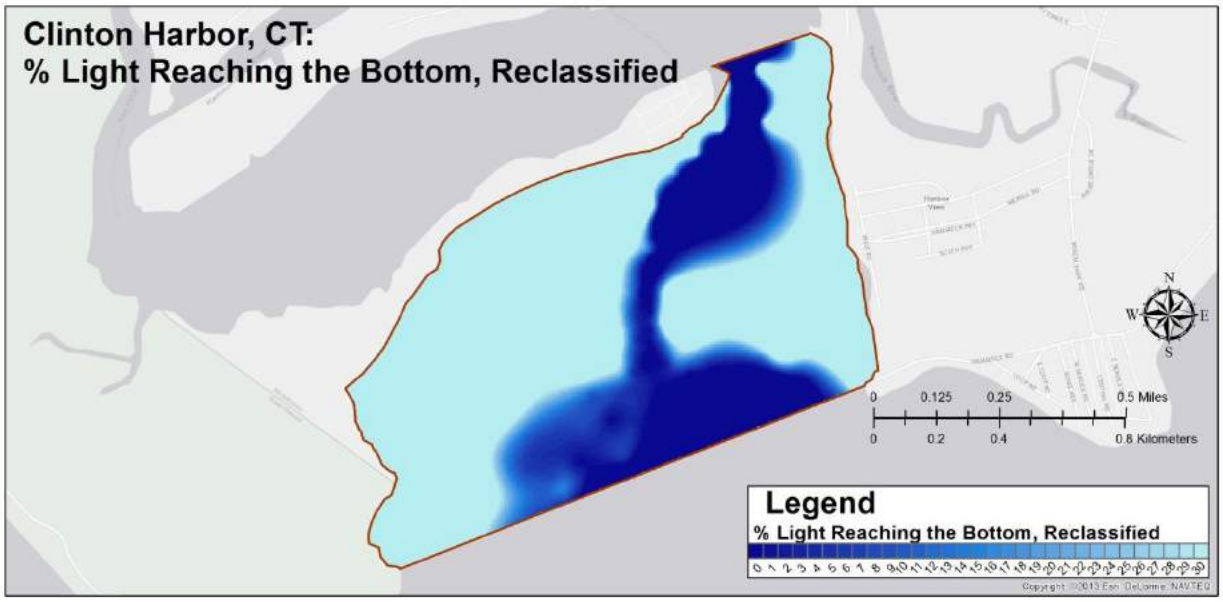


Figure 102: Clinton Harbor, % Light Reaching the Bottom Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

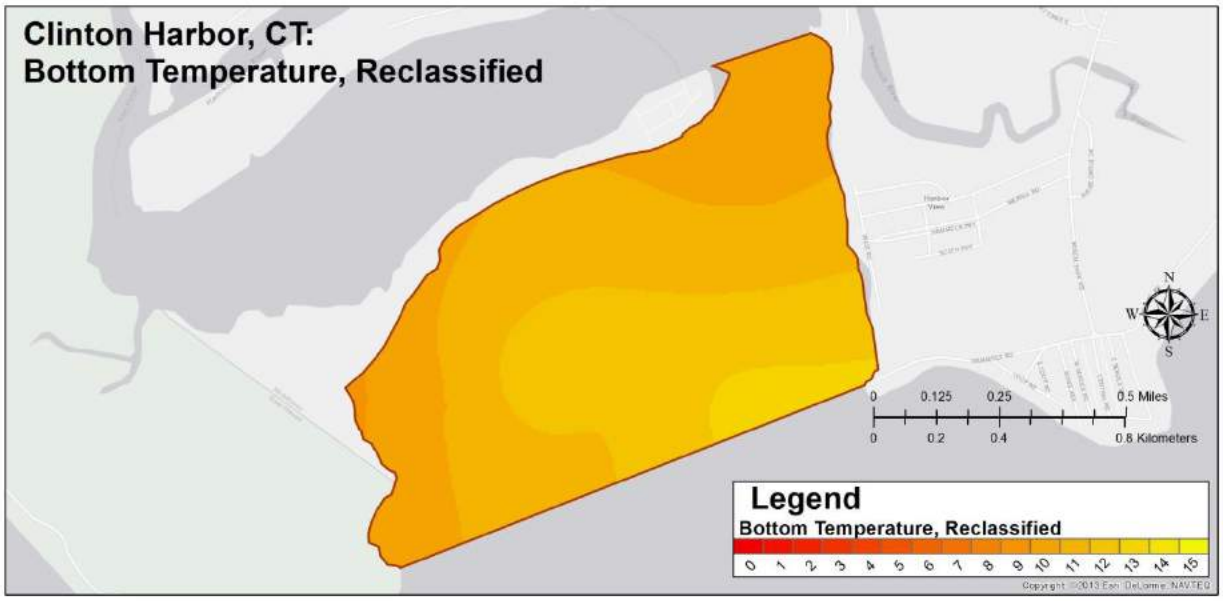


Figure 103: Clinton Harbor, Bottom Temperature Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

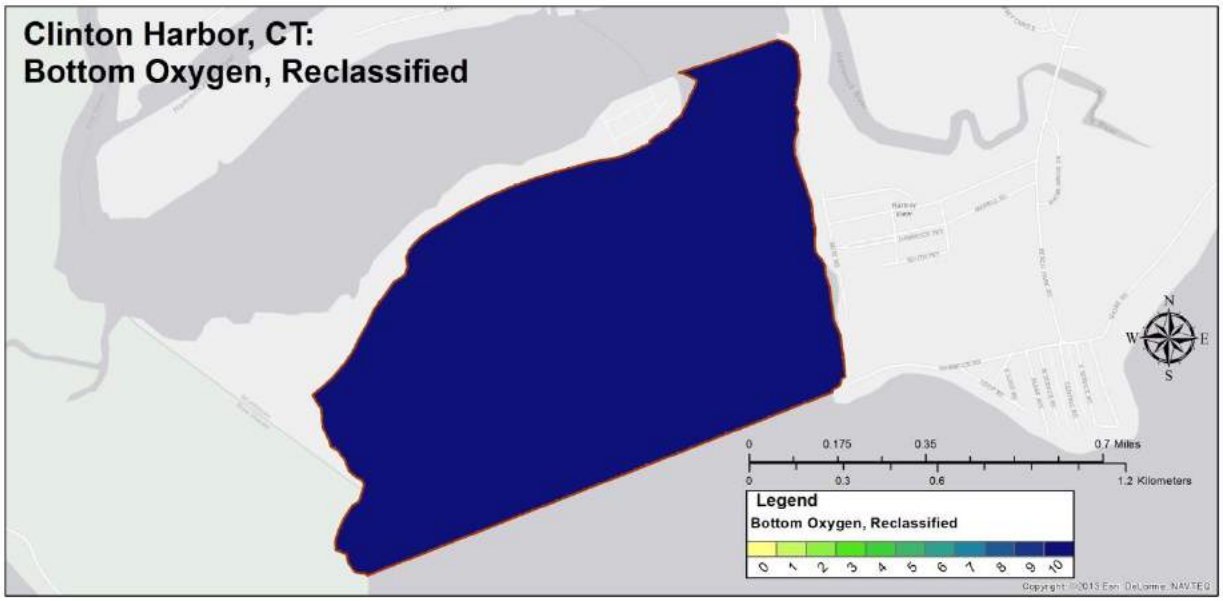


Figure 104: Clinton Harbor: Bottom Oxygen Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

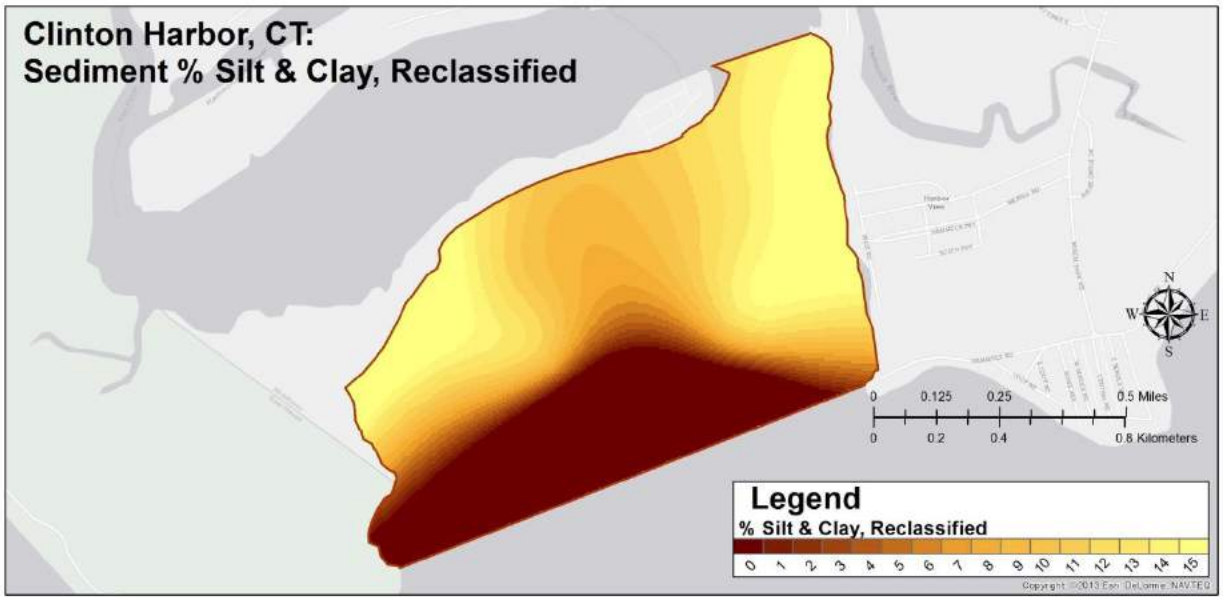


Figure 105: Clinton Harbor, Sediment % Silt & Clay Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

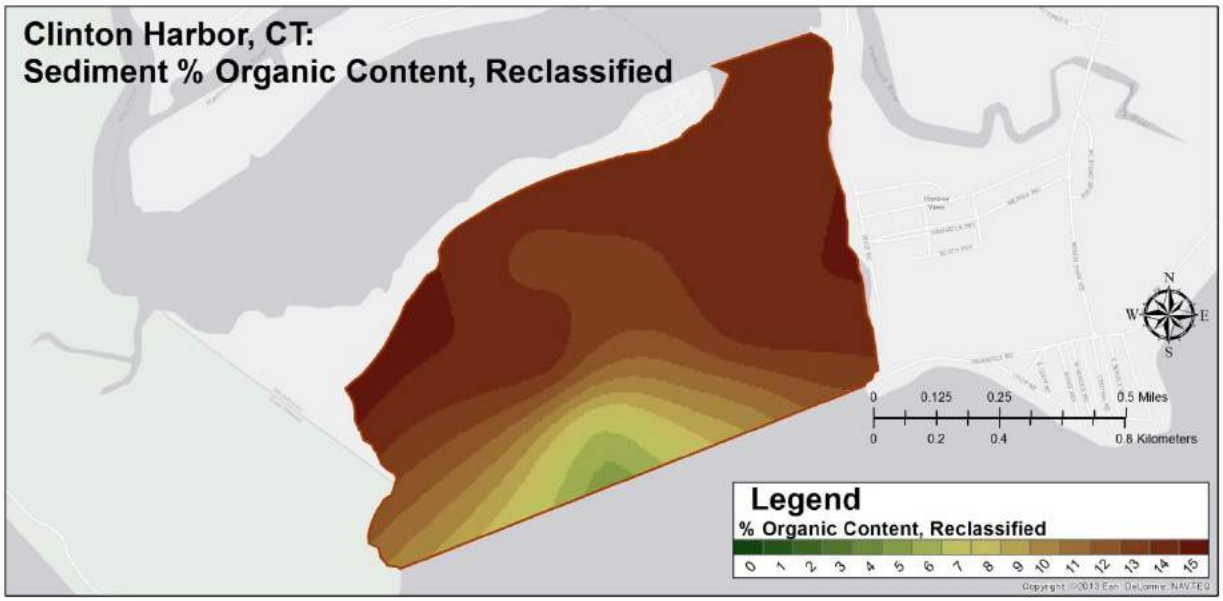


Figure 106: Clinton Harbor, Sediment % Organic Content Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

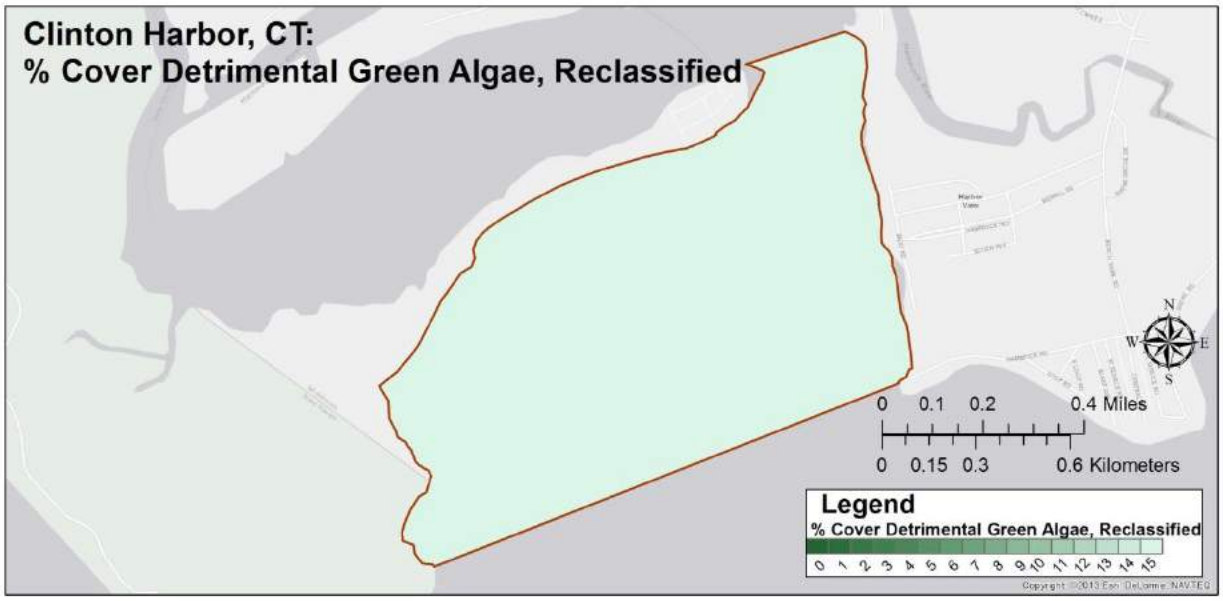


Figure 107: Clinton Harbor, % Detrimental Green Algae Cover Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

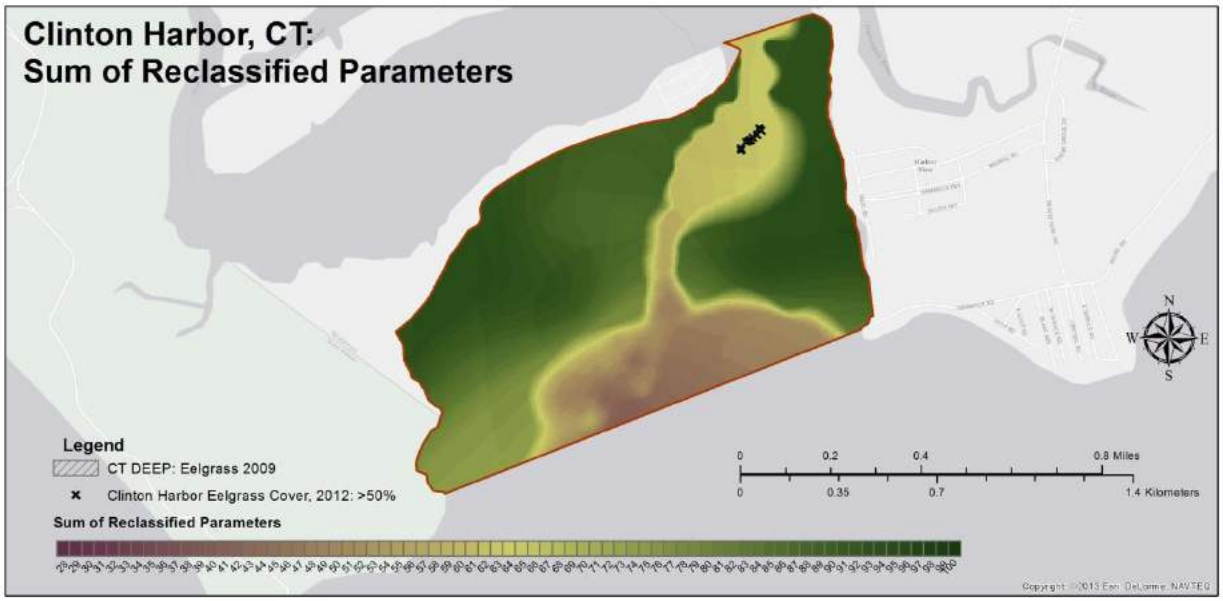


Figure 108: Clinton Harbor, Sum of Weighted Parameters.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18). Current eelgrass population is indicated by black marks.

7.6.2 COCKENOE ISLAND RESULTS

Each interpolated parameter from Cockenoe Island, CT was reclassified into a weighted ranking. The range for reclassification and the structure of the model rankings are provided in Section 7.6. The model score for each parameter was summed to yield the model score for the case study site. Figures shown are for the model weighting scheme "Adjustment 2" (see Table 18, Section 7.6), which includes the detrimental green algae. The model output from the case study sites using the LIS-wide weighting scheme (no macroalgae) is compared to the EHSI Model output in Section 8 (page 146).

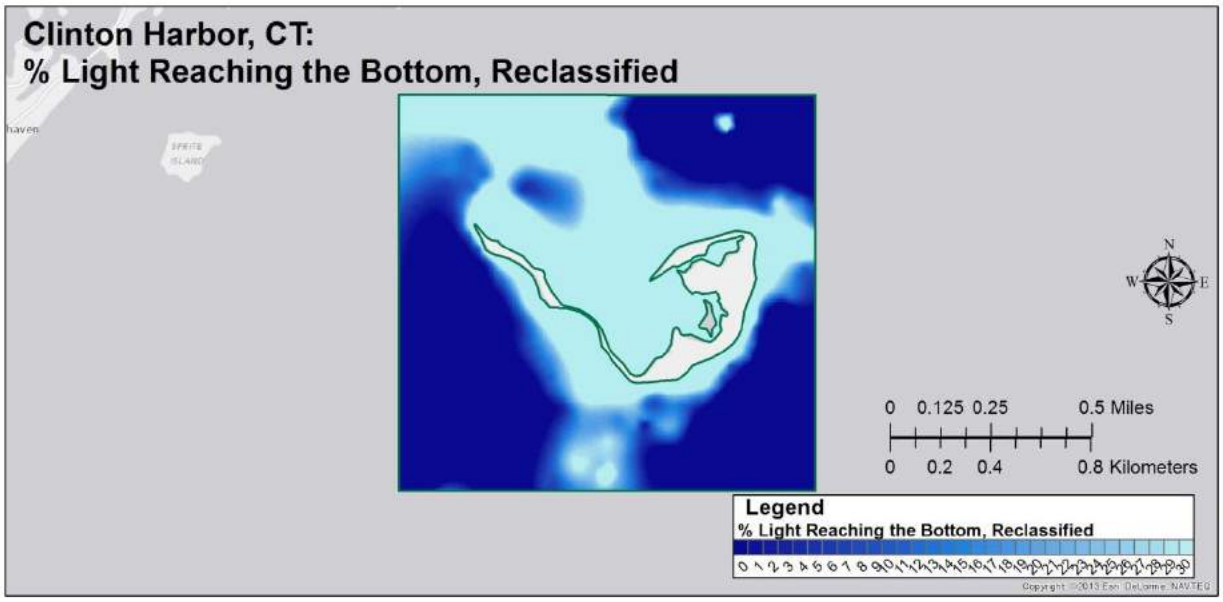


Figure 109: Cockenoe Island, % Light Reaching the Bottom Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

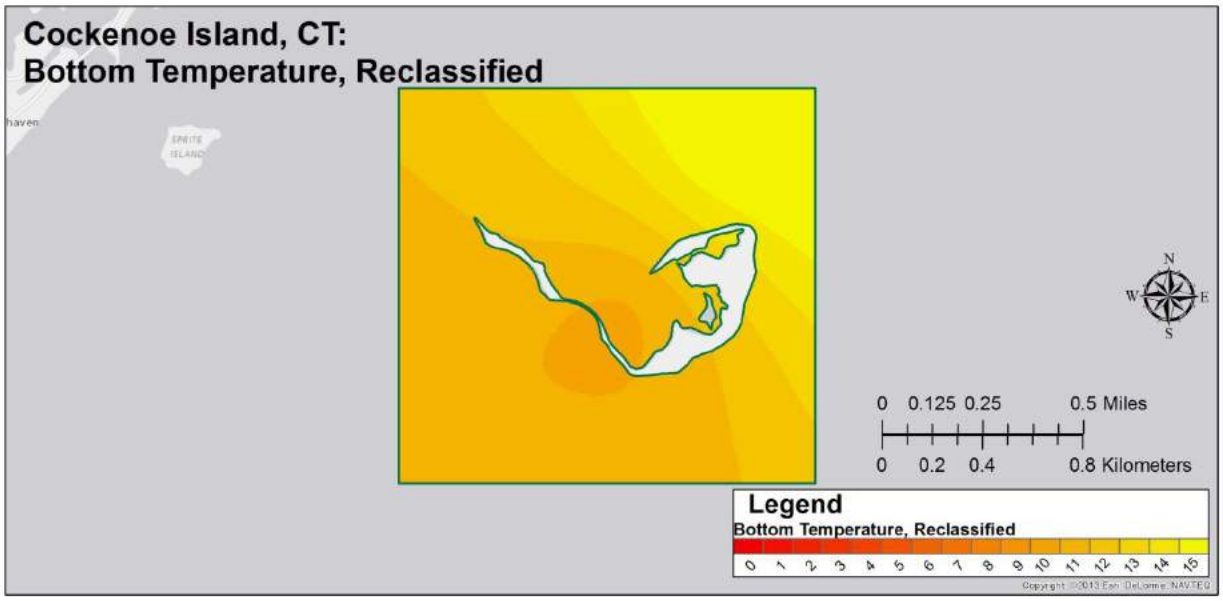


Figure 110: Cockenoe Island, Bottom Temperature Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

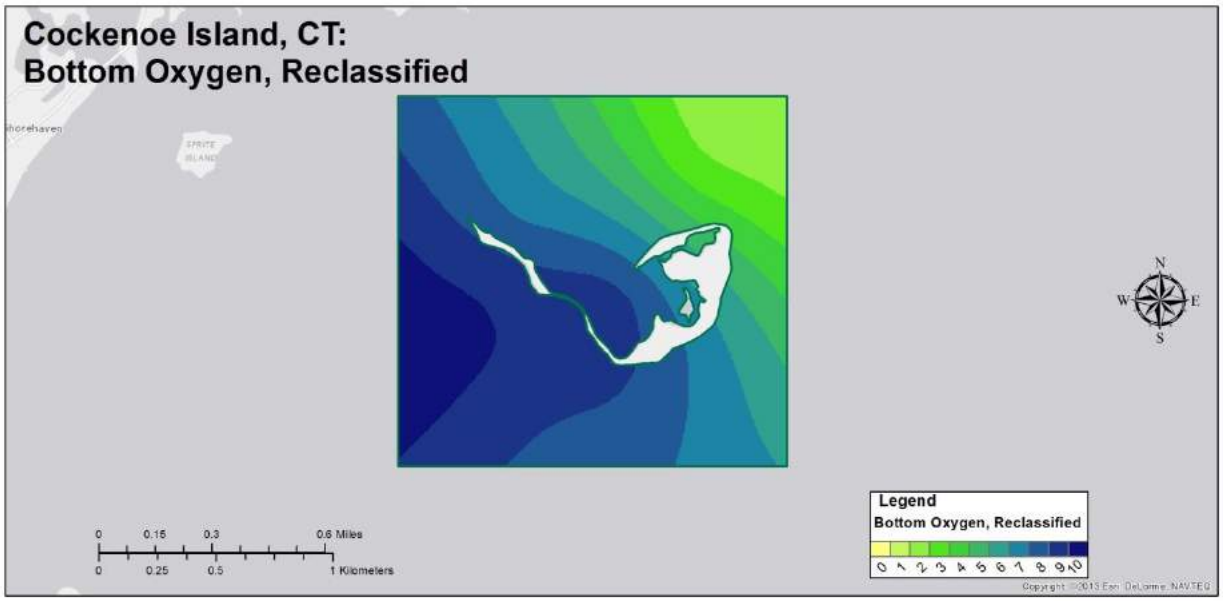


Figure 111: Cockenoe Island, Bottom Oxygen Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

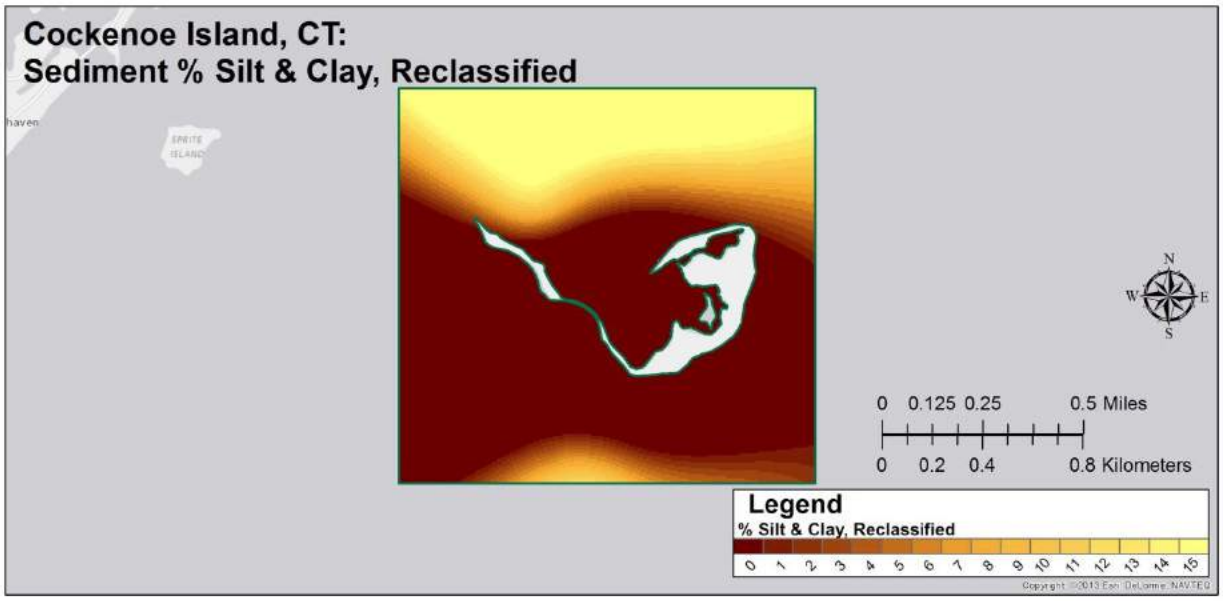


Figure 112: Cockenoe Island, Sediment % Silt & Clay Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

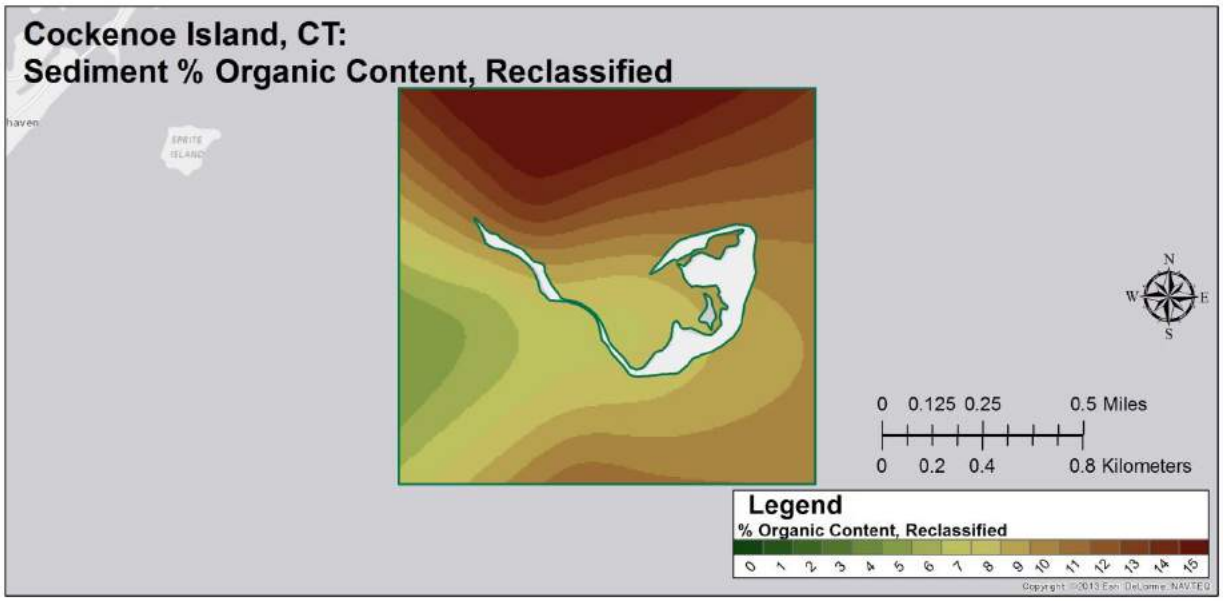


Figure 113: Cockenoe Island, Sediment % Organic Content Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

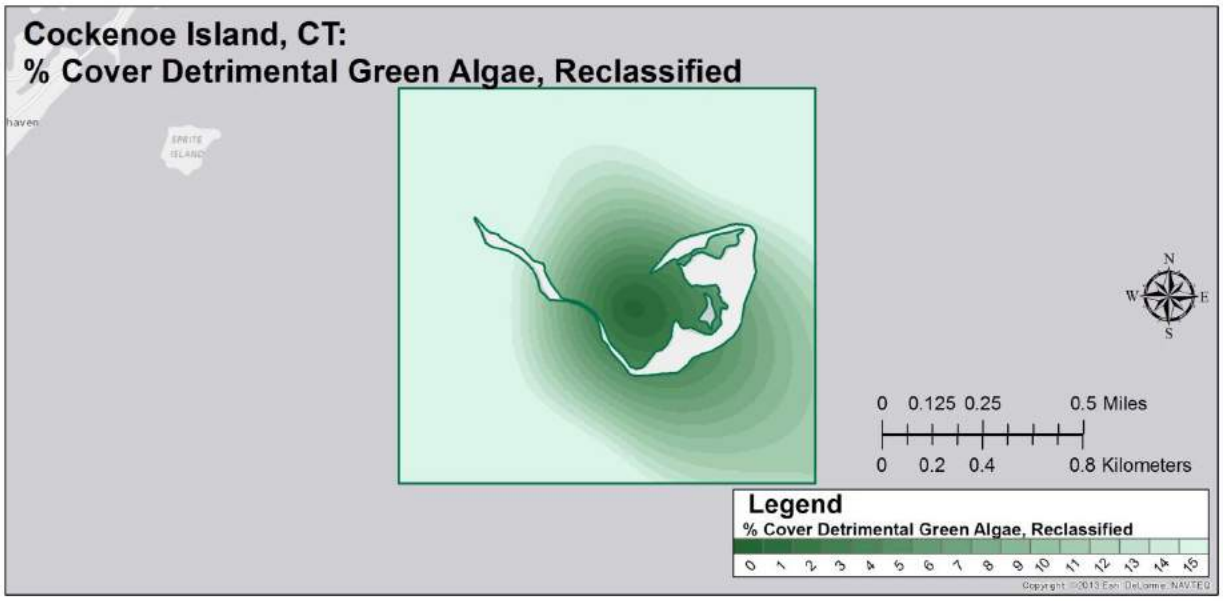


Figure 114: Cockenoe Island, % Detrimental Green Algae Cover Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

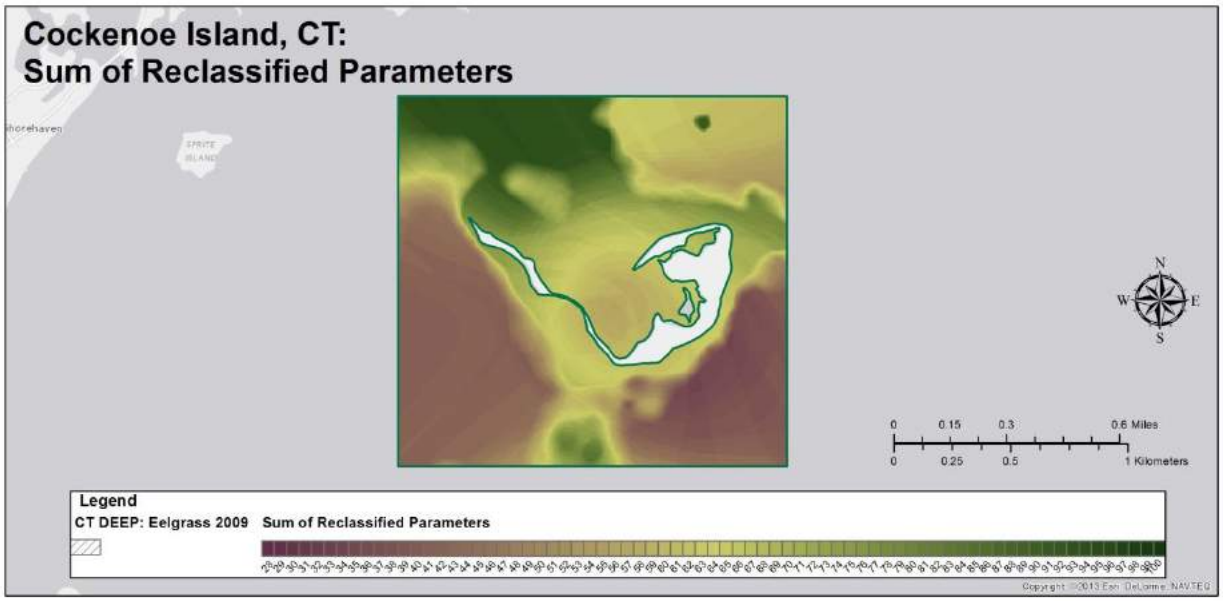


Figure 115: Cockenoe Island, Sum of Reclassified Parameters.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

7.6.3 DUCK POND POINT RESULTS

Each interpolated parameter from Duck Pond Point, NY was reclassified into a weighted ranking. The range for reclassification and the structure of the model rankings are provided in Section 7.6. The model score for each parameter was summed to yield the model score for the case study site. Figures shown are for the model weighting scheme "Adjustment 2" (see Table 18, Section 7.6), which includes the detrimental green algae. The model output from the case study sites using the LIS-wide weighting scheme (no macroalgae) is compared to the EHSI Model output in Section 8 (page 146).

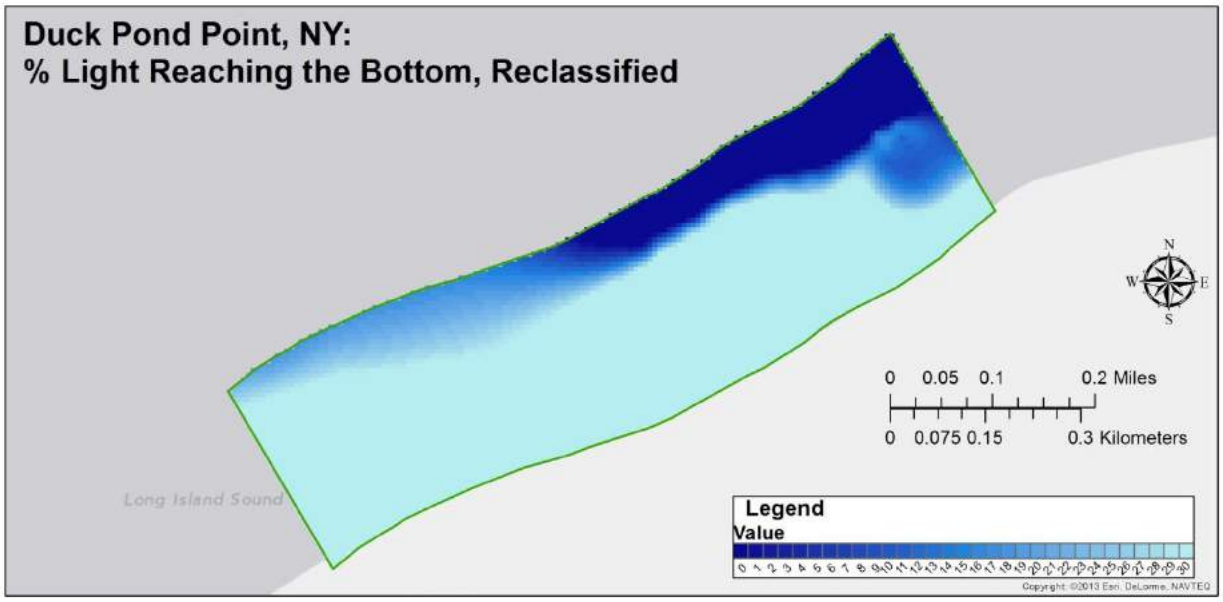


Figure 116: Duck Pond Point, % Light Reaching the Bottom Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

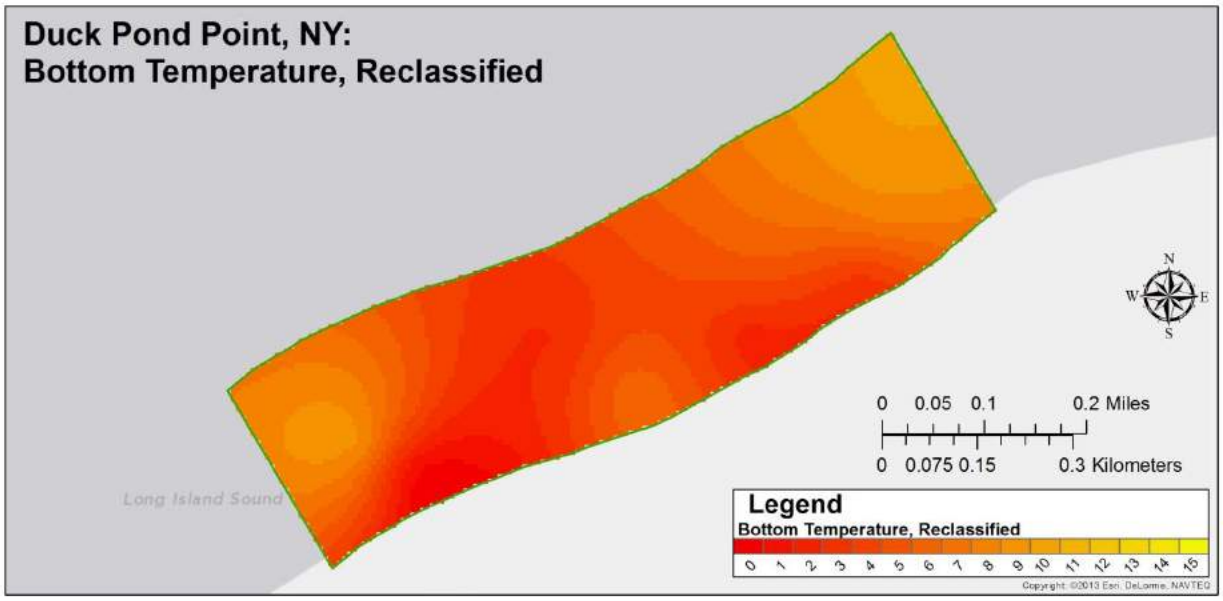


Figure 117: Duck Pond Point, Bottom Temperature Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

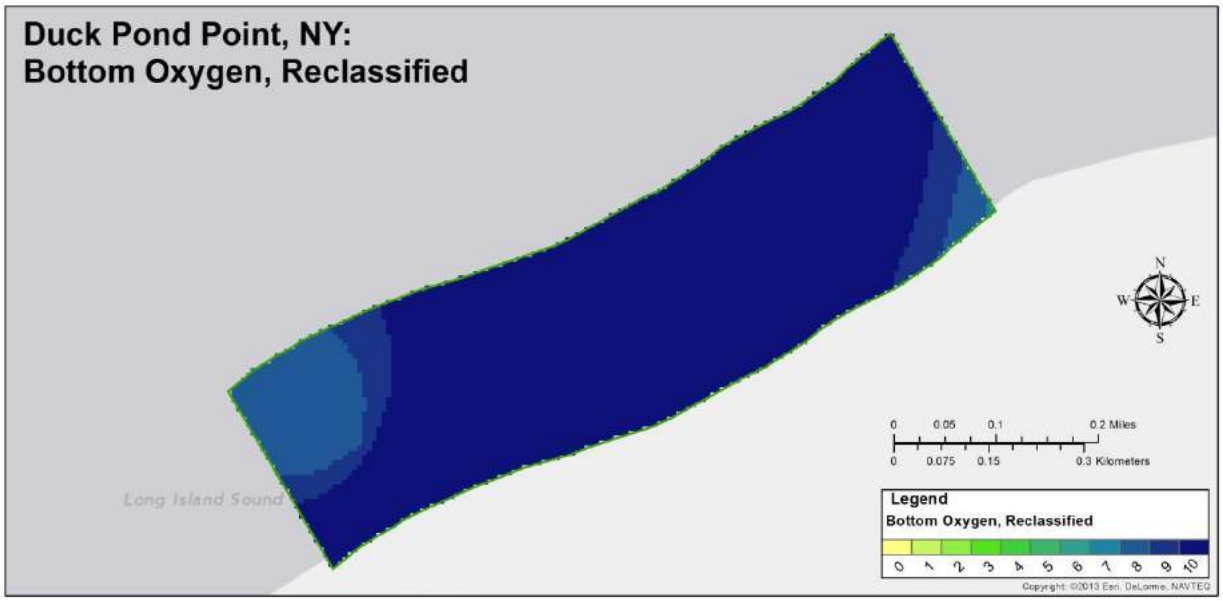


Figure 118: Duck Pond Point, Bottom Oxygen Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

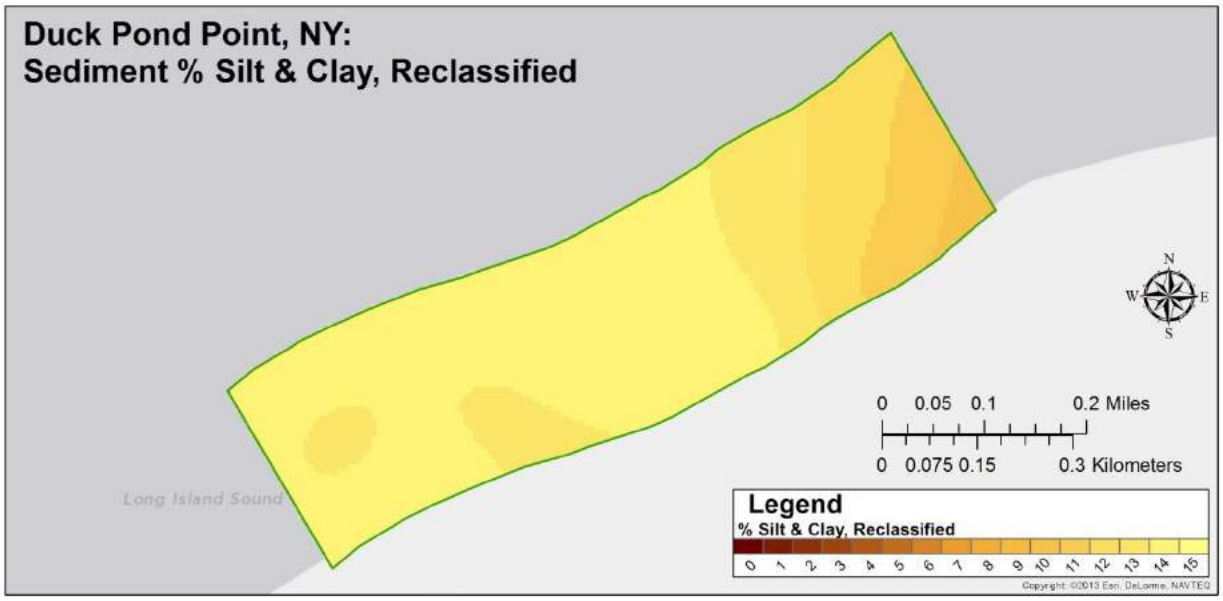


Figure 119: Duck Pond Point, Sediment % Silt & Clay Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

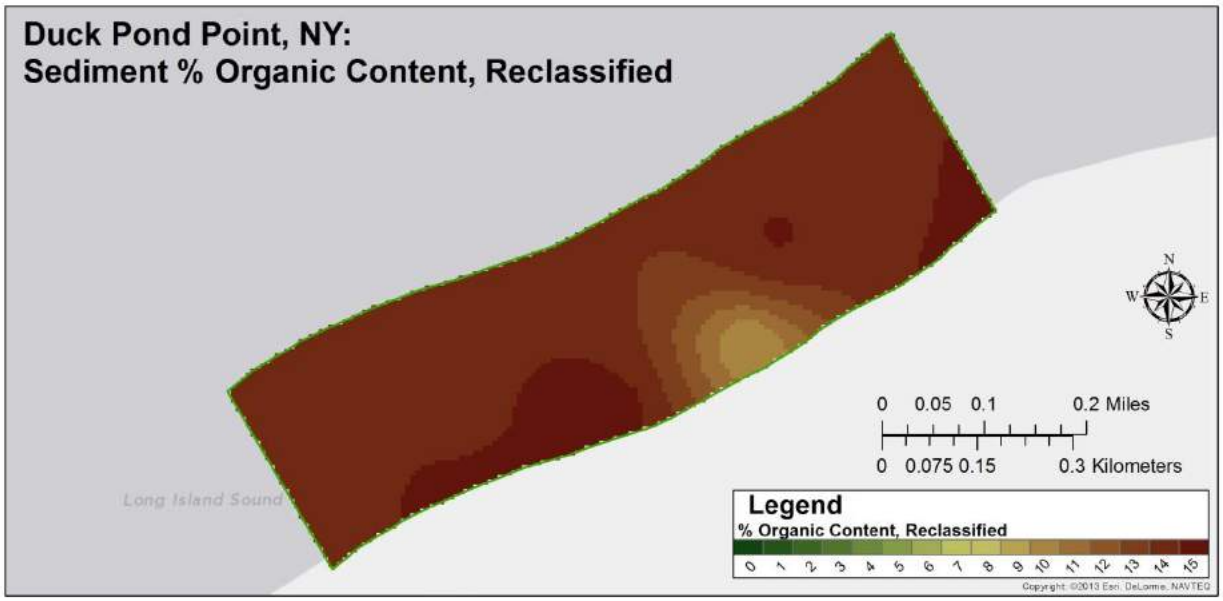


Figure 120: Duck Pond Point, Sediment % Organic Content Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

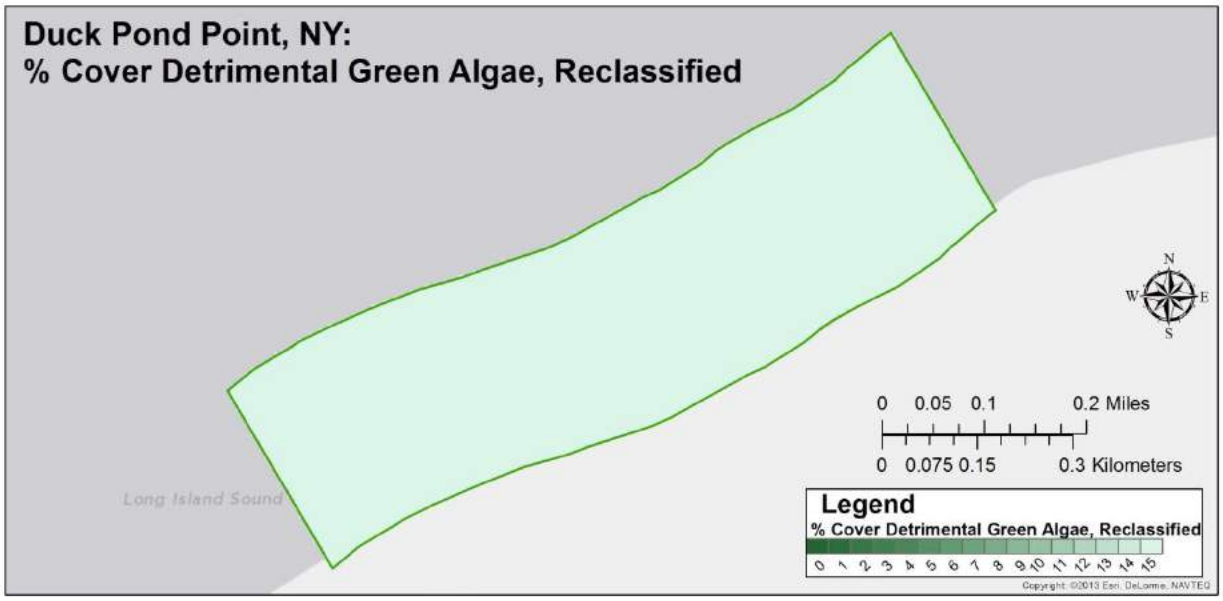


Figure 121: Duck Pond Point, % Detrimental Green Algae Cover Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

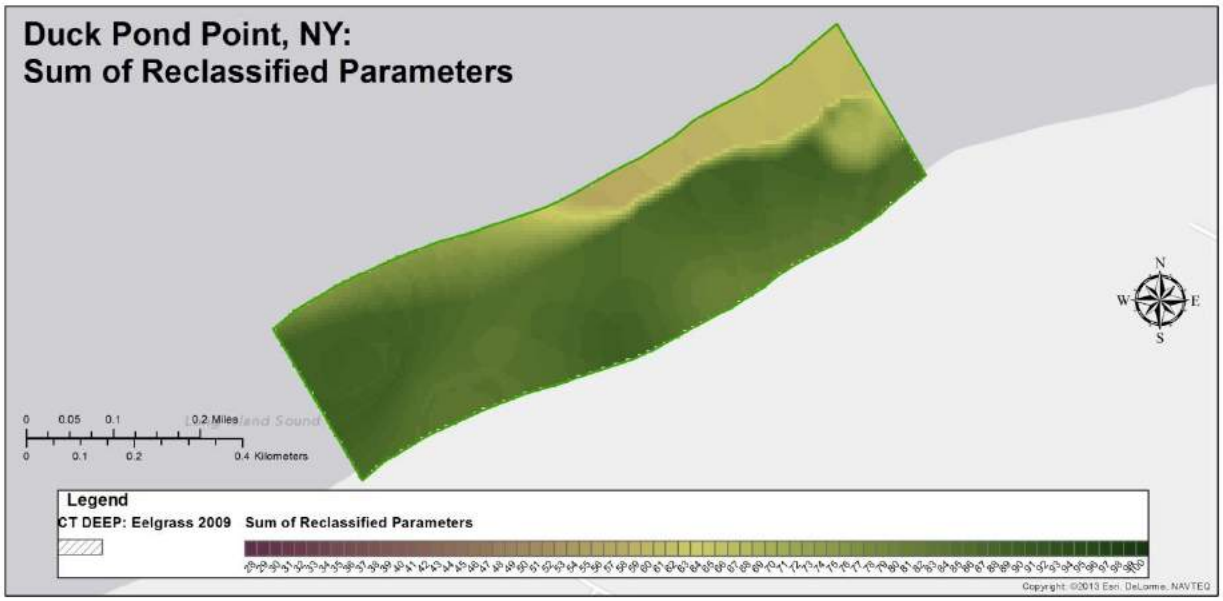


Figure 122: Duck Pond Point, Sum of Reclassified Parameters.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

7.6.4 NIANTIC BAY RESULTS

Each interpolated parameter from Niantic Bay, CT was reclassified into a weighted ranking. The range for reclassification and the structure of the model rankings are provided in Section 7.6. The model score for each parameter was summed to yield the model score for the case study site. Figures shown are for the model weighting scheme "Adjustment 2" (see Table 18, Section 7.6), which includes the detrimental green algae. The model output from the case study sites using the LIS-wide weighting scheme (no macroalgae) is compared to the EHSI Model output in Section 8 (page 146).

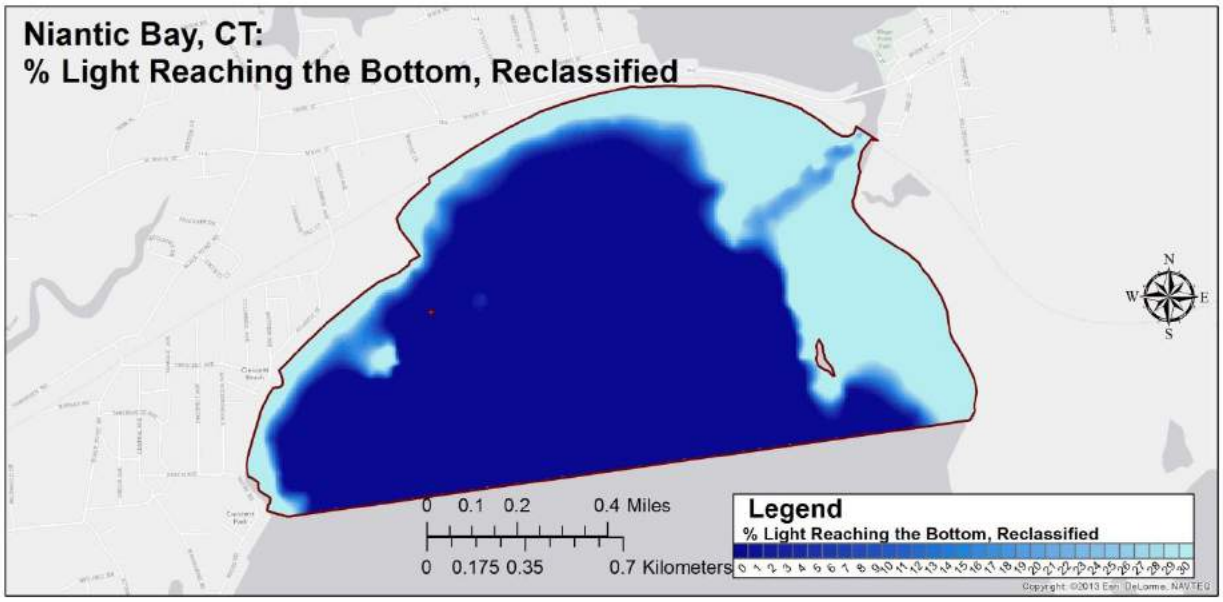


Figure 123: Niantic Bay, % Light Reaching the Bottom Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

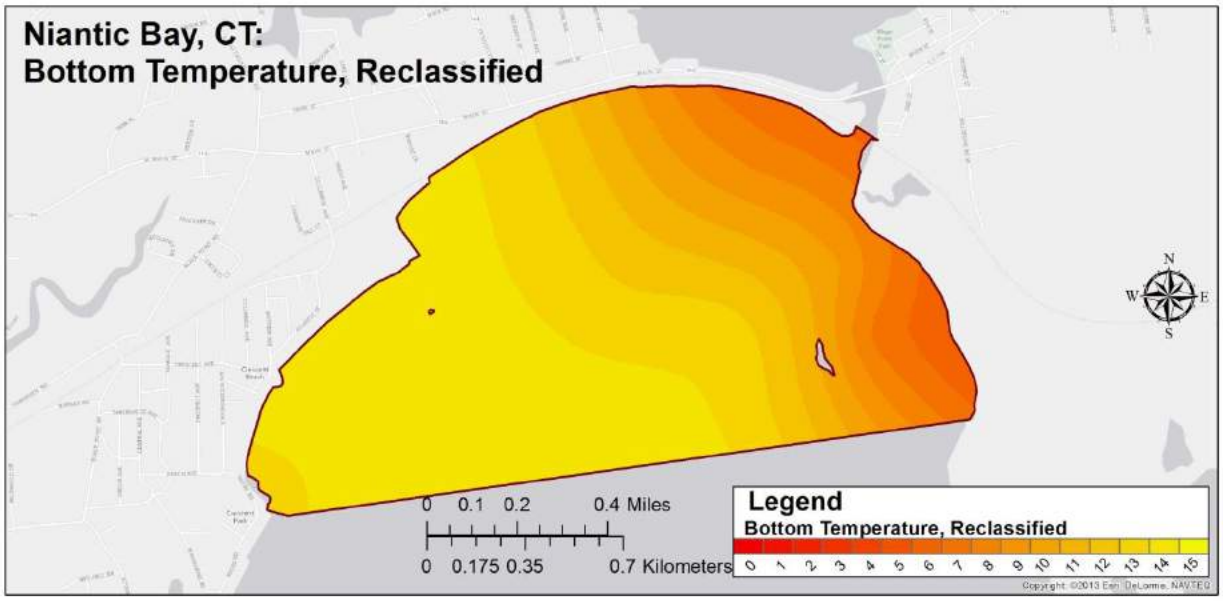


Figure 124: Niantic Bay, Bottom Temperature Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

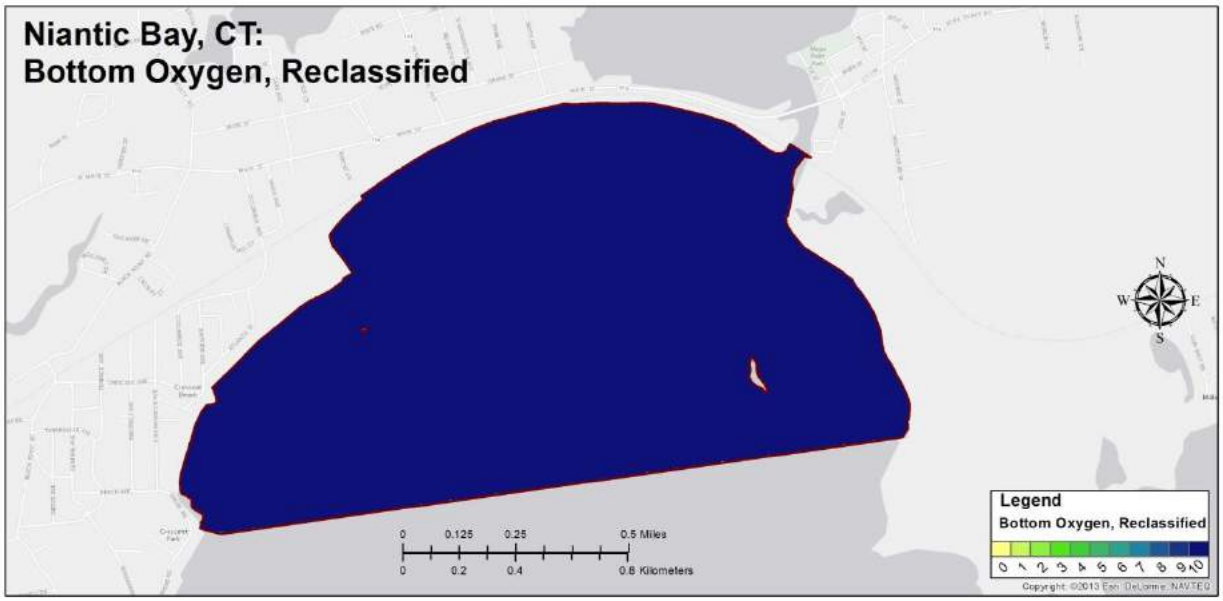


Figure 125: Niantic Bay, Bottom Oxygen Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

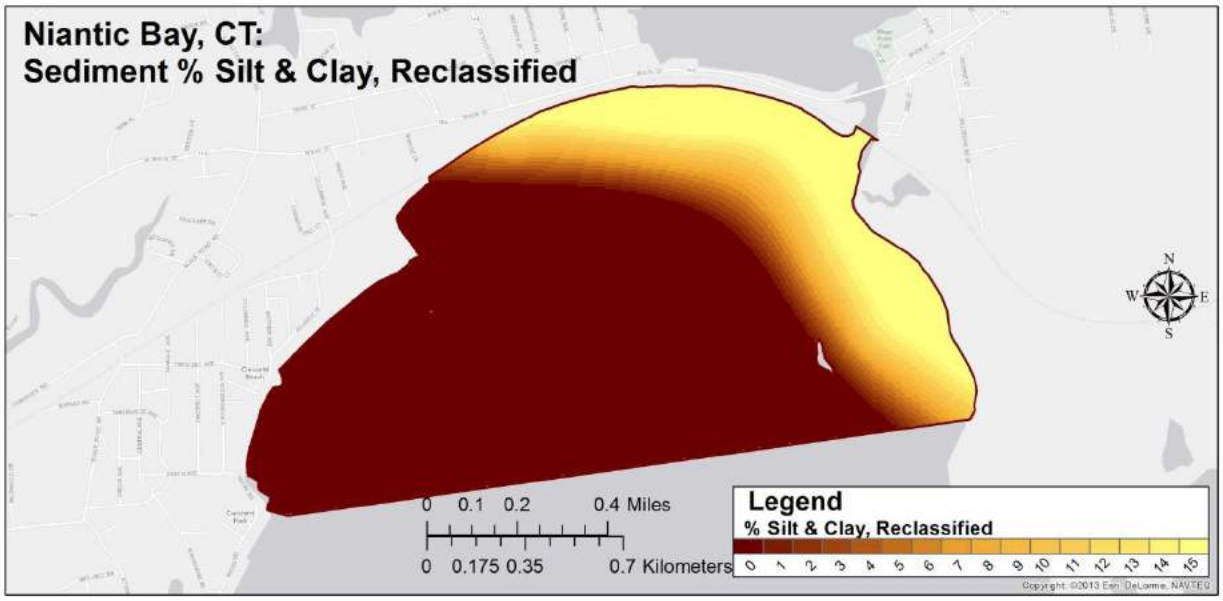


Figure 126: Niantic Bay, Sediment % Silt & Clay Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

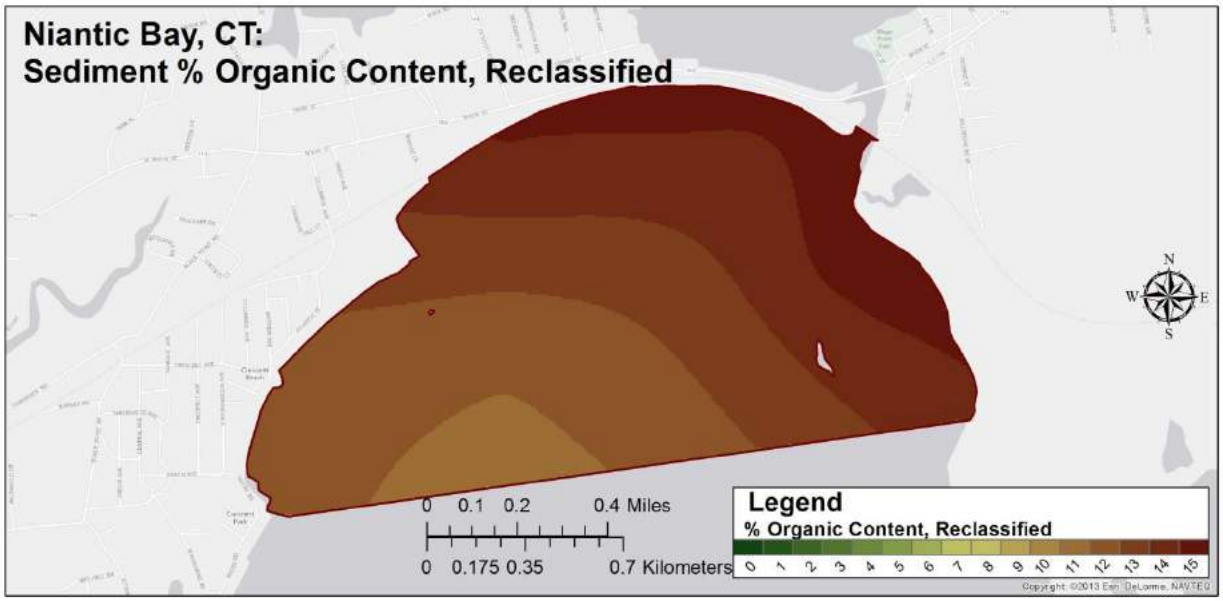


Figure 127: Niantic Bay, Sediment % Organic Content Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

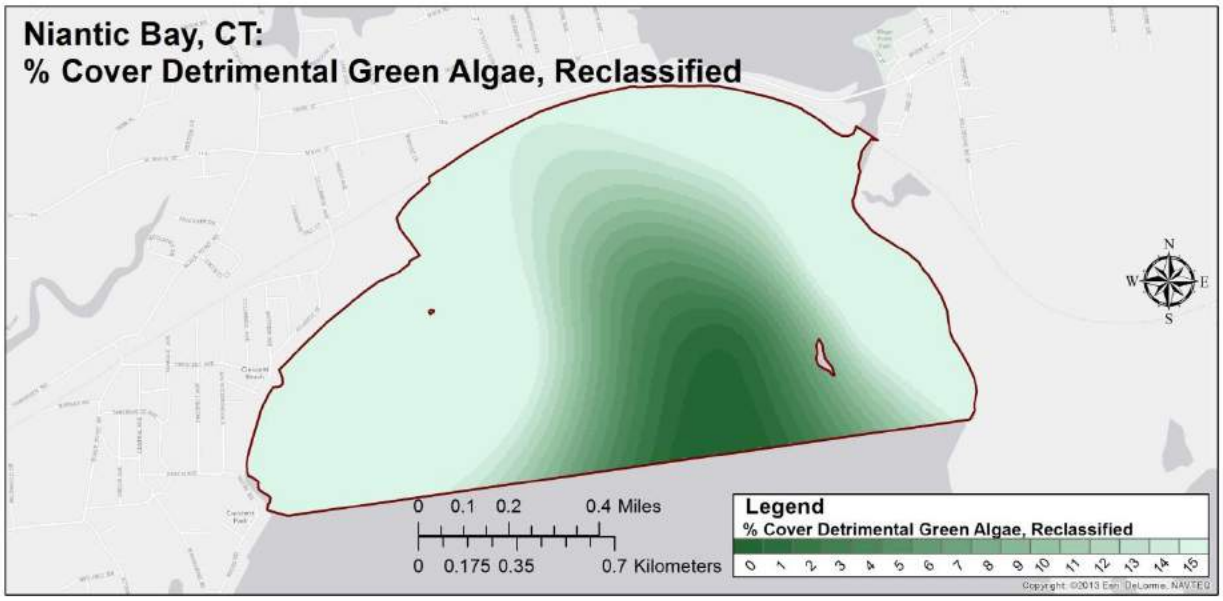


Figure 128: Niantic Bay, % Detrimental Green Algae Cover Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

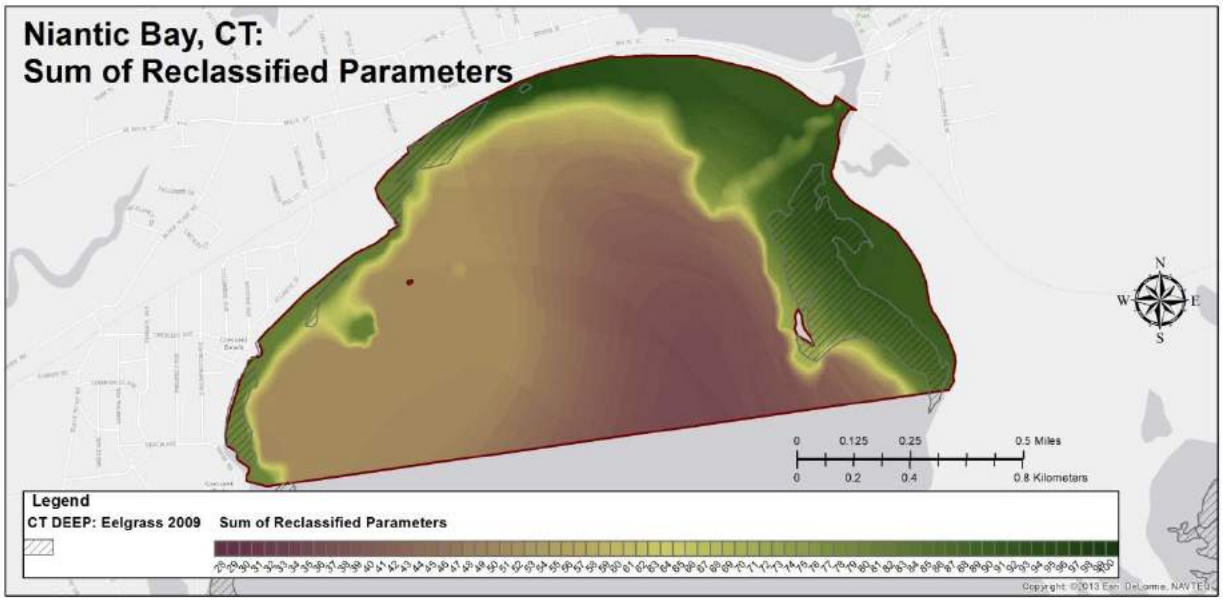


Figure 129: Niantic Bay, Sum of Reclassified Parameters.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18). The current location of eelgrass is indicated by the grey hatched areas.

7.6.5 PETTY'S BIGHT RESULTS

Each interpolated parameter from Petty's Bight, NY was reclassified into a weighted ranking. The range for reclassification and the structure of the model rankings are provided in Section 7.6. The model score for each parameter was summed to yield the model score for the case study site. Figures shown are for the model weighting scheme "Adjustment 2" (see Table 18, Section 7.6), which includes the detrimental green algae. The model output from the case study sites using the LIS-wide weighting scheme (no macroalgae) is compared to the EHSI Model output in Section 8 (page 146).

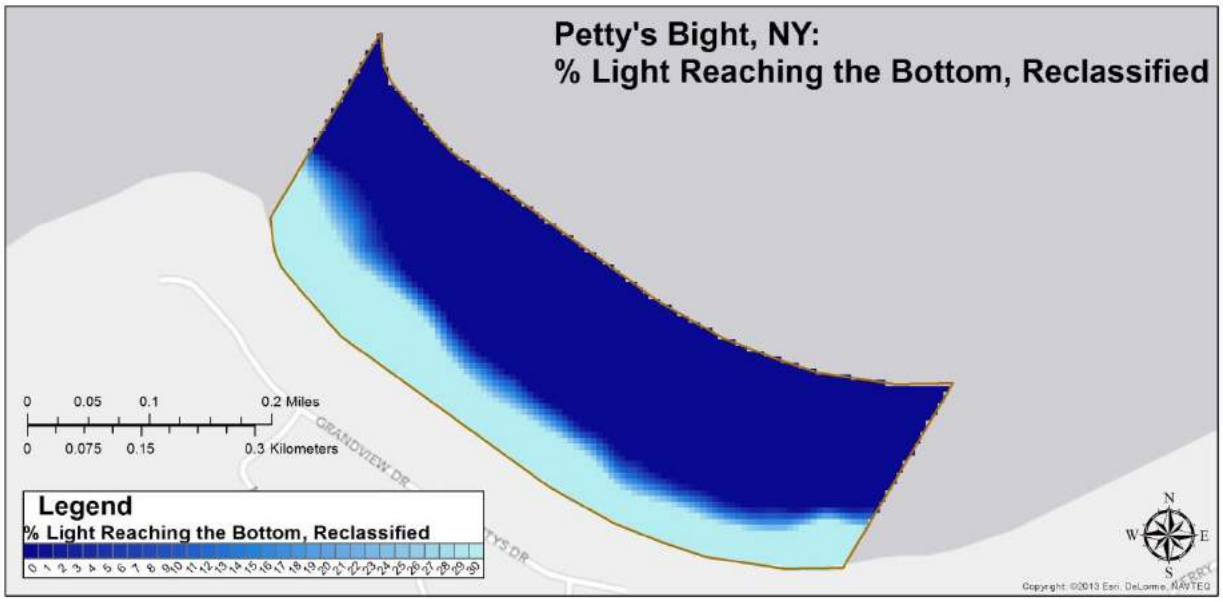


Figure 130: Petty's Bight, % Light Reaching the Bottom Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

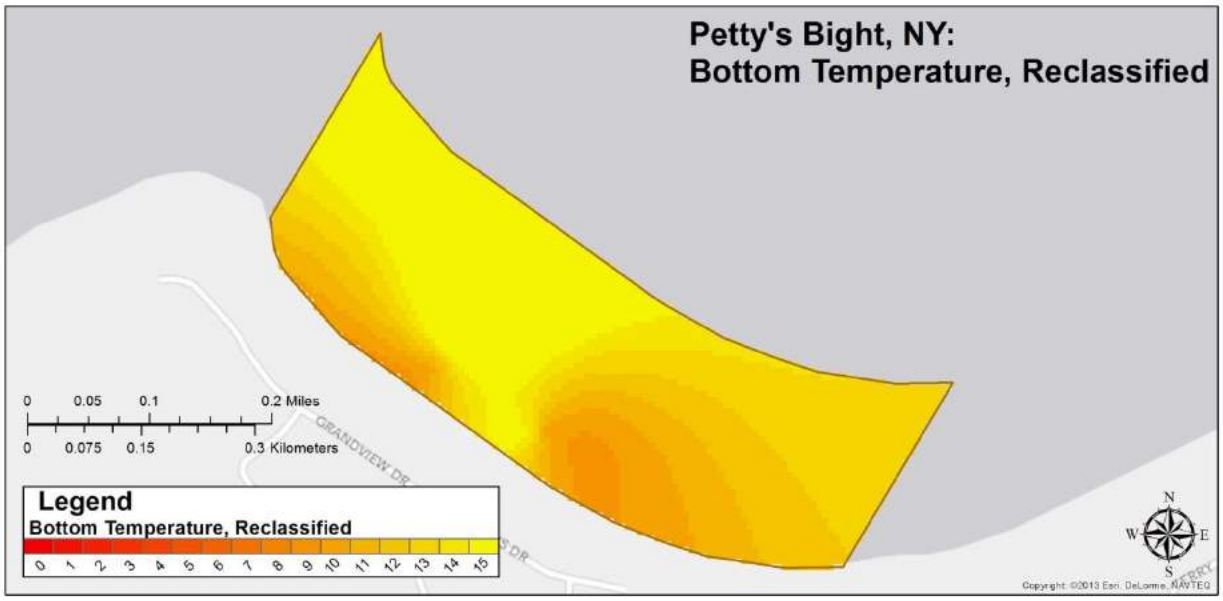


Figure 131: Petty's Bight, Bottom Temperature Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

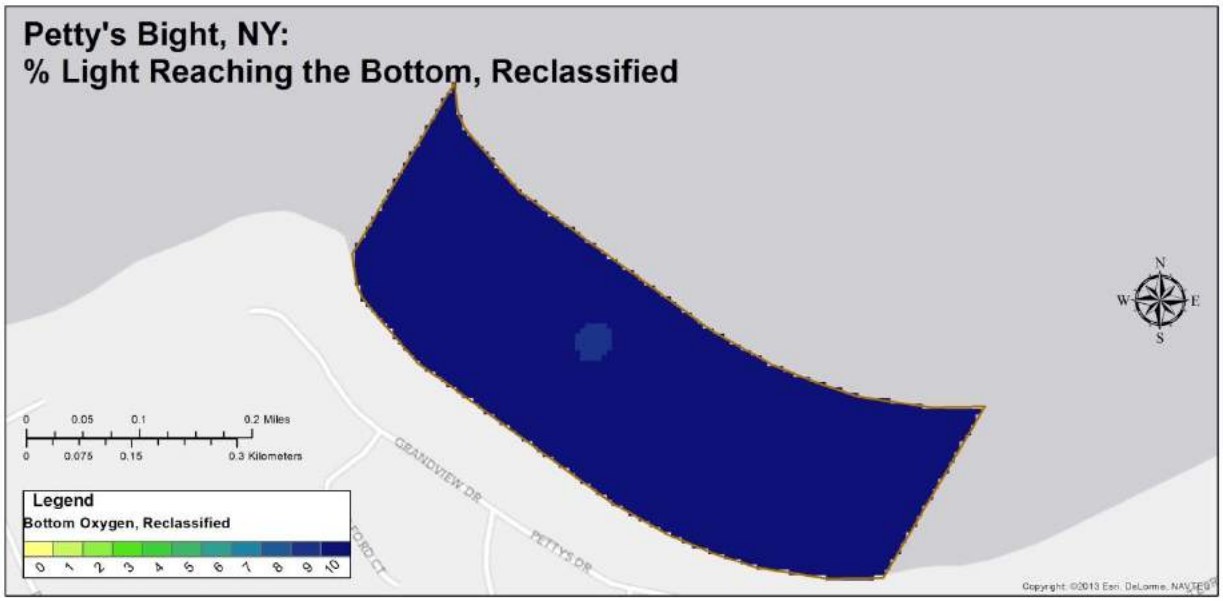


Figure 132: Petty's Bight, Bottom Oxygen Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

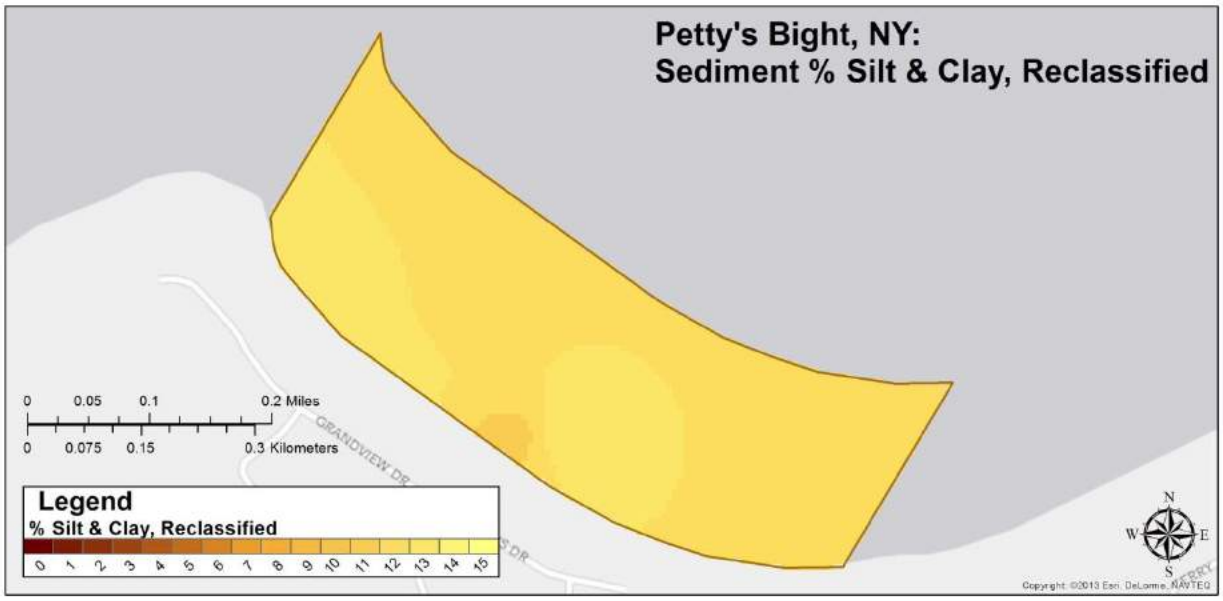


Figure 133: Petty's Bight, Sediment % Silt & Clay Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

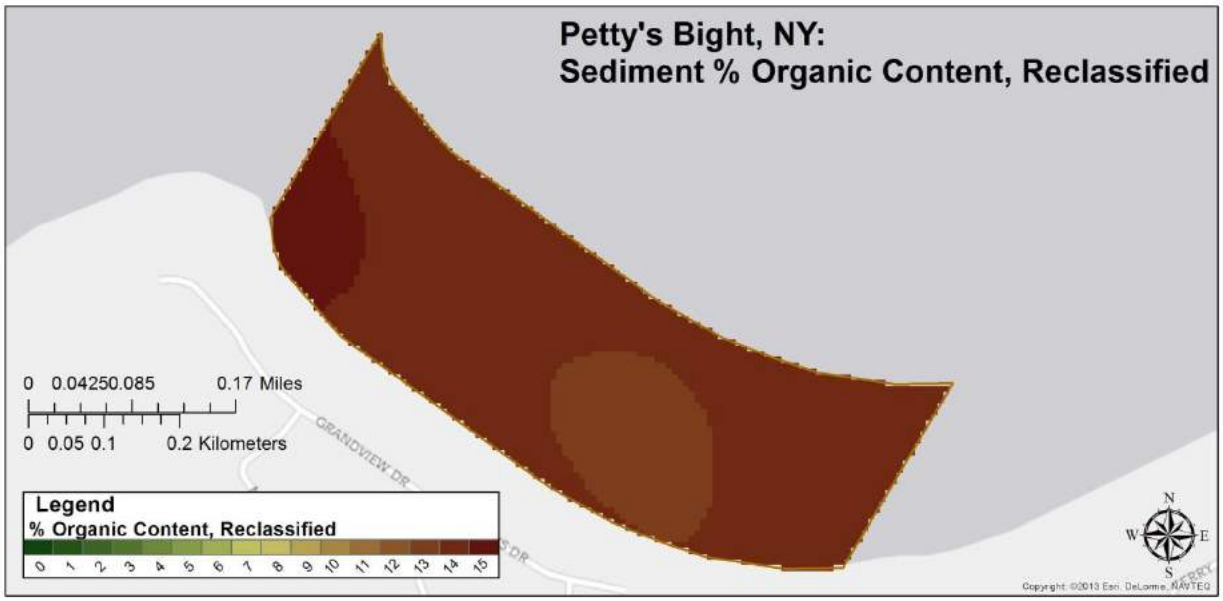


Figure 134: Petty's Bight, Sediment % Organic Content Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

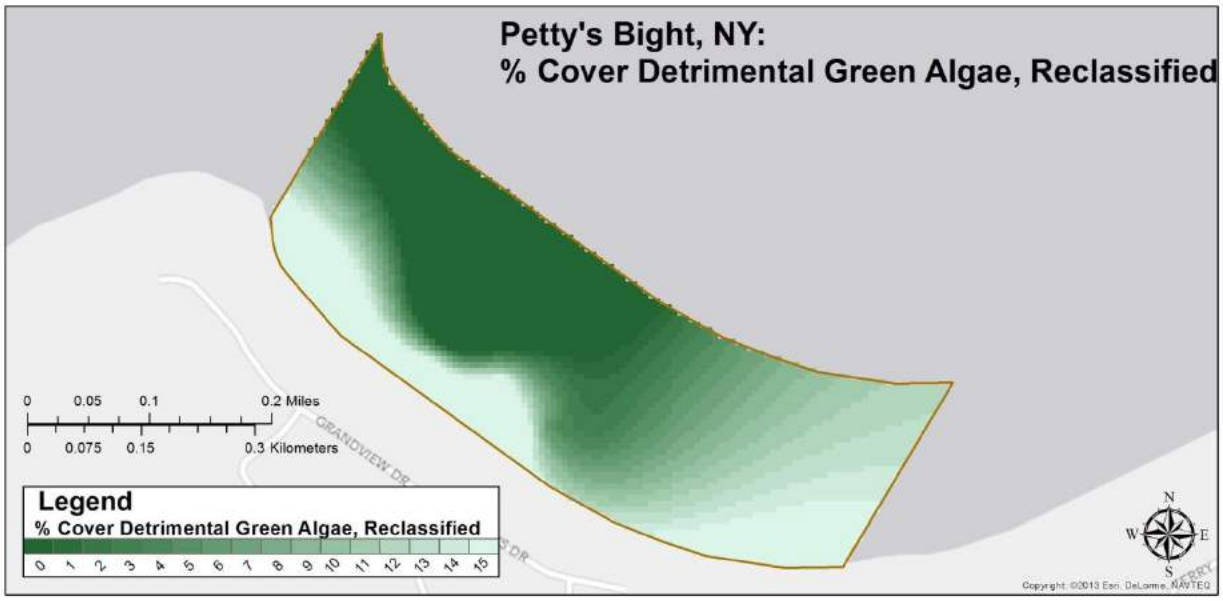


Figure 135: Petty's Bight, % Detrimental Green Algae Cover Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

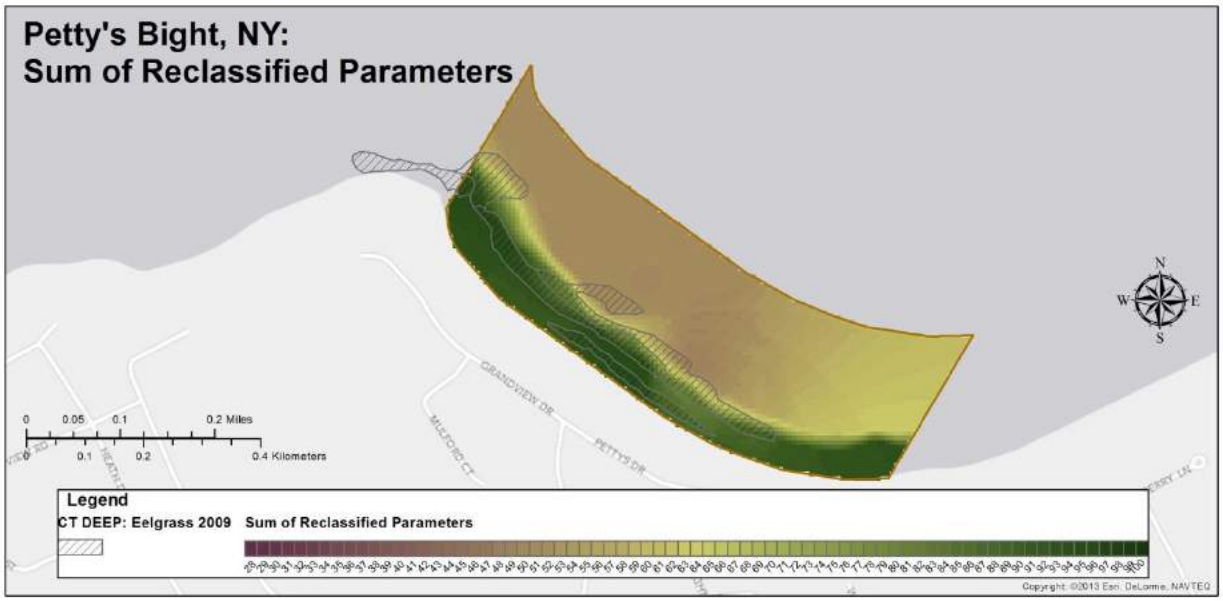


Figure 136: Petty's Bight, Sum of Reclassified Parameters.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18). The current location of eelgrass is indicated by the grey hatched areas.

7.6.6 ST. THOMAS POINT RESULTS

Each interpolated parameter from St. Thomas Point, NY was reclassified into a weighted ranking. The range for reclassification and the structure of the model rankings are provided in Section 7.6. The model score for each parameter was summed to yield the model score for the case study site. Figures shown are for the model weighting scheme "Adjustment 2" (see Table 18, Section 7.6), which includes the detrimental green algae. The model output from the case study sites using the LIS-wide weighting scheme (no macroalgae) is compared to the EHSI Model output in Section 8 (page 146).

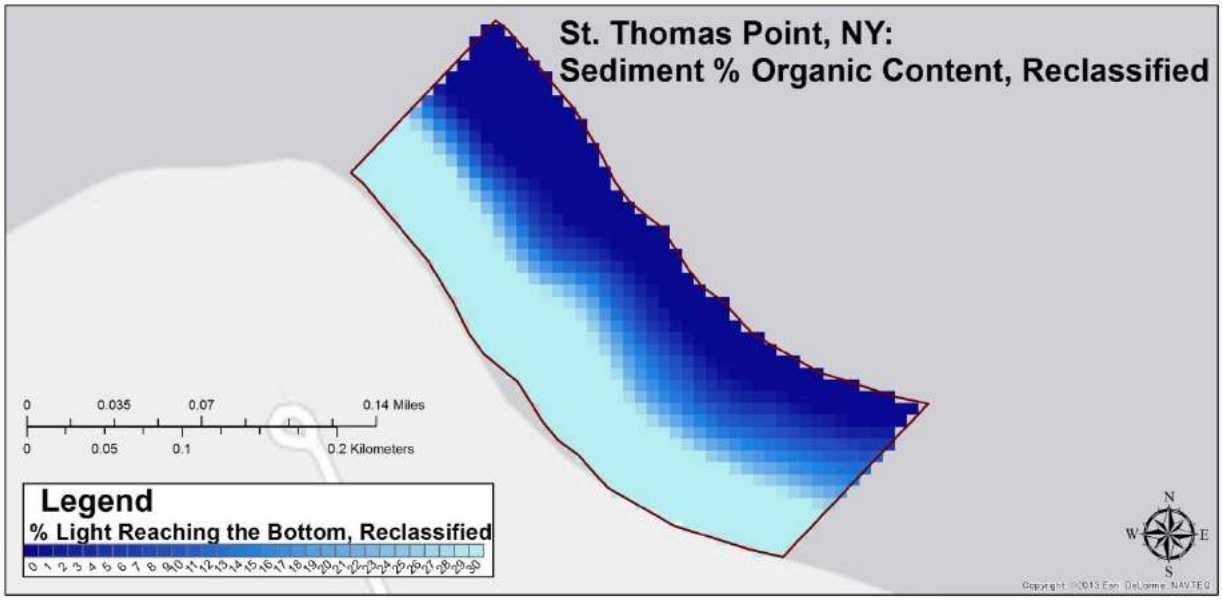


Figure 137: St. Thomas Point, % Light Reaching the Bottom.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

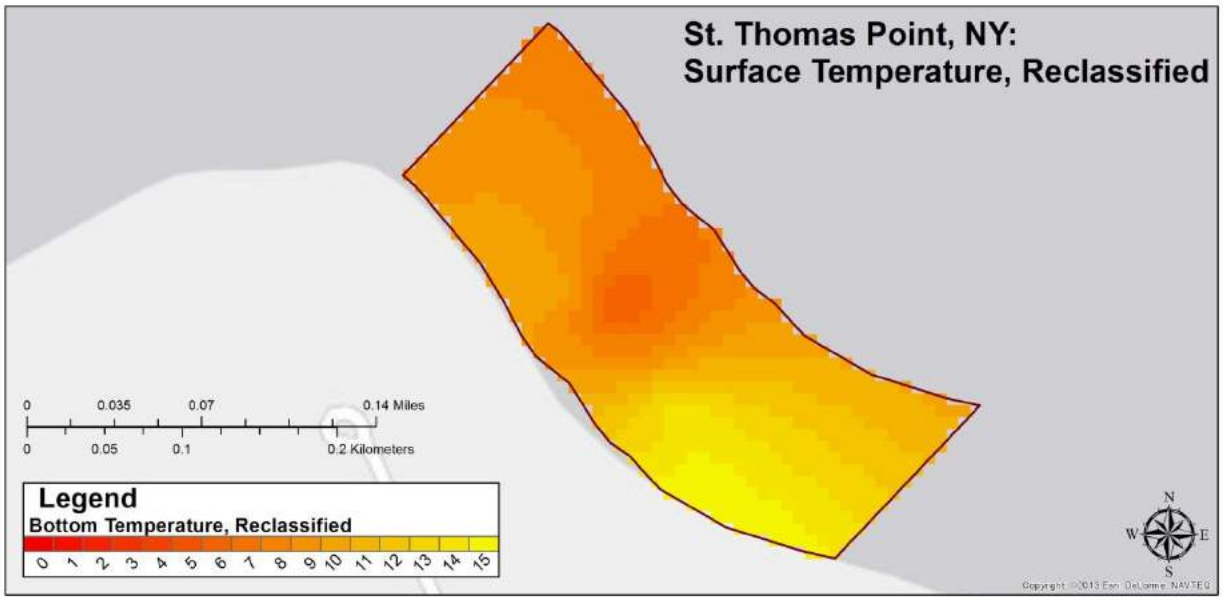


Figure 138: St. Thomas Point, Bottom Temperature Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

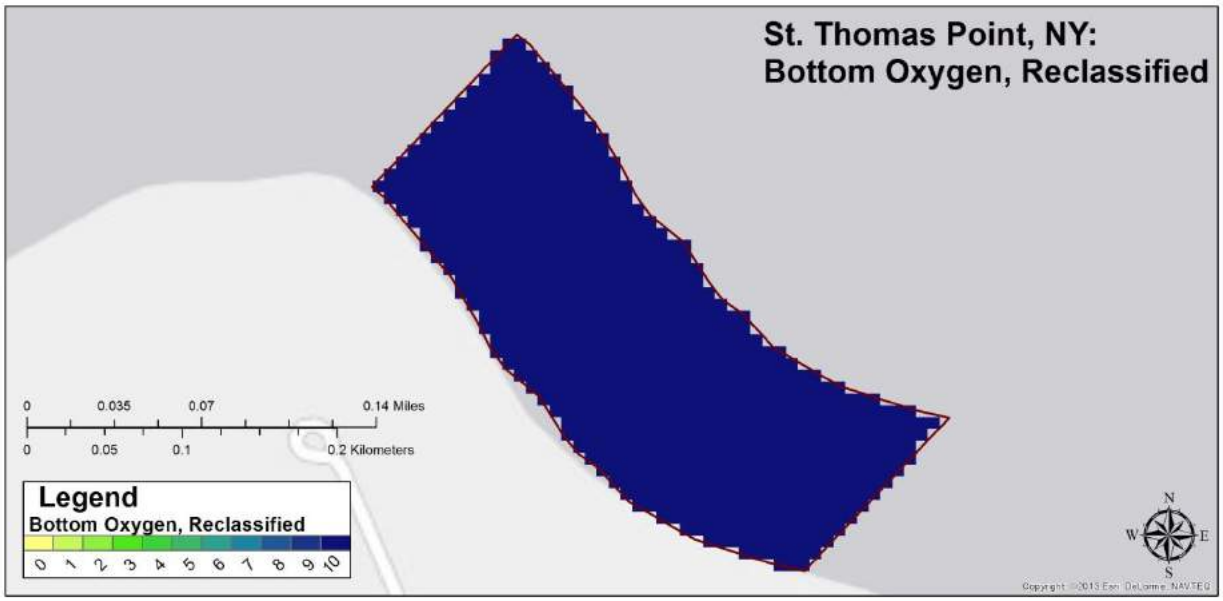


Figure 139: St. Thomas Point, Bottom Oxygen Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

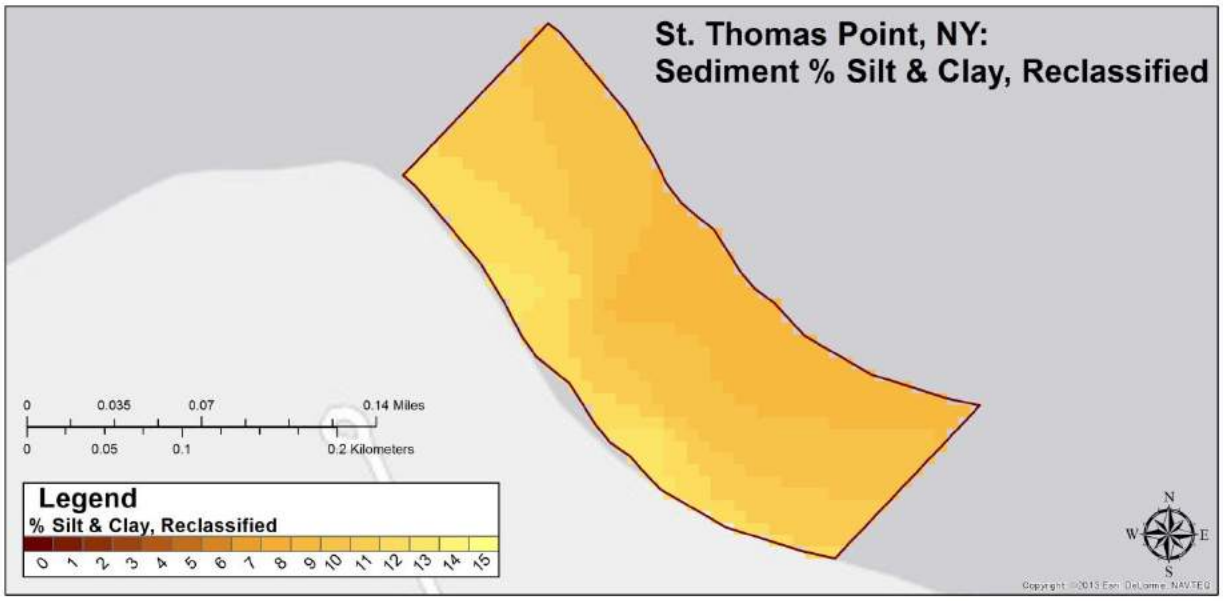


Figure 140: St. Thomas Point, Sediment % Silt and Clay Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

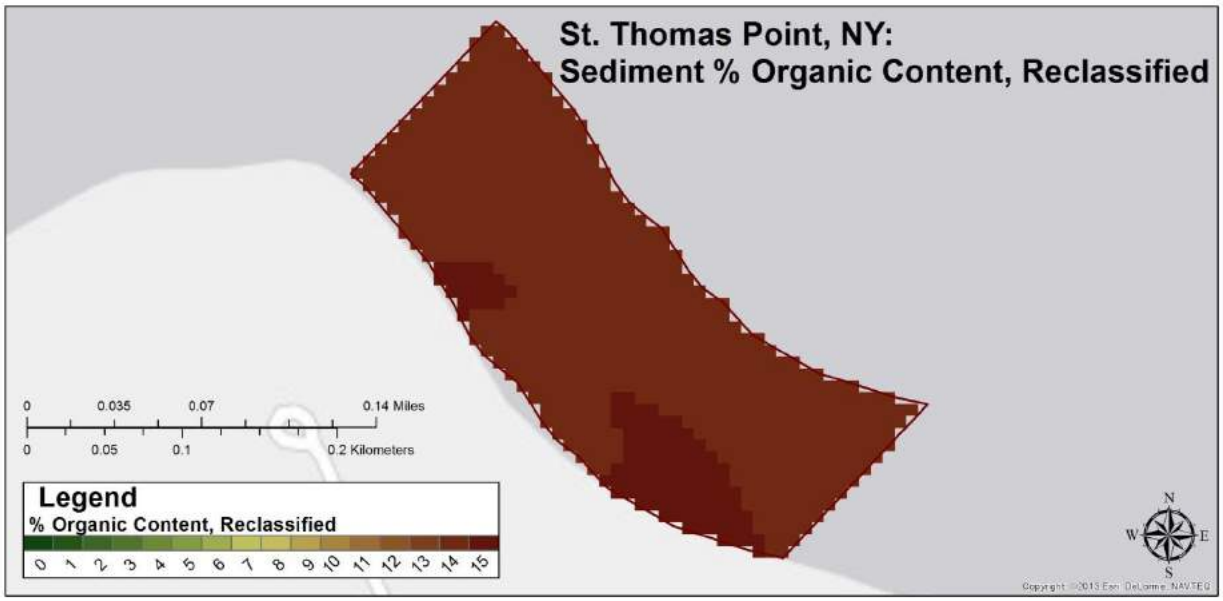


Figure 141: St. Thomas Point, Sediment % Organic Content Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

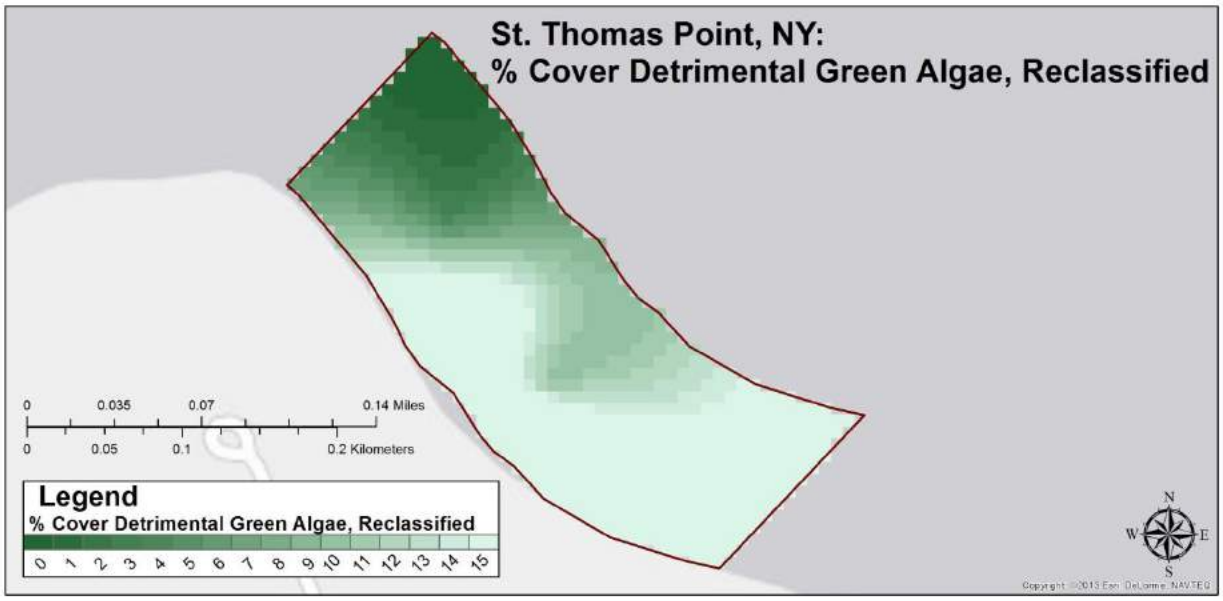


Figure 142: St. Thomas Point, % Detrimental Green Algae Cover Reclassified.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

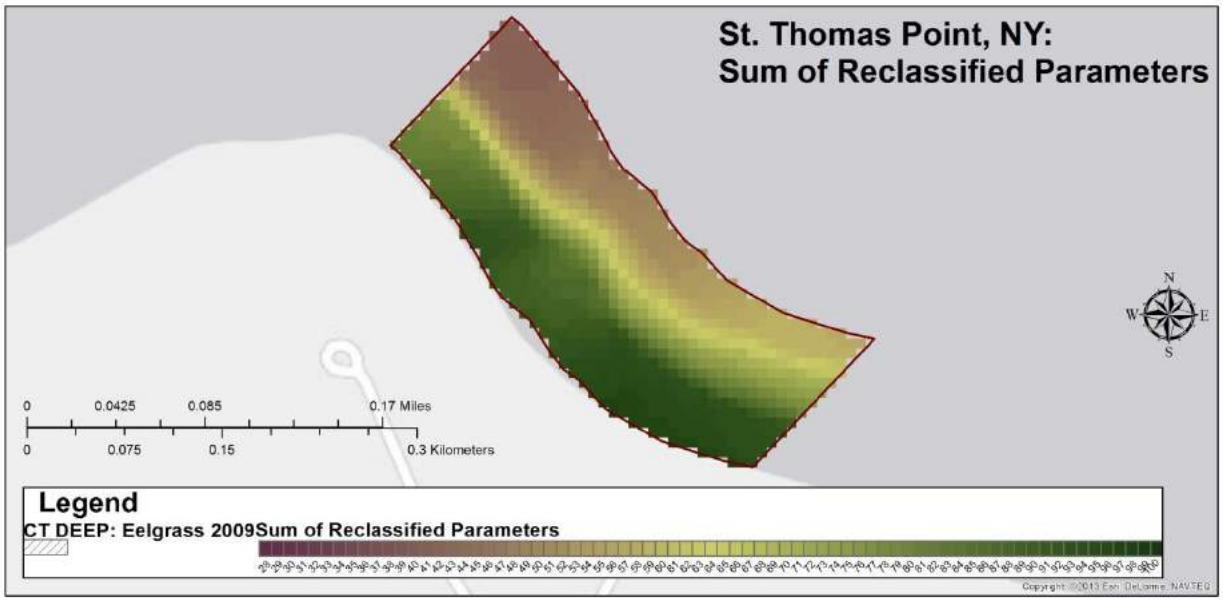


Figure 143: St. Thomas Point, Sum of Reclassified Parameters.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

7.7 EHSI Sub-Model Calibration and Skill Assessment

One purpose of the EHSI Sub-Model assessment was to evaluate the effect of adding a macroalgae parameter to the model structure. Excessive macroalgae has been identified as detrimental to eelgrass, but data on macroalgae coverage and biomass are lacking on a LIS-wide basis. The outputs from the EHSI Sub-Model results for the weighting scheme used in the EHSI Model were compared to a range of model structures which included detrimental green macroalgae (Table 19).

Table 19: EHSI Sub-Model Structure
Weighting scheme for parameters from the LIS-wide calibrated model as applied to the EHSI Sub-Model and adjustments to the EHSI Sub-Models incorporating green macroalgae.

Parameter	EHSI Model	Adj1	Adj2	Adj3
% Light Reaching the Bottom	30	30	30	30
Bottom Temperature	20	14	15	18
Bottom Oxygen	10	9	10	8
Sediment % Silt & Clay	20	13	15	18
Sediment % Organic Content	20	14	15	18
% Detrimental Green Algae Cover	0	20	15	8

7.7.1 EHSI SUB-MODEL CALIBRATION

The calibration of the EHSI Sub-Model inclusive of green macroalgae was conducted by examining model output for four of the six case study sites relative to eelgrass distribution and past restoration efforts. Cockenoe Island and Duck Pond Point were not included as they do not currently support eelgrass.

Clinton Harbor was an especially useful site for calibration as it contains an eelgrass bed living at the edge of suitability, a failed restoration site, and a successful restoration site (Figure 144). Adjustments one and two both yield model scores greater than 88 in the location of the successful restoration sites. For all adjustments to the model weighting scheme, the failed restoration site is located at a transition zone from suitable (scores > 88) to less suitable (scores 50 to 88). The transition of model scores from 50 to 88 in the area of the failed restoration site are largely due to changes in the percent of light reaching the bottom and the sediment grain size transitioning from sandier sediment (higher score) to sediment with more silt and clay (Figures 102 & 105). The existing eelgrass bed, which is variable, is located in an area where scores are between 50 and 88.

Comparing adjustments one and two for Niantic Bay, the area with scores less than 50 is larger in adjustment two (Figure 145). For Petty's Bight, adjustment one yields the larger area for scores less than 50 (Figure 146). In St. Tomas Point, the difference in area for model scores less than 50 is negligible (Figure 147). In Petty's Bight, the eelgrass extends to the edge of the area with scores less than 50. The proximity of the eelgrass to areas with a low score indicate that adjustment two, with a lesser extent of low model score area in Petty's Bight (but greater in Niantic Bay) is the best choice.

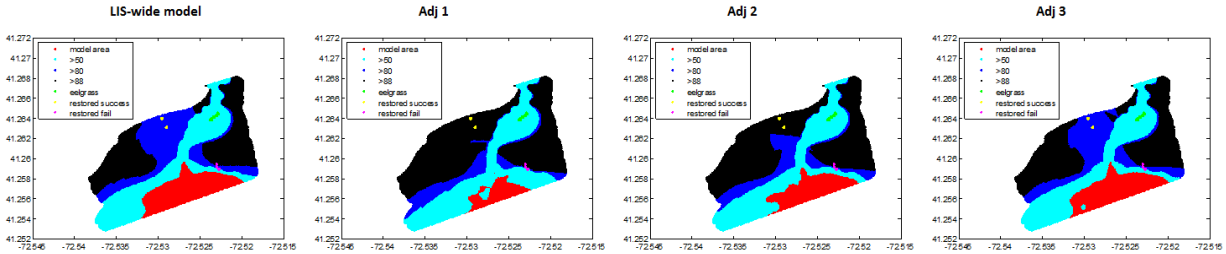


Figure 144: Clinton Harbor EHSI Sub-Model, Maps of Model Output for Four Model Configurations
Model output was visualized using different colors to represent thresholds overlain with colors indicating the presence of naturally occurring eelgrass (green), restoration sites which were successful (yellow), and restoration sites which failed (pink). Colors indicate: score > 88 (black); 88 ≥ score > 80 (dark blue); 80 ≥ score > 50 (light blue); 50 ≥ score (red).

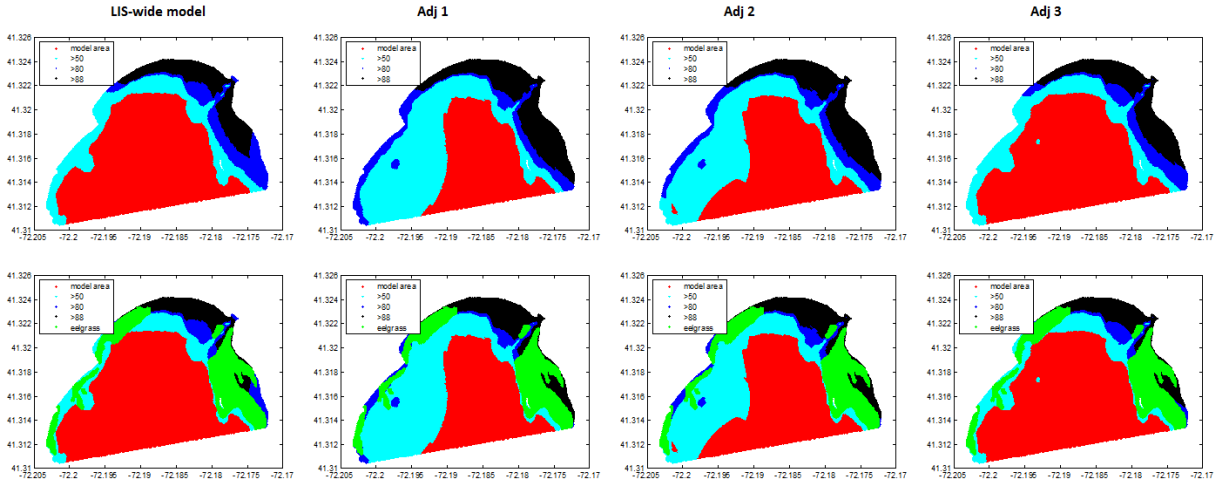


Figure 145: Niantic Bay EHSI Sub-Model, Maps of Model Output for Four Model Configurations
The upper panel shows model output only. The lower panel is the figure from the upper panel overlain with data points for eelgrass. Model output was visualized using different colors to represent thresholds overlain with colors indicating the presence of naturally occurring eelgrass (green), restoration sites which were successful (yellow), and restoration sites which failed (pink). Colors indicate: model score > 88 (black); 88 ≥ score > 80 (dark blue); 80 ≥ score > 50 (light blue); 50 ≥ score (red).

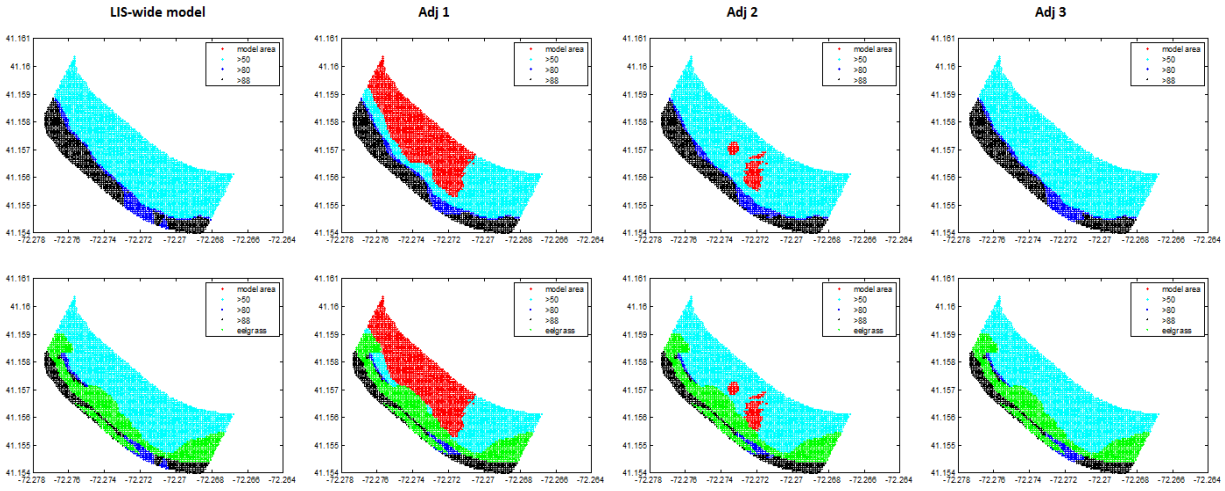


Figure 146: Petty's Bight EHSI Sub-Model, Maps of Model Output for Four Model Configurations
The upper panel shows model output only. The lower panel is the figure from the upper panel overlain with data points for eelgrass. Model output was visualized using different colors to represent thresholds overlain with colors indicating the presence of naturally occurring eelgrass (green), restoration sites which were successful (yellow), and restoration sites which failed (pink). Colors indicate: model score > 88 (black); 88 ≥ score > 80 (dark blue); 80 ≥ score > 50 (light blue); 50 ≥ score (red).

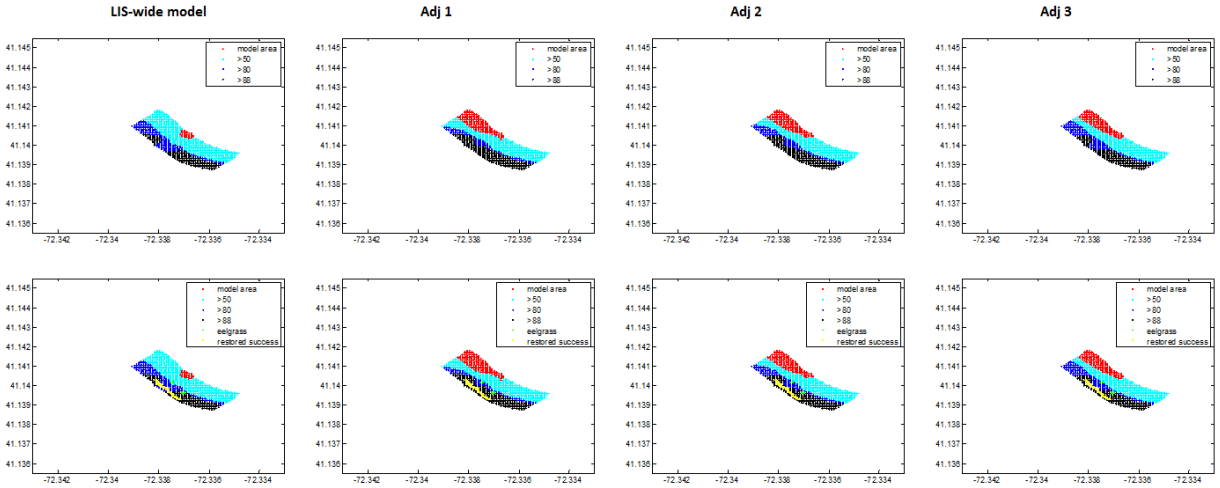


Figure 147: St. Thomas Point EHSI Sub-Model, Maps of Model Output for Four Model Configurations
The upper panel shows model output only. The lower panel is the figure from the upper panel overlain with data points for eelgrass. Model output was visualized using different colors to represent thresholds overlain with colors indicating the presence of naturally occurring eelgrass (green), restoration sites which were successful (yellow), and restoration sites which failed (pink). Colors indicate: model score > 88 (black); 88 ≥ score > 80 (dark blue); 80 ≥ score > 50 (light blue); 50 ≥ score (red).

7.7.2 SKILL ASSESSMENT OF THE CALIBRATED EHSI SUB-MODEL

The visual assessment of the EHSI Sub-Model indicated some improvement in model accuracy with the choice of adjustment two, which included the effect of detrimental green macroalgae. The skill obtained with the inclusion of the macroalgae was considered across the four case study sites (Table 20). The percent of grids with eelgrass for scores greater than 88 essentially did not change. Even when the macroalgae is assigned 20% of the model score weighting, the inclusion does not have an appreciable effect on the model skill (Table 20, Adjustment 1). Unlike the case presented for the development and calibration of the EHSI Model (Section 6.5.2), where the small change in skill from 10.00% to 10.56% was warranted by a coinciding shift in the distribution of eelgrass containing grids (Figures 27 and 29), the distribution of eelgrass grids did not change in a substantial manner for the EHSI Sub-Model (Figure 148, red bars).

While the inclusion of macroalgae seems theoretically sound, it appears to be an over-parameterization of the model. For this reason, inclusion of macroalgae in the model is not recommended.

Table 20: Skill Assessment of EHSI Sub-Model
The change in the percent of grids with eelgrass for model scores greater than 88 and less than 89 were assessed for the EHSI Sub-Model. Values shown are the sum of the category shown for Clinton Harbor, Niantic Bay, Petty's Bight, and St. Thomas Point.

Run	percent of grids with eelgrass	number of grids	number of grids with eelgrass
Scores Over 88			
LIS-wide model	15.7	14081	2211
Adj. 1	15.6	21594	3377
Adj. 2	15.1	19772	2986
Adj. 3	15.7	15954	2502
Scores Under 89			
LIS-wide model	9.9	63032	6226
Adj. 1	9.1	55519	5060
Adj. 2	9.5	57341	5451
Adj. 3	9.7	61159	5935

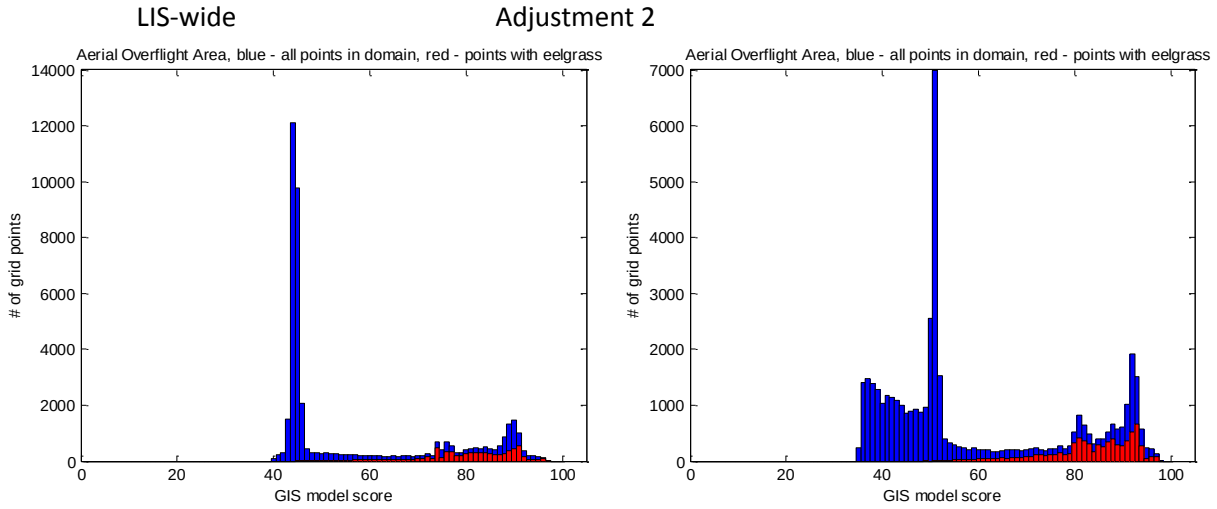


Figure 148: Comparison of EHSI Sub-Model Structure
Only data in the Niantic Bay case study site are shown. The red bars indicate areas with eelgrass, the blue indicate areas without eelgrass. The left panel is the EHSI Model formulation, the right panel is adjustment 2 which included detrimental green macroalgae. Note that the y-axis scale is different in the two panels.

7.7.3 Evaluation of Error Associated with Interpolation to the Edge of the Domain

As introduced in Section 7.5 (page 93), there is error associated with extrapolating parameter values from stations to the edge of the model domain, though the typical proximity of <200 m of stations to the edge limit this error. To quantify the effect of interpolation on overestimation or underestimation of model score at the edges of the domain, the values of parameters were examined relative to the ranges over which the model score varies. In all cases, the rationale for determining error was to find the area which had the greatest potential contribution of error, thus these are "worst case" scenarios. The goal was not to provide a definitive level of error at each location along the edge of the model domain, but to identify the potential maximum error in order to demonstrate that the error associated with interpolation was acceptable given the level of uncertainties in the model overall and the skill of the model at predicting current eelgrass distributions. The maximum error in the parameter was determined from the station to model boundary with the greatest difference (Table 21). This was translated into the maximum potential error in model score (Table 21) by evaluating the difference in parameter value relative to the weighting and range used to calculate the model score for that parameter. Estimates of error in model score were verified by examining the maps of model output for each parameter in each case study site (Section 7.6, 113).

In some cases, such as temperature, all case study sites had a maximum potential error at the edges which would overestimate temperature resulting in a lower model score. For all sites, error in the sediment organic content model output predicted higher model scores than found at neighboring stations. Bottom oxygen and grain size both exhibited underestimates and overestimates in sites. The light at the edge of the model domain typically received the highest score possible in shallow water and

the lowest score possible in deep water, thus no error was associated with this estimate. The error associated with extrapolating to the edge of the model domain ranges from -3% to 4%. The 4% value is associated with eastern end of Petty's Bight, with a distance of 300 m between the station and the model domain. A model score with 4% error at the edges of the domain is considered acceptable for justifying the extrapolation of data to the edge of the domain in the EHSI Sub-Model as applied to the case study sites.

Table 21: Error associated with interpolation to the edge of the model domain.
The range of variability shown for each parameter is the range over which the model score varies between a maximum and minimum score (see Table 17, page 113 for a full description). The maximum parameter error refers to the maximum difference in a station and model domain edge in the units indicated for rage of variability. The max. potential model error refers to the model score, out of a perfect score of 100. NIR indicates the values at the edge were not in the range of variability and thus have no error associated with the model output for that parameter.

		% Light Reaching the Bottom	Temperature	Bottom Oxygen	Sediment Grain Size, % Silt & Clay	Sediment Organic Content	Detrimental Green Algae Coverage	Sum of Potential Error in Model Output
	range of variability:	25-50%	21-25°C	3-6 mg/L	2-20%	0.5-10%	10-50%	
Clinton Harbor	max. parameter error	NIR	0.37	NIR	2.09	0.45	NIR	
	max. potential model error	*0*	*-1*	*0*	*2*	*1*	*0*	*2*
Cockenoe Island	max. parameter error	NIR	0.16	0.43	4.383	0.719	NIR	
	max. potential model error	*0*	*-1*	*-1*	*4*	*1*	*0*	*3*
DucK Pond Point	max. parameter error	NIR	0.37	1.17	1.737	0.346	NIR	
	max. potential model error	*0*	*1*	*-4*	*-1*	*1*	*0*	*-3*
Niantic Bay	max. parameter error	NIR	0.65	NIR	2.914	1.751	NIR	
	max. potential model error	*0*	*-2*	*0*	*2*	*3*	*0*	*3*
Petty's Bight	max. parameter error	NIR	0.77	NIR	2.123	0	17	
	max. potential model error	*0*	*-3*	*0*	*1*	*0*	*6*	*4*
St. Thomas Point	max. parameter error	NIR	0.57	NIR	2.77	NIR	10.33	
	max. potential model error	*0*	*-3*	*0*	*-2*	*0*	*4*	*-1*

7.8 Physical Effects on Eelgrass Success: the Role of Fetch on Wave Action

While we can estimate a minimum depth for eelgrass based on tidal amplitude, wind and wave action also play a role in determining the minimum depth. Niantic Bay and Clinton Harbor in Connecticut are well protected by land which encircles more than half of the perimeters of these two bays, mitigating wave action in these sites. Case study sites along Long Island shores, however, are more open and highly exposed resulting in excessive and damaging hydrodynamic forces on eelgrass beds attributed to heavy winds and seasonal storms originating mostly from the north and northwest.

The case study site at St. Thomas Point, NY is a perfect example of the impact of storm scour during the winter months and wave action on these shallow exposed habitats. Early attempts at restoration here failed based on planting at depths that were too shallow and susceptible to wave damage. Only after moving out into deeper water where the waves could not interact with the bottom were plantings successful. Review of the locations of these plantings identified a minimum depth of 2 m as suitable for eelgrass (Pickerell, *unpublished data*).

This means that areas from 0 m to 2 m should be excluded from the overall ranked area along exposed shorelines, if storm scour is accounted for in the model. As an example of how inclusion of the effect of fetch and storm scour may change model output, an updated bathymetry layer for St. Thomas Point based on field based measurements of depth (Figure 149) was clipped to only include areas greater than 2 m within the case study site. The resulting raster was applied to the original ranking result for St. Thomas Point (Figure 150) to remove all areas shallower than 2 m within the case study site (Figure 151).

The revised model output exhibits a high score of 66, thus the area would not be recommended for restoration efforts. These values are supported by the failure in two separate years for restoration efforts at this site, and highlights the need for better shallow water bathymetry data and the inclusion of a measure of potential wave stress to define the shallow water limit of potential suitable habitat for eelgrass.

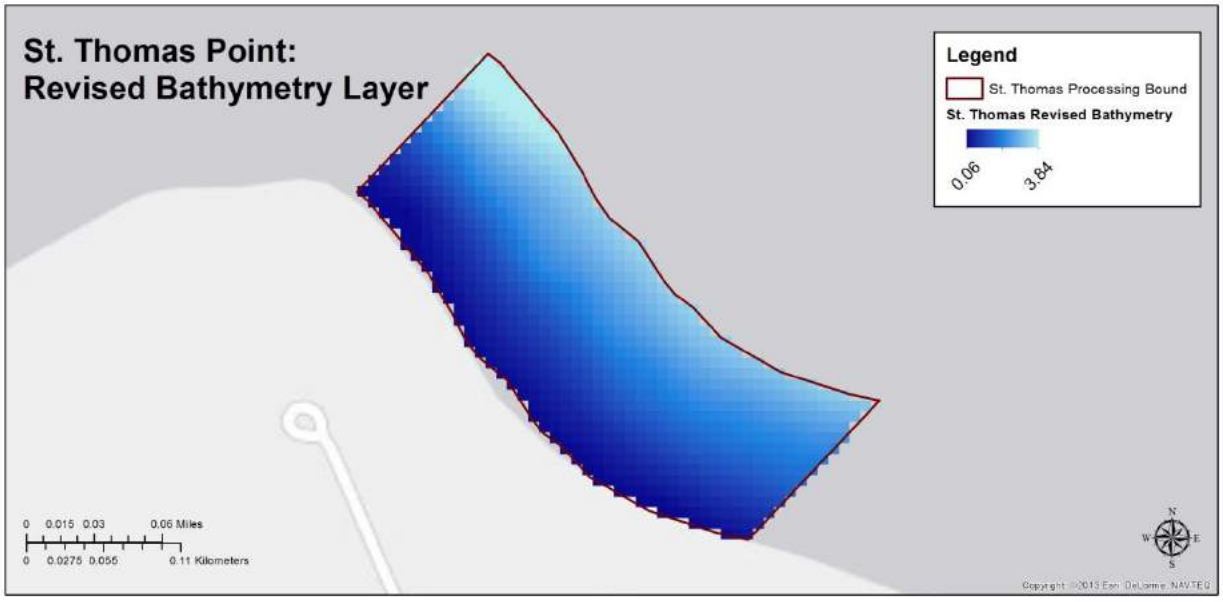


Figure 149: St. Thomas Point, Revised Bathymetry Layer.

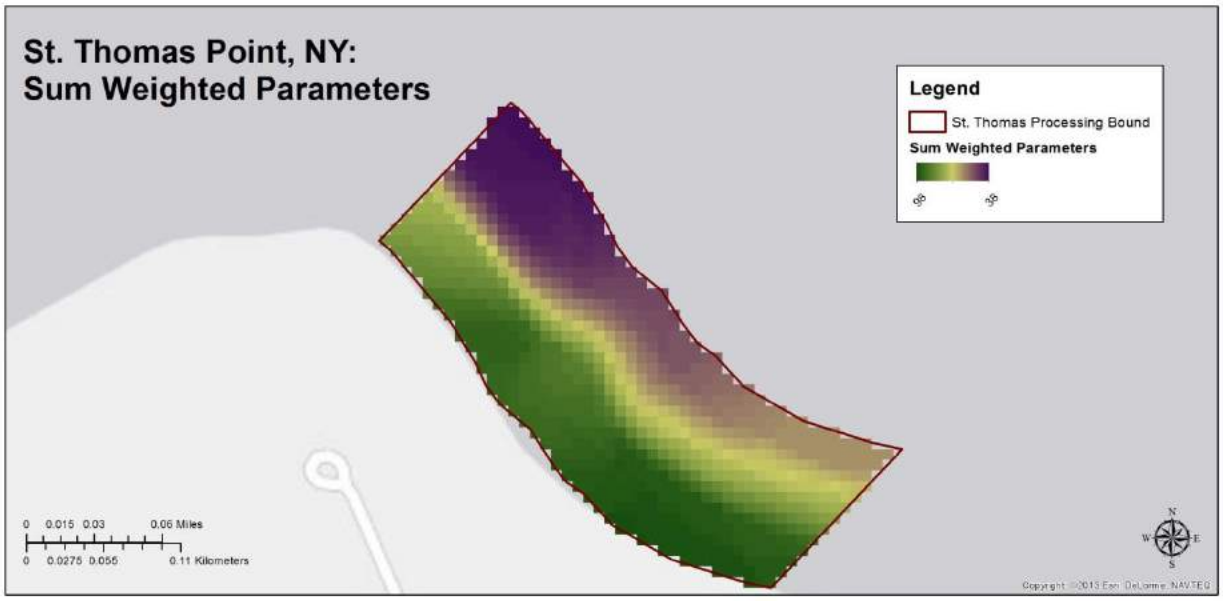


Figure 150: St. Thomas Point, Sum of Reclassified Parameters.
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18).

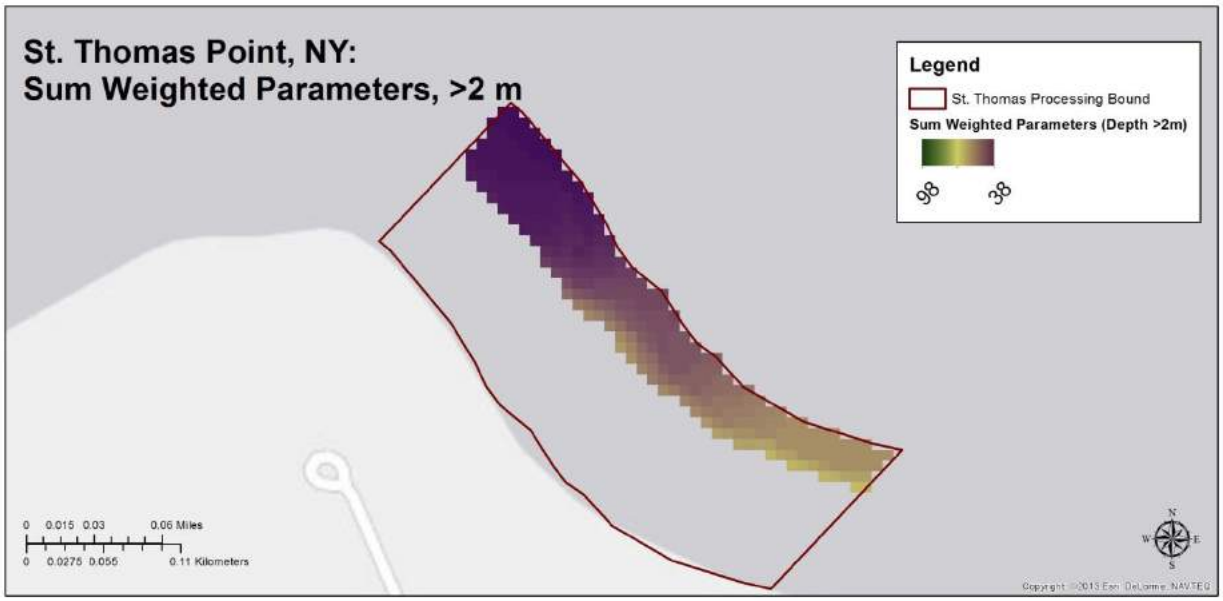


Figure 151: St. Thomas Point, Sum of Reclassified Parameters Adjusted for Fetch
Data shown are for EHSI Sub-Model Adjustment 2 (Table 18). Model area includes the effect of wave action by excluding depths >2m.

8 Determination of Uncertainty in the EHSI Model

The data and model output from the case study sites were compared to the EHSI Model data and model output to assess the error associated with extrapolating conditions into the margins of Long Island Sound based on data from deeper areas of the Sound. The EHSI Model is calculated with a grid size of 30.48 m x 30.48 m. The case study sites are calculated on a much finer scale, with 16 grid cells for every grid cell in the EHSI Model. In order to compare the model output, data from the nearest grids in the EHSI Sub-Model were averaged to yield a score representative of the area. For comparison of the actual parameter values, all grid cells from both models were used to assess the distribution of values, so the EHSI Sub-Model included ~16 x as much data as the EHSI Model.

All statistical analyses were conducted in *SigmaPlot*, v.11.0.

8.1 Error in the Interpolated Parameter Estimates Based on LIS-wide Datasets

In the EHSI Model, data available throughout Long Island Sound, typically sampled in the deeper areas of the Sound, were interpolated between stations and extrapolated into the shallow margins of the Sound. The case study sites provided site specific data with which to compare and assess the extrapolated LIS-wide data.

The data from each model (LIS-wide, Mini) were compared for each site, yielding significant differences among the two models for each parameter in each site (p-value < 0.05). These statistical differences were expected due to the large number of data points compared (~22,000 per site).

The greatest difference in the model score due to the parameter values were seen for the light and the temperature (Table 22). For each of these parameters, three of the six case study sites exhibited a difference in model score > 3 (out of 100) for the parameter. Both of these parameters involve a comparison between a longer term average for the LIS-wide dataset and a single point in time for the case study data set. For both parameters, a dataset which averages over a longer period of time is desirable, as a single point in time may not capture the variability or long-term average for the parameter. However, the LIS-wide data extrapolated into the shallow margins is especially suspect for these two parameters.

The difference in the model scores for light and temperature reflect that extrapolating data from the main stem of LIS into the shallow areas contributes more to the error of the EHSI Model than other parameters. The shallow margin is expected to be more turbid than the surface water of the main portion of LIS, as is evidenced by the lower percent of light reaching the bottom in four of the six case study sites (Table 22). For temperature, the shallow margin of the Sound should be warmer than what would be predicted from the surface water of the deeper Sound, as seen in all case study sites (Table 22). The characterization of light and temperature in shallow areas are critical to improving the accuracy of the EHSI Model. A summertime deployment of a combination temperature and light sensor could yield valuable information on the typical levels over a few weeks for these parameters. Such meters are

available for less than $60. Deployments could be targeted to areas where model scores are high enough to warrant consideration for restoration.

Good agreement is seen between the EHSI Model and the EHSI Sub-Model for both sediment characteristics: grain size (% silt & clay) and organic content. For each parameter, only one site exhibited a difference in model score greater than three points (Table 22). The dataset used for these parameters extended into shallow waters and included many more stations than the water quality monitoring stations. This high density of data coupled with the fact that sediment values do not exhibit the day-to-day variability seen in water quality yields good agreement between the models.

Good agreement between the models was also evident for oxygen. The model assesses low oxygen as a detrimental condition for eelgrass. Only one case study site, Cockenoe Island, was in a location where low oxygen was likely to cause a problem. The EHSI Model predicted a value of 4.7 mg/L while the median for the site on the date sampled was 5.4 mg/L. Given the day-to-day variability in oxygen these two values are in good agreement. Like light and temperature, oxygen is a parameter that varies within a daily cycle and can exhibit high variability on a day-to-day basis. A deployed sensor would also be useful for oxygen, where it is thought to be a concern. In reality, the oxygen levels in sites targeted for restoration are unlikely to be an issue, as evidenced by the “perfect” score received by the other five case study sites. If oxygen is likely to be a problem, the EHSI Model should be capable of predicting the low oxygen value.

A comparison of the case study site data with the parameter estimates based on the LIS-wide datasets indicates that light and temperature are the two parameters most in need of additional data. The light parameter (percent of surface light reaching the bottom) is a function of the light attenuation coefficient and the bathymetry of the site, thus better bathymetry data in shallow waters is also a priority. Sediment characterization is not required, but may be needed if sediment is thought to have changed since the last surveys for a particular area. Additional site specific oxygen data is unlikely to be helpful.

Table 22: Comparison of Parameter Values Used in Case Study Sites
The EHSI Model data are based on Sound data extrapolated into the margins of the Sound. The EHSI Sub-Model data are based on field work conducted in the case study sites. The median and percentiles for the actual data are show in the three columns on the left, the score associated with these parameter values is shown on the right. The range associated with a changing score are shown just below the parameter identification. Values above and below these ranges yield a score of 0 or 100% of the weight associated with the parameter. The maximum score for each parameter is: light, 30; temperature, 20; sediment grain size, 20; sediment organic content, 20; low oxygen, 10. Bold values indicate a difference in model score > 3 for the median.

Light Reaching Bottom (% of Surface)	ACTUAL VALUE			SCORE		
25 - 50	25th percentile	median	75th percentile	25th percentile	median	75th percentile
Clinton Harbor - LIS-wide Model	56.0	77.0	96.1	30	30	30
Clinton Harbor - Mini Model	31.1	72.1	90.9	7	30	30
Cockenoe Island - LIS-wide Model	12.5	21.8	54.3	0	**0**	30
Cockenoe Island - Mini Model	17.5	33.2	62.3	0	**10**	30
Duck Pond Point - LIS-wide Model	39.7	46.6	79.1	18	**26**	30
Duck Pond Point - Mini Model	42.2	57.2	75.7	21	**30**	30
Niantic Bay - LIS-wide Model	15.2	23.1	48.2	0	0	28
Niantic Bay - Mini Model	10.2	17.6	49.4	0	0	29
Pettys Bight - LIS-wide Model	12.3	22.4	43.7	0	0	22
Pettys Bight - Mini Model	3.1	9.8	45.3	0	0	24
St. Thomas - LIS-wide Model	42.6	50.9	85.1	21	**30**	30
St. Thomas - Mini Model	24.3	38.2	65.4	0	**16**	30

Temperature (deg. C)	ACTUAL VALUE			SCORE		
25 - 21	25th percentile	median	75th percentile	25th percentile	median	75th percentile
Clinton Harbor - LIS-wide Model	21.1	21.1	21.2	20	**19**	19
Clinton Harbor - Mini Model	21.8	22.0	22.2	16	**15**	14
Cockenoe Island - LIS-wide Model	21.5	21.6	21.6	17	17	17
Cockenoe Island - Mini Model	21.5	21.8	22.1	18	16	15
Duck Pond Point - LIS-wide Model	22.3	22.4	22.5	13	**13**	13
Duck Pond Point - Mini Model	23.0	23.7	24.2	10	**6**	4
Niantic Bay - LIS-wide Model	19.2	19.2	19.2	20	20	20
Niantic Bay - Mini Model	21.2	21.4	22.2	19	18	14
Pettys Bight - LIS-wide Model	19.4	19.4	19.5	20	20	20
Pettys Bight - Mini Model	20.6	21.4	21.8	20	18	16
St. Thomas - LIS-wide Model	19.5	19.5	19.6	20	**20**	20
St. Thomas - Mini Model	21.7	22.4	22.8	17	**13**	11

Oxygen, low (mg/L)	ACTUAL VALUE			SCORE		
3 - 6	25th percentile	median	75th percentile	25th percentile	median	75th percentile
Clinton Harbor - LIS-wide Model	6.0	6.0	6.1	10	10	10
Clinton Harbor - Mini Model	7.5	7.6	8.0	10	10	10
Cockenoe Island - LIS-wide Model	4.6	4.7	4.7	5	6	6
Cockenoe Island - Mini Model	4.8	5.4	5.8	6	8	9
Duck Pond Point - LIS-wide Model	6.3	6.3	6.3	10	10	10
Duck Pond Point - Mini Model	6.3	7.1	7.7	10	10	10
Niantic Bay - LIS-wide Model	7.2	7.2	7.2	10	10	10
Niantic Bay - Mini Model	8.0	8.4	8.7	10	10	10
Pettys Bight - LIS-wide Model	7.2	7.2	7.2	10	10	10
Pettys Bight - Mini Model	6.6	7.1	7.4	10	10	10
St. Thomas - LIS-wide Model	7.1	7.1	7.1	10	10	10
St. Thomas - Mini Model	7.2	7.5	7.7	10	10	10

Grain Size (% Silt & Clay)	ACTUAL VALUE			SCORE		
20 - 2	25th percentile	median	75th percentile	25th percentile	median	75th percentile
Clinton Harbor - LIS-wide Model	6.9	7.2	8.5	15	14	13
Clinton Harbor - Mini Model	3.3	9.5	23.3	19	12	0
Cockenoe Island - LIS-wide Model	5.3	28.1	49.2	16	0	0
Cockenoe Island - Mini Model	8.5	22.8	34.5	13	0	0
Duck Pond Point - LIS-wide Model	2.9	4.2	4.4	19	18	17
Duck Pond Point - Mini Model	2.9	3.2	4.2	19	19	18
Niantic Bay - LIS-wide Model	36.2	49.1	55.8	0	0	0
Niantic Bay - Mini Model	12.8	37.6	55.9	8	0	0
Pettys Bight - LIS-wide Model	4.8	5.6	6.2	17	16	15
Pettys Bight - Mini Model	4.5	5.0	5.4	17	17	16
St. Thomas - LIS-wide Model	3.0	3.1	3.5	19	**19**	18
St. Thomas - Mini Model	6.2	7.5	8.4	15	**14**	13

Sediment Organic Content (%)	ACTUAL VALUE			SCORE		
10 - 0.5	25th percentile	median	75th percentile	25th percentile	median	75th percentile
Clinton Harbor - LIS-wide Model	0.4	0.4	0.4	20	20	20
Clinton Harbor - Mini Model	0.8	1.3	2.4	19	18	16
Cockenoe Island - LIS-wide Model	1.1	1.1	1.2	19	**19**	18
Cockenoe Island - Mini Model	1.9	3.7	4.9	17	**13**	11
Duck Pond Point - LIS-wide Model	0.1	0.1	0.1	20	20	20
Duck Pond Point - Mini Model	0.6	0.7	0.9	20	20	19
Niantic Bay - LIS-wide Model	0.4	0.4	0.4	20	20	20
Niantic Bay - Mini Model	0.8	1.5	2.2	19	18	17
Pettys Bight - LIS-wide Model	0.1	0.1	0.1	20	20	20
Pettys Bight - Mini Model	0.6	1.0	1.1	20	19	19
St. Thomas - LIS-wide Model	0.2	0.2	0.2	20	20	20
St. Thomas - Mini Model	0.6	0.8	1.0	20	19	19

8.2 Error in the EHSI Model Output

For evaluation of the error associated with the model output, data from the four case study sites containing eelgrass were used, as for other skill assessments. A visual comparison of the maps of model output indicates that differences are present in the model estimates between the EHSI Model and the EHSI Sub-Model, though the general patterns of model score hold true for most areas (Figures 152, 153, 154, 155). While the case study sites provided more detailed data on many of the parameters, the bathymetry data used in these sites are the same. The bathymetry affects the light reaching the bottom (used with the light attenuation coefficient), a major factor contributing to model score. Detailed bathymetry is one of the datasets key to improving model accuracy.

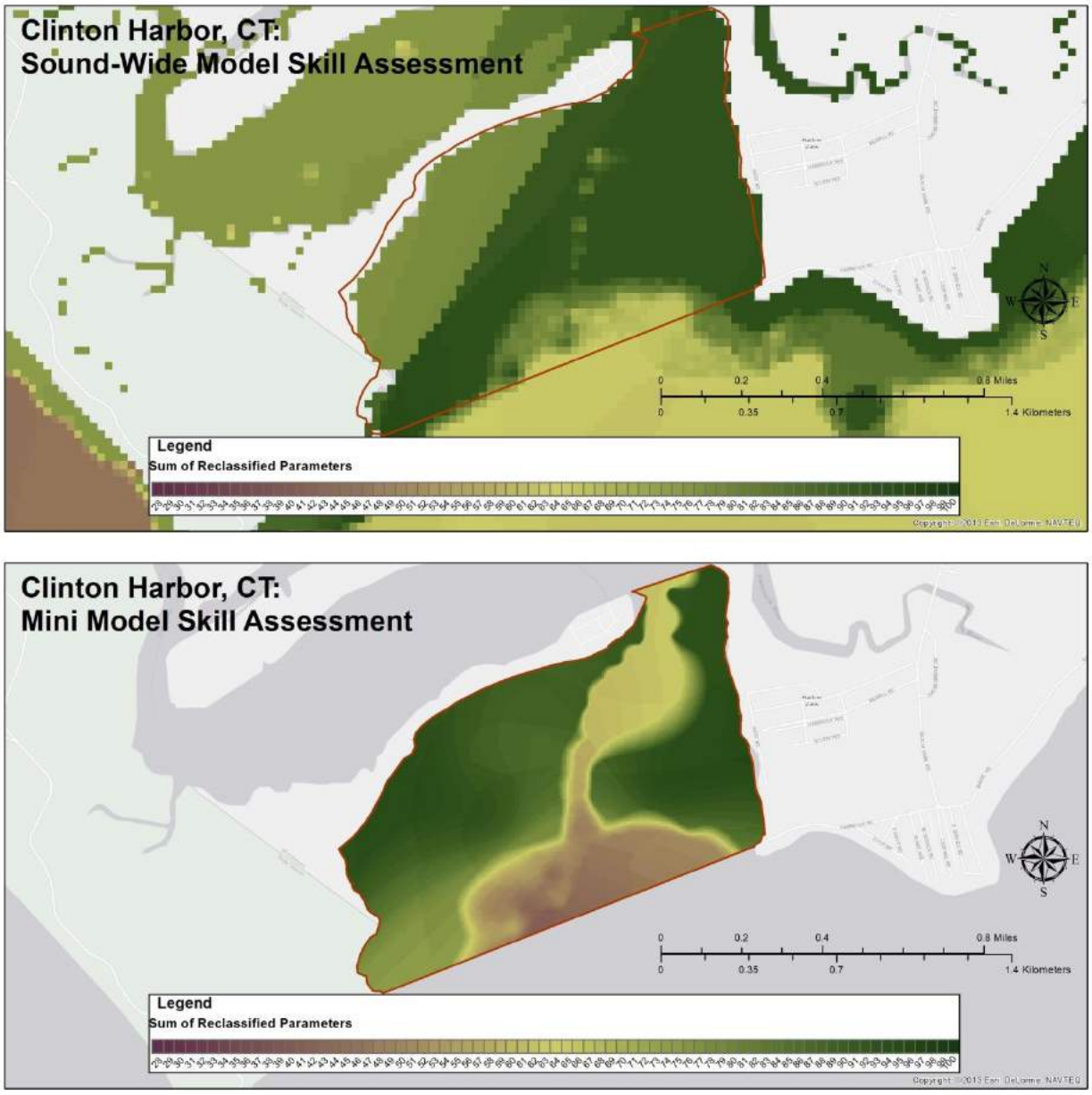


Figure 152: Comparison of output from EHSI Model and EHSI Sub-Model: Clinton Harbor
The upper panel presents model scores from the EHSI Model. The lower panel present scores from the case study site EHSI Sub-Model.

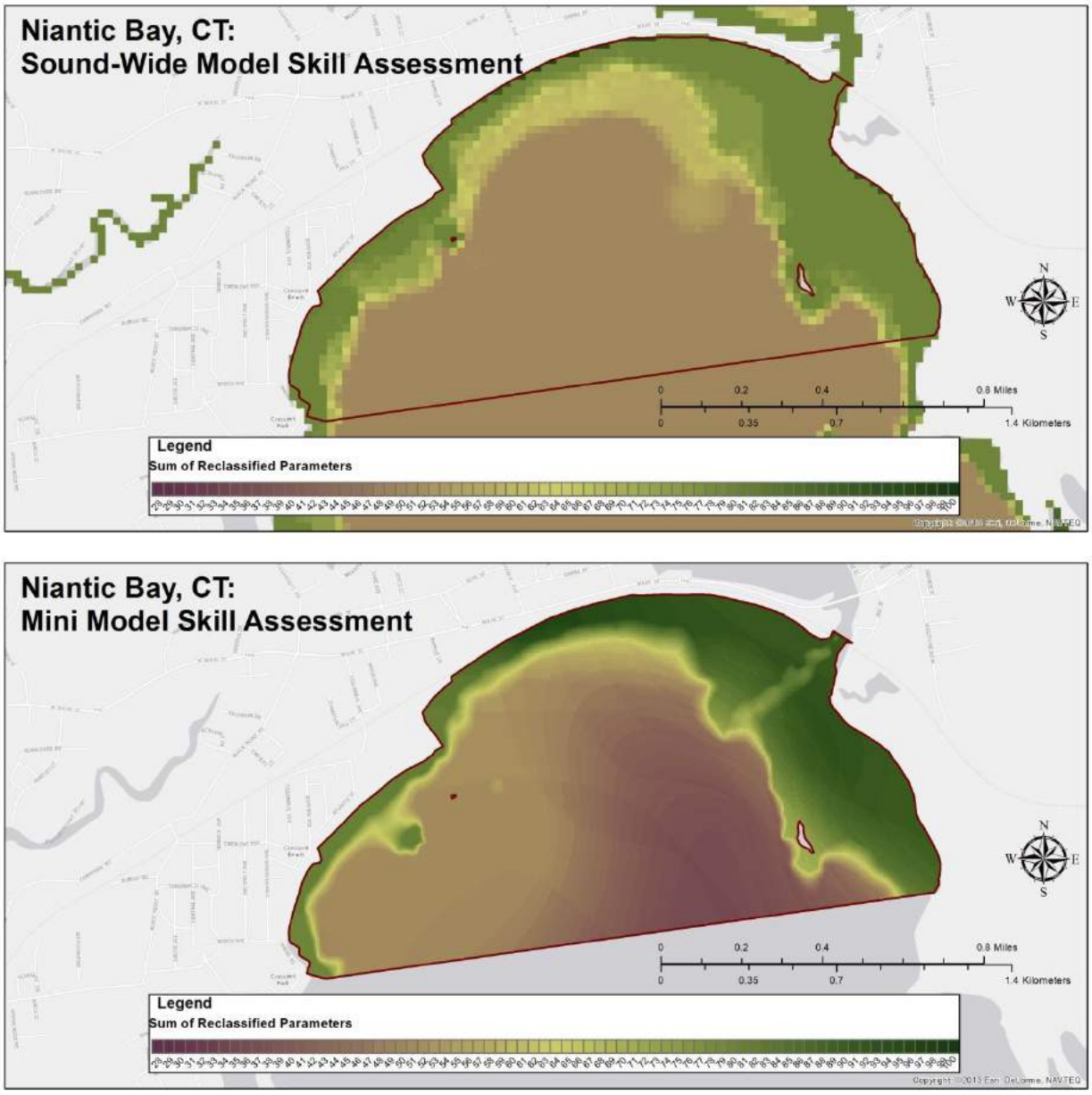


Figure 153: Comparison of output from EHSI Model and EHSI Sub-Model: Niantic Bay
The upper panel presents model scores from the EHSI Model. The lower panel present scores from the case study site EHSI Sub-Model.

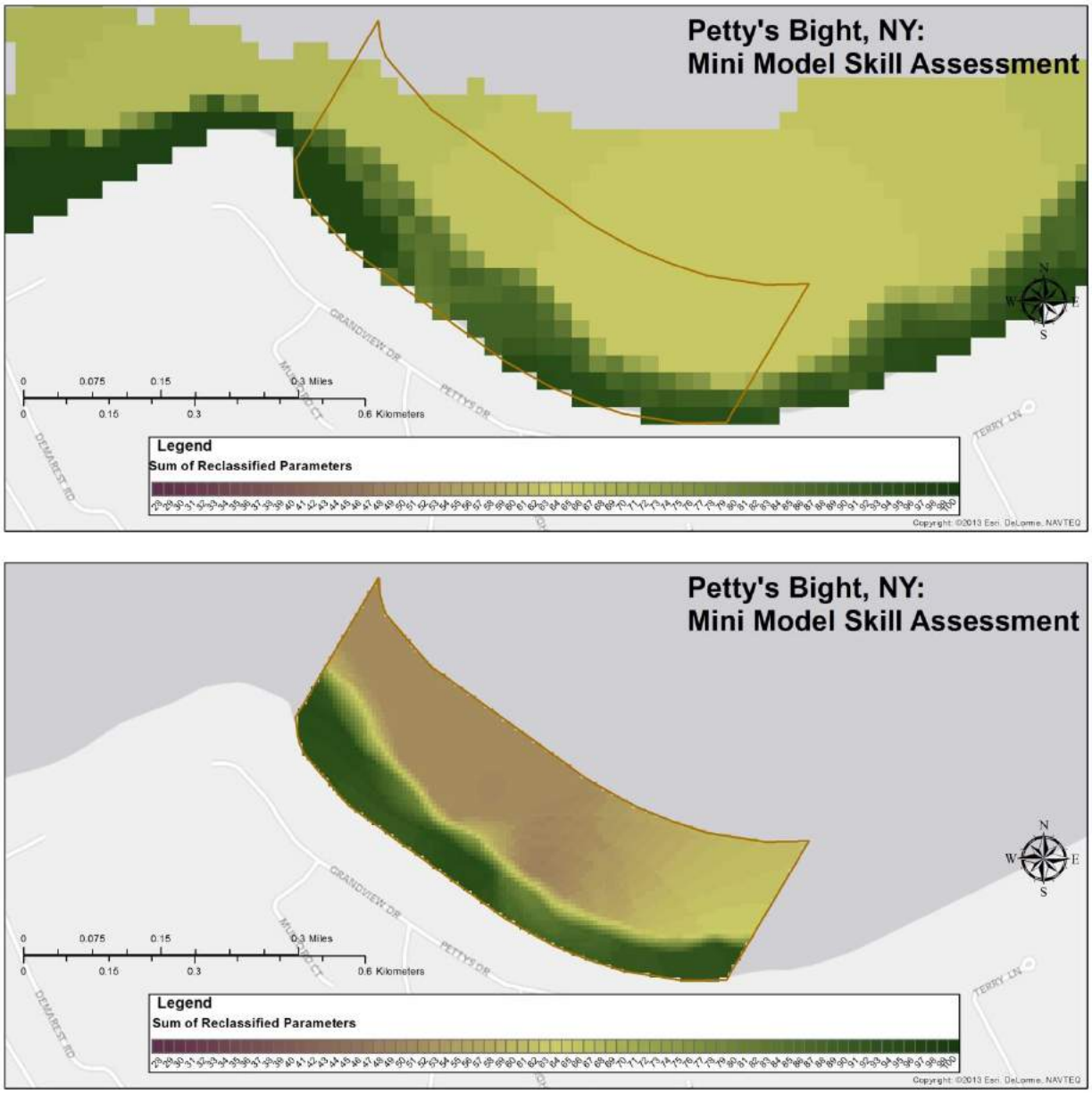


Figure 154: Comparison of output from EHSI Model and EHSI Sub-Model: Petty's Bight
The upper panel presents model scores from the EHSI Model. The lower panel present scores from the case study site EHSI Sub-Model.

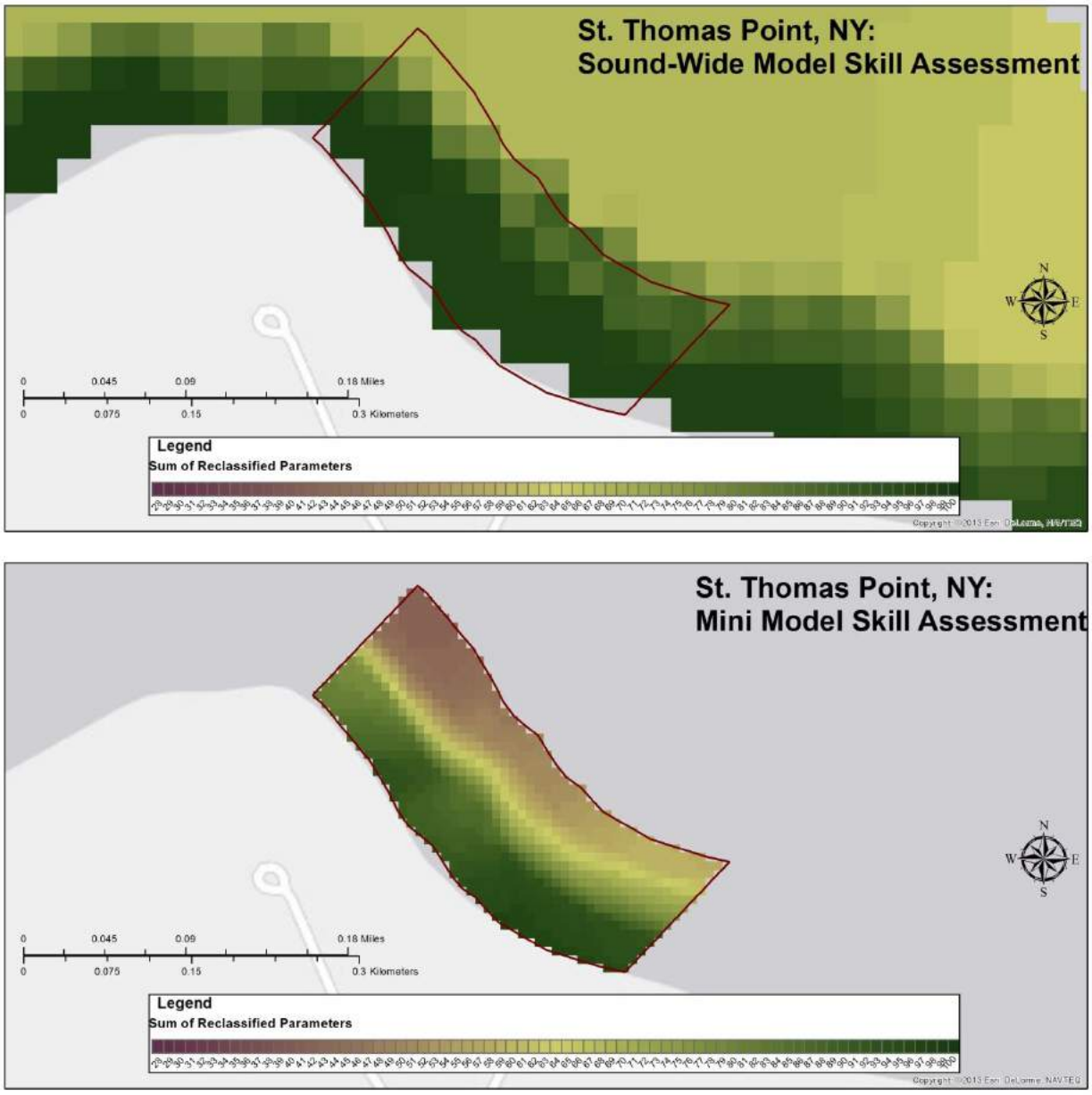


Figure 155: Comparison of output from EHSI Model and EHSI Sub-Model: St. Thomas Point
The upper panel presents model scores from the EHSI Model. The lower panel present scores from the case study site EHSI Sub-Model.

The model output was compared grid-by-grid for the two models (Figure 156). A linear regression yielded a slope close to 1 (0.979, p-value < 0.001) with a small intercept of -1.223 (p-value = 0.088). The R^2, which describes the degree to which the two set of data are correlated, was 0.659. The scatter of data seen in Figure 156 may seem at odds with the high R^2 of the regression and the tight fit of the 95% confidence band. However, a single data point shown in Figure 156 may represent hundreds of grid points with that particular combination of EHSI Model output and EHSI Sub-Model output. Figure 157 presents these data in a three dimensional format which indicates that a large number of the data points fall very close to the 1 : 1 line (line with a slope of 1). A statistical comparison of the models by case study site indicated that the EHSI Model tends to overestimate the model score in Clinton Harbor and St. Thomas Point and underestimate the score in Niantic Bay and Petty's Bight (Mann Whitney Rank Sum Test p-value < 0.05 for all sites).

The large number of points with low scores and with high scores shown in Figure 156 have a definite influence on the apparent goodness of statistical agreement between the EHSI Model and the EHSI Sub-Models. A more appropriate or fair way to assess the accuracy of the EHSI Model compared to the EHSI Sub-Model is to examine the model scores relative to the critical thresholds already identified for the model output: eelgrass restoration should be targeted in areas with model scores greater than 88 (Section 6.5.1, page 48) & eelgrass is not predicted in areas with model scores less than 51 (Section 6.5.1, page 48). For the threshold of greater than 88 (or less than 89), the EHSI Model matches the EHSI Sub-Model 73% of the time (Table 23). This indicates that the EHSI Model is accurate (assuming the EHSI Sub-Model is the standard against which we judge accuracy) about 73% of the time, making the EHSI Model relatively skilled at predicting suitable areas for restoration efforts. The second threshold of less than 51 (or greater than 50) identifies model output indicating the area is unlikely to be suitable for eelgrass, either natural or restored populations (Section 6.5.1, page 48). For the threshold of less than 51 (or greater than 50), the EHSI Model matches the EHSI Sub-Model 86% of the time (Table 23). Thus the EHSI Model is highly skilled at predicting areas which are unsuitable for eelgrass.

Table 23: Comparison of EHSI Model to EHSI Sub-Model Score in Areas with Eelgrass
The EHSI Model score and EHSI Sub-Model score were evaluated at the two critical threshold values identified for restoration success (> 88) and for general site suitability of eelgrass (> 50). Green indicates the EHSI Model matches the score of the EHSI Sub-Model, yellow indicates a disagreement in model scores. Within the four case study sites with eelgrass, 4684 grid points were evaluated.

	EHSI Model < 89	EHSI Model > 88
EHSI Sub-Model < 89	61%	22%
EHSI Sub-Model > 88	5%	12%

EHSI Model matches EHSI Sub-Model	73%
EHSI Model does not match EHSI Sub-Model	27%

	EHSI Model < 51	EHSI Model > 50
EHSI Sub-Model < 51	40%	2%
EHSI Sub-Model > 50	12%	45%

EHSI Model matches EHSI Sub-Model	86%
EHSI Model does not match EHSI Sub-Model	14%

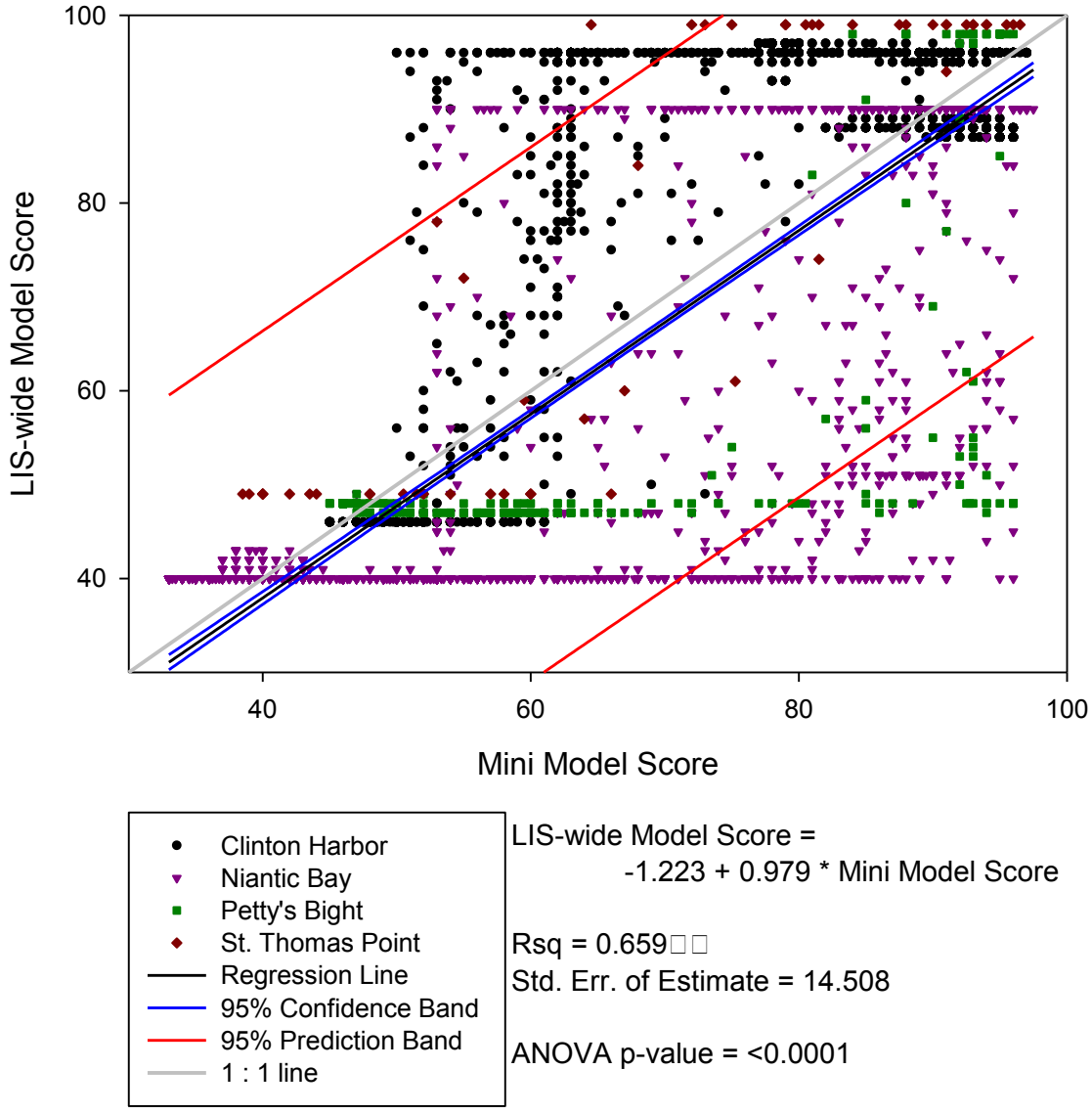


Figure 156: Comparison of EHSI Model and EHSI Sub-Model Output
Linear regression of EHSI Model score on the EHSI Sub-Model score indicates the two model outputs are correlated (R^2 = 0.659). Individual points shown in the graph can represent hundreds of actual points (Figure 157).

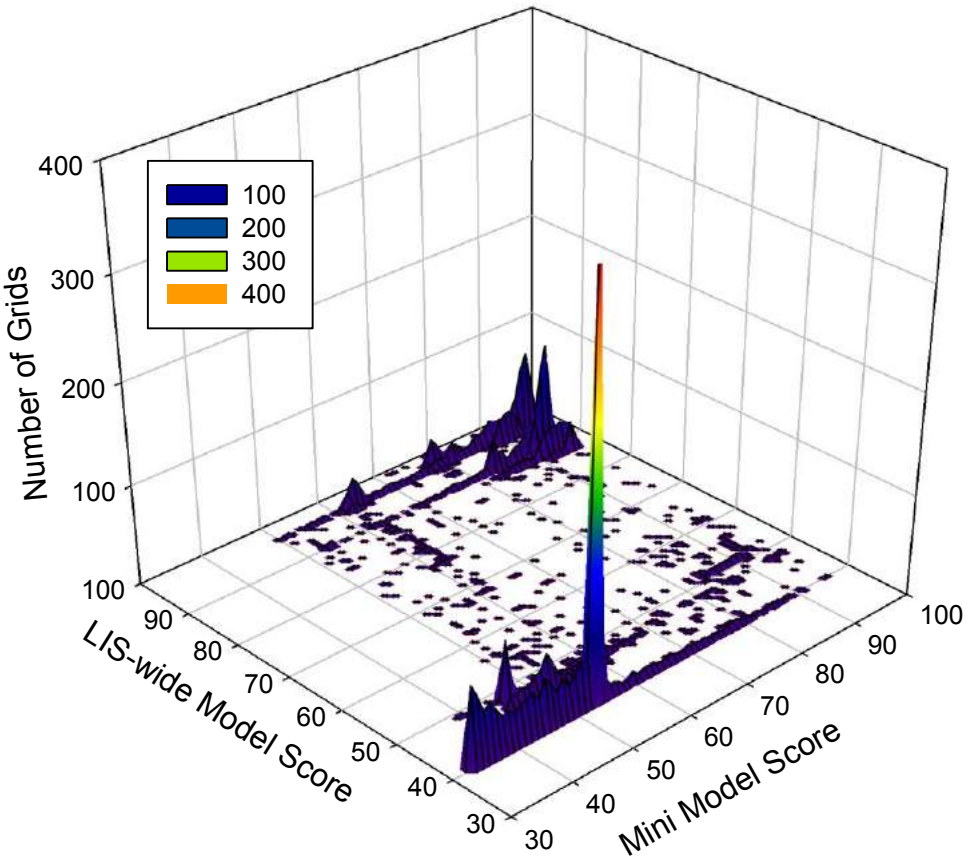


Figure 157: EHSI Model vs. EHSI Sub-Model, distribution of points
Each data point shown in Figure 156 represents many grids with the given model scores.

8.3 Summary of EHSI Model Error Assessment

In summary, the EHSI Model adequately captures the trends in habitat conditions. The agreement between the two models is reflected by the slope of 0.979 and the small intercept of -1.223 model points. The EHSI Model is relatively skilled at predicting areas which are determined by the EHSI Sub-Model as suitable for eelgrass restoration, with the EHSI Model matching the EHSI Sub-Model scores 73% of the time at the threshold model score of 88. The EHSI Model is highly skilled at predicting areas which are determined by the EHSI Sub-Model as unsuitable for eelgrass restoration or natural eelgrass beds, with the EHSI Model matching the EHSI Sub-Model scores 86% of the time at the threshold model score of 50.

9 Nutrient Pollution Indicator (NPI)

9.1 NPI Introduction

Nutrient loads and the accompanying proliferation of phytoplankton and macroalgae have been implicated in eelgrass declines, typically working through the mechanism of reducing the light available to eelgrass (*Zostera marina* L.) (see reviews: Burkholder et al. 2007; Lee et al. 2007). The GIS-based Eelgrass Habitat Suitability Index Model (EHSI Model) incorporates much data on water quality and sediment characteristics for the generation of predictions, but does not utilize nutrient loads or estimates of the expression of eutrophication beyond summertime minimum dissolved oxygen levels. As one step in model verification and to assess the suitability of the case study sites for eelgrass restoration using an empirical method, a bioindicator of eutrophication was employed in the case study sites.

The Nutrient Pollution Indicator (NPI) has been proposed as a method for assessing the early stages of eutrophication in estuarine settings (Lee et al., 2004). Use of this bioindicator implicitly assumes conditions are still suitable for eelgrass, but may be at the early stages of worsening. The NPI is calculated from eelgrass plant tissue as the leaf nitrogen content (%N) divided by the mass of the section analyzed (mg cm^{-2}). The NPI can be assessed on eelgrass plants harvested directly from beds along a gradient, allowing for comparison within a single confined estuarine system. However, when comparing among systems, collecting plants from a single area and deploying the plants on floating racks is advised (Short and Burdick, 2003a, 2003b). The rack deployment should remove any site-specific effects associated with the benthos and yield information on the suitability of the water column parameters for eelgrass survival.

The utility of NPI as an indicator of the early stages of eutrophication and the suitability for eelgrass is still in the evaluation phase. The bioindicator was developed and tested in Great South Bay, NH; Waquoit Bay, MA; and Narragansett Bay, RI (Short and Burdick 2003a; Lee et al. 2004). The NPI was independently assessed in the Barnegat Bay–Little Egg Harbor system in New Jersey (Kennish and Fertig 2012). The New Jersey evaluation was conducted on eelgrass harvested from beds versus plants deployed from racks, as in this study. Kennish and Fertig (2012) concluded that NPI was not a good bioindicator for comparing between sites in the highly eutrophic Barnegat Bay-Little Egg Harbor system. The failure of NPI to operate in the Barnegat Bay-Little Egg Harbor system indicates the limits of the utility of this method. The NPI was originally tested in estuaries ranging in length from 5 to 20 km (Short and Burdick 2003a; Lee et al. 2004). The Barnegat Bay-Egg Harbor sites were spread over 60 km along the axis of the system (Kennish and Fertig 2012). While the NPI as applied to intact eelgrass samples may not hold for large systems like Barnegat Bay-Little Egg Harbor and Long Island Sound (170 km long), we proposed that the NPI evaluated from eelgrass deployed on racks originating from a common donor bed will provide information on the relative suitability of the case study sites for supporting eelgrass.

9.2 NPI Methods

Six locations within Long Island Sound were chosen to evaluate the NPI as an indicator of the suitability of water quality for eelgrass restoration efforts, three along the Connecticut shore and three along the New York shore. These sites coincide with the case study sites chosen for model development. Sites were selected where the EHSI Model score was greater than 50 for at least 50% of the identified case study area (Table 24). The location of the deployment in each site was predicted as a suitable area for eelgrass restoration in the model output.

Case study sites were chosen to include stable beds of eelgrass, failed and successful restoration sites, and a Western Sound site unlikely to support eelgrass. The sites from East to West spanned a range of approximately 100 km along the main axis of Long Island Sound. The three New York sites experience relatively low inputs of nitrogen from the watershed, as they are located along the relatively rural shoreline of Eastern Long Island. In addition, these three sites are along the open coast as indicated by their names (see Table 24, e.g. Bight & Point) and experience a great deal of flushing compared with the Connecticut sites. The Connecticut sites span a gradient of lower nitrogen loading in the East, associated with less development and fewer people; to higher nitrogen loading in the West. All three Connecticut deployments were located in areas protected from the main flow of Long Island Sound. Niantic Bay and Clinton Harbor deployments were located within the protection offered by the headlands forming the entrance to these two bays. The Cockenoe Island deployment was situated between the Island and a sandbar which is exposed at low tide.

Table 24: Site Description for NPI deployments.
The six case study sites were used for NPI deployments. Niantic Bay served as the donor bed for all plants.

Site	Eelgrass Restoration Site Suitability Model score	Current Status
Petty's Bight, NY	80	existing natural eelgrass bed, stable
St. Thomas Point, NY	70	successful restoration, first planted in 2003
Duck Pond Point, NY	85	unsuccessful restoration site (2010, 2012)
Niantic Bay, CT	95	existing natural eelgrass bed, stable
Clinton Harbor, CT	95	variable natural bed (small), 1 successful restoration site (2011), 1 failed restoration site (2011)
Cockenoe Island, CT	70	no eelgrass, unlikely to support eelgrass

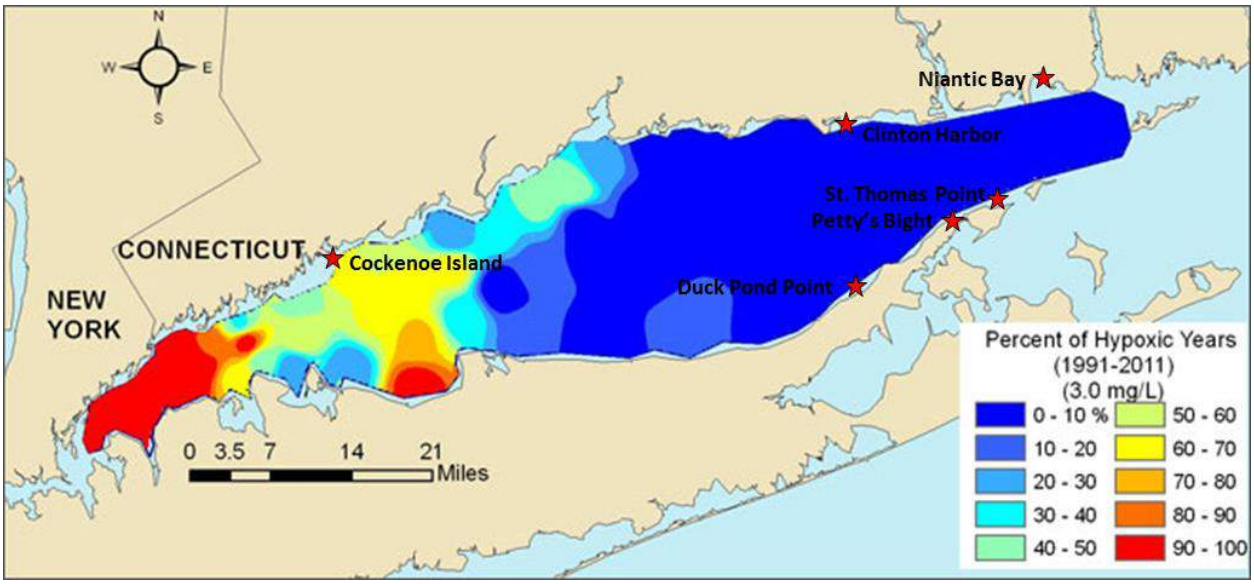


Figure 158: Locations of NPI deployments within Long Island Sound (red stars).
All plants deployed on NPI racks were collected from a single donor bed in Niantic Bay. The background map is the percent of years in which summertime hypoxia occurs in a given location, an indicator of the level of eutrophication (map provided courtesy of the Long Island Sound Study; http://longislandsoundstudy.net/indicator/frequency-of-hypoxia/, downloaded 12 Sep 2013).

Eelgrass plants were collected from a stable, natural eelgrass bed located in Niantic Bay, CT. Only intact plants with rhizomes containing at least two internodes were used for the NPI deployments. Plants were attached to a 0.4 m x 0.25 m plastic-coated wire rack suspended from floats at a fixed depth of 0.6 m. The NPI racks were deployed for 27 to 28 days, late July through mid-August, 2012. The method recommends deployments in July through September, the NPI is not as sensitive during other times of the year (Short and Burdick 2003a).

Upon retrieval, some plants were damaged or heavily fouled with epiphytic algae or fauna. Of the 15 plants deployed per rack, between 6 and 15 plants were recovered for processing. Each plant was evaluated to determine sheath length, number of leaves, length of each leaf, and the percent of each leaf with wasting disease (Burdick et al. 1993; Lee et al. 2004; Short and Burdick 2003a, 2003b). Material for the NPI was collected from the second and third youngest leaves by harvesting the 20 cm just above the sheath (Lee et al. 2004; Short and Burdick 2003b). Area was determined by measuring the length and width of the harvested leaf section with the goal of obtaining at least 20 cm^2 of plant material. If more material was needed, the first 10 cm above the sheath was harvested from the youngest leaf and fourth youngest leaf. In all cases, immature leaf tissue and grazed or damaged leaf tissue were avoided. Leaf sections were wiped with a Kimwipe to remove epiphytic organisms and dipped in distilled water to remove salt. Leaf sections were dried at 50^{o}C and weighed to obtain the mass of each section (mg cm^{-2}).

Leaf sections were analyzed for elemental composition of nitrogen and carbon on a Perkin-Elmer Series II 2400 CHNS/O Analyzer at the University of Connecticut, Stamford campus. Two to three leaf sections were composited into a single sample to provide sufficient material for elemental analysis, yielding between three and five replicates for NPI per site.

The NPI is calculated as leaf nitrogen content (%N) / leaf mass (mg cm^{-2}).

NPI results were compared among sites in *SigmaPlot v.11.0* using a One Way ANOVA and the Holm-Sidak method for pairwise multiple comparisons. NPI data met assumptions of normality and equal variance required for these methods. For all other comparisons, data failed the normality test or the assumption of equal variance and were thus analyzed using the nonparametric Kruskal-Wallis One Way ANOVA on ranks and the Dunn's multiple comparisons test. Significance was defined for all tests as $p \leq 0.05$.

9.3 NPI Results

The NPI results clearly follow the trend expected based on location within Long Island Sound (Figure 159). The areas along Long Island, in the southeastern waters of Long Island Sound, exhibit the best water quality conditions for eelgrass growth (Figures 158, 159). The NPI from these three sites were not statistically significantly different (p-value < 0.001). Petty's Bight hosts a natural bed of eelgrass and St. Thomas Point has maintained a restored eelgrass bed for ten years. The Duck Pond Point site also exhibited a low NPI, but restoration of eelgrass in this site has not been successful (Table 24). The Connecticut sites show an increasing trend in NPI moving East to West, coinciding with the trend of worsening water quality along the axis of Long Island Sound (Figure 159; p-value < 0.001) .

Short and Burdick's (2003a, 2003b) original evaluation of the NPI indicated that values greater than 0.45 from eelgrass suspended in the water column indicate severe eutrophication. Values between 0.3 and 0.45 indicate moderate nutrient overexposure which is evidence of early eutrophication. Under these criteria, all sites from this study indicate acceptable water quality for eelgrass (Figure 159).

The NPI is calculated as the %N in the leaf section divided by the leaf mass. The leaf masses were low for the Connecticut sites and higher for the New York sites (Figure 159). The nitrogen content in the leaves showed an increasing trend from East to West among the three New York sites and also among the three Connecticut sites (Figure 159), though not when all sites are considered together.

Upon retrieval, a number of the racks and eelgrass plants exhibited a heavy epiphyte load. The epiphytes were dominated by filamentous red algae (*Neosiphonia harveyi*) at most sites, with filamentous green present in Niantic Bay. The filamentous green algae is common in the naturally occurring beds in Niantic Bay. The red algae was also found growing on the eelgrass at the New York sites, though not as dense as what was seen on the Connecticut deployments. Barnacles were found attached to the leaves of plants deployed in Clinton Harbor and Cockenoe Island.

The wasting disease index on eelgrass leaves from the donor bed in Niantic Bay, CT was relatively high when compared with estimates of wasting disease coverage on retrieved plants (Figure 161). The NPI deployment in Niantic Bay exhibited the highest level of wasting disease upon retrieval. Petty's Bight and St. Thomas were the least affected by wasting disease.

The sheath length, which has been used as an indicator of growth rate (Gaekle et al. 2006), was similar among the sites (Figure 159). Only Cockenoe Island and Clinton Harbor exhibited a statistically significant difference in sheath length. Assuming that sheath length can be used as a proxy for growth in these deployments, the lower growth rate at Clinton Harbor is likely linked to the high turbidity at this site. The light intensity at Cockenoe Island, as measured with HOBO deployable light meters attached to the deployment racks, was similar to that in Niantic River. Clinton Harbor daytime light was between 50 and 65% of the other two Connecticut sites (data not shown).

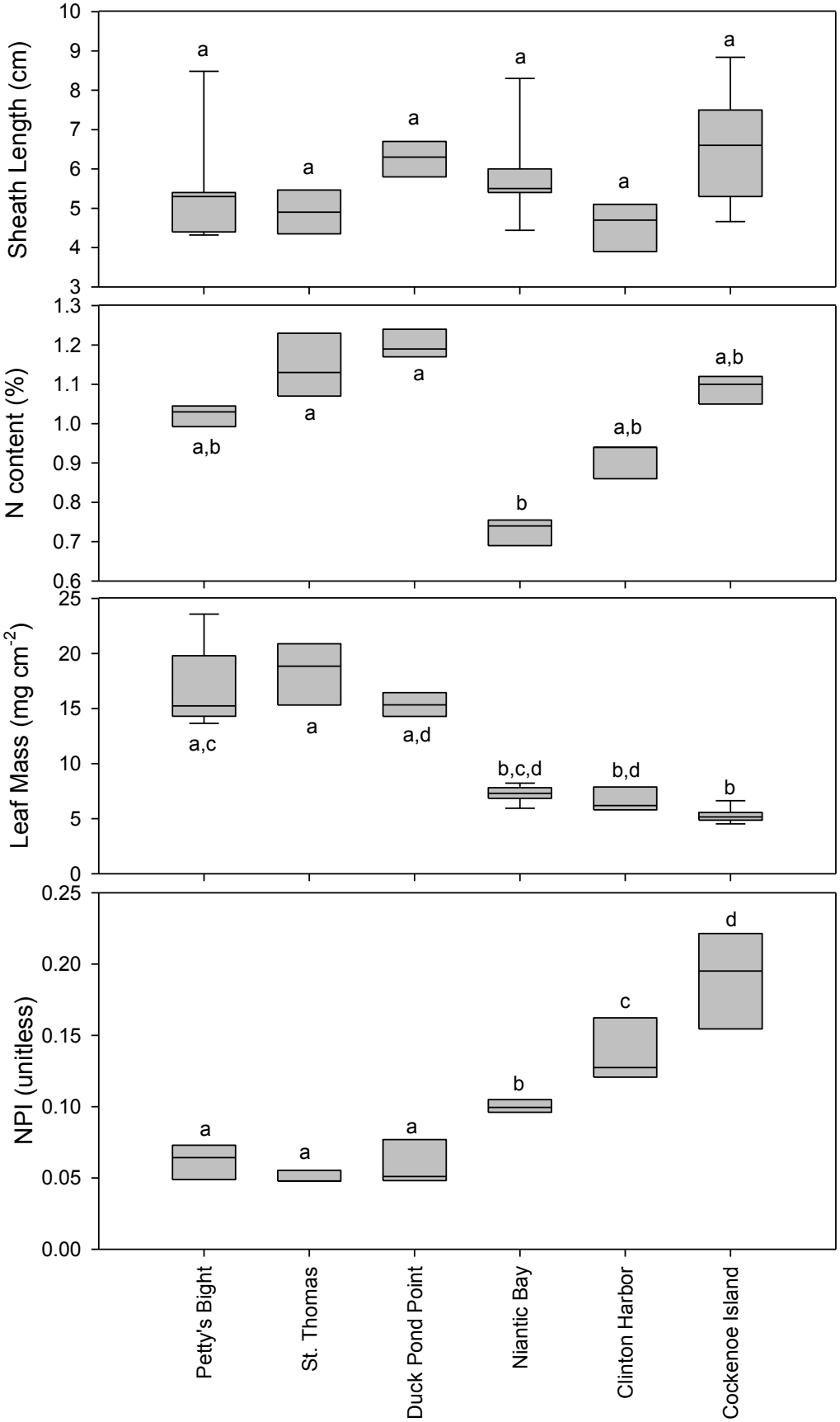


Figure 159: NPI Results
The Nutrient Pollution Indicator is a unitless number used here for comparing the suitability of water quality for eelgrass success. The lower the value, the greater the suitability for eelgrass. The NPI is calculated as the %N divided by leaf mass. Statistical significance within a panel is indicated by the letters, the same letter in two or more sites indicates the difference in the two sites is not statistically significant.

Niantic River **Clinton Harbor** **Coceknoe Island**

Figure 160: Images of NPI deployment rack on the retrieval day.
Note that Niantic River eelgrass exhibits some filamentous green epiphytes, but eelgrass leaves are still visible. The turbidity at the Clinton Harbor site was high, leaves exhibited an epiphyte load similar to Niantic Bay, but the epiphytes were dominated by filamentous red algae. Cockenoe Island eelgrass leaves were almost completely hidden by the fine branching red algae (all algae present in the Cockenoe Island photo are attached to the eelgrass leaves or the deployment rack).

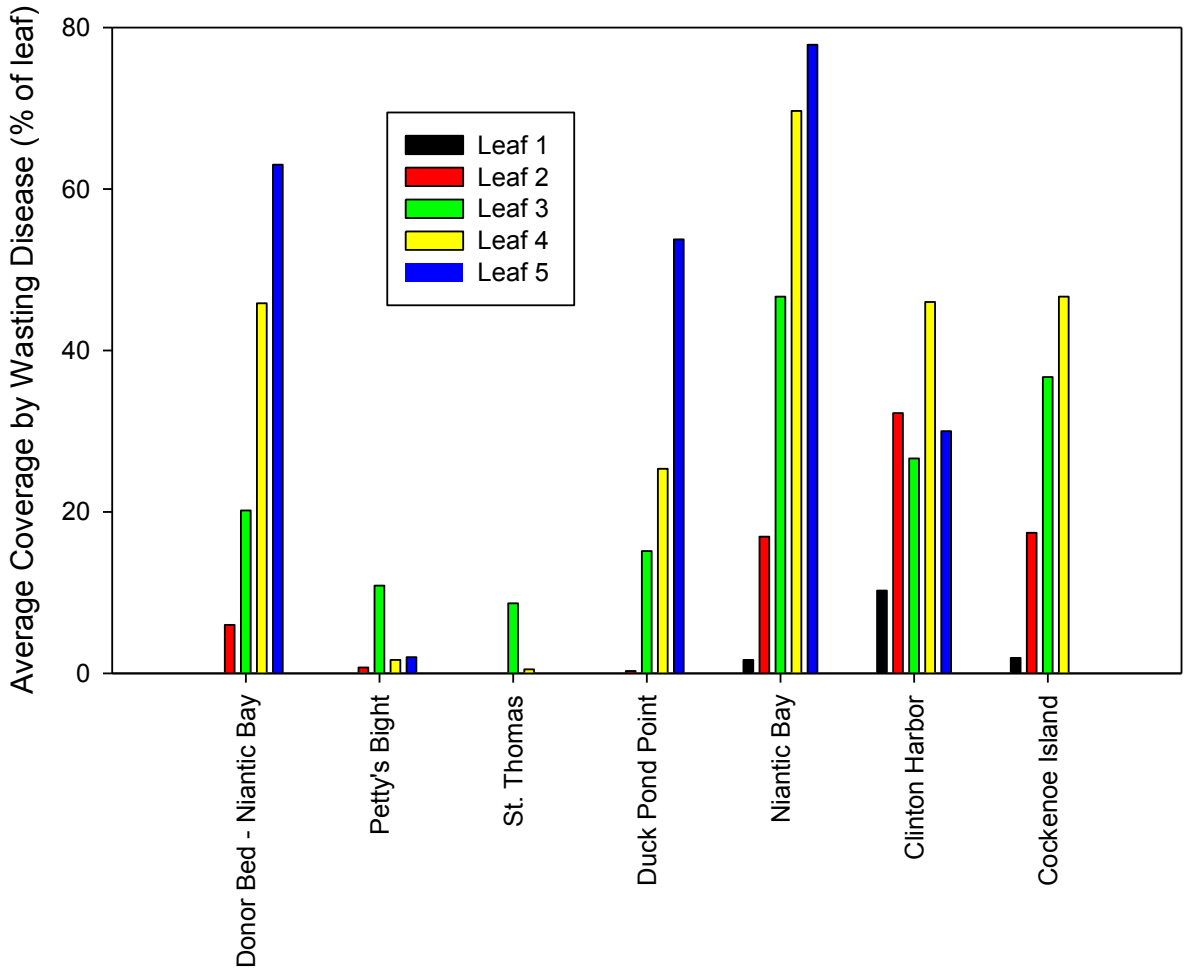


Figure 161: Wasting disease on eelgrass used for NPI Deployment.
The area of wasting disease was evaluated for each leaf of each plant recovered from the NPI rack deployments. Leaf 1 is the youngest leaf, leaf 5 is the oldest leaf. St Thomas and Cockenoe Island plants did not have a fifth leaf.

9.4 NPI Discussion

The calculation of NPI from eelgrass collected from a single donor bed and deployed into sites of interest appears to be a sensitive indicator of the suitability of a site for eelgrass. As with any effort at determining site suitability for restoration efforts, the best approach is to use a suite of indicators. Traditionally, restoration efforts have relied upon personnel's knowledge of local areas and experience with restoration efforts to determine the best conditions required for a given region. The EHSI Model provides an additional tool for identifying locations within the region which may already be targeted as potential sites and for identifying new areas which might have been overlooked (i.e. Norwalk Islands, CT). The deployment of a rack of eelgrass in a potential site is a relatively easy process in terms of field work and lab analysis. The NPI results can be used to verify the EHSI Model output or may indicate that while the model score is good, other factors not included in the model disqualify the site as a good candidate for restoration success.

The NPI results indicate a course of action for applying this empirical indicator to assist with restoration site selection. The trend in NPI across the six sites supports the general opinion of restoration personnel on the potential for success in these specific locations. The data collected allow for the NPI guidelines suggested by Short and Burdick to be refined for application in Long Island Sound (Short and Burdick, 2003a, 2003b). While our results provide compelling evidence that NPI (as applied to eelgrass deployed on racks) is a good relative indicator among sites evaluated during the same time period, additional deployments using eelgrass from a variety of donor beds and conducted in different years would be necessary to apply a general rule to the NPI value desired for restoration work. An additional confounding factor in this study was the length of the deployment. The recommended maximum deployment time is three weeks (Short and Burdick 2003a). After three weeks, eelgrass is likely to begin to experience nutrient limitation as it does not have access to the sediment pool of nutrients (Lee et al. 2007; Short and Burdick 2003a). Evidence of such limitation may include black leaves and increased evidence of wasting disease. Some black leaves were noted at the Cockenoe Island site, where the leaves of plants were not visible upon retrieval due to the heavy epiphyte load. However, leaf appearance, sheath length as an indicator of growth, and extent of wasting disease indicate that the 29 day deployment still yielded valid results.

The New York sites have all been deemed suitable for restoration efforts. One site hosts an existing natural bed, a second site has hosted a restored bed for ten years, and eelgrass restoration has been attempted at the third site on two separate occasions (Table 24). According to the model output and to expert opinion, these three sites exhibit a high chance of success for restoration of eelgrass. The NPI data support these assessments, with values of NPI < 0.08 for all three sites. The fact that restoration attempts at Duck Pond Point have failed has been attributed to the open nature of this site, characterized by heavy wave action during winter and storm events. The influence of the prevailing wind direction and the fetch experienced at a site has not been factored into the EHSI Model and is not captured by a short summertime NPI deployment. The history of efforts at this site highlights the continuing need for local knowledge.

The Connecticut sites span a range in quality of site suitability for restoration. The Niantic Bay, with a maximum NPI of 0.11, hosts a stable bed of naturally occurring eelgrass. While the bed has proved stable for many years (Keser et al. 2003), the eelgrass typically carry a heavy epiphyte load likely indicating an abundance of available nutrients (Hauxwell et al. 2003); but other factors such as a lack of grazers could also account for this situation (Moore and Wetzel 2000; Neckles et al. 1993). The lower N content in eelgrass from the Connecticut deployments relative to New York may indicate the effect of reduced N availability due to the presence of the macroalgae epiphytes (Figure 159). A restoration attempt was made at two locations in Clinton Harbor in 2011, where the maximum NPI from this deployment was 0.16. Eelgrass planted at one location disappeared within a few months. The other location survived for over a year. During the fall and winter of 2012-2013, a few storms and a winter dredging event may have contributed to the decline of the planted bed. Clinton Harbor is an especially turbid site, though a small naturally occurring bed was found after the start of this project and a second bed can be found at Duck Island breakwater, just east of Clinton Harbor. Cockenoe Island, with a maximum NPI of 0.23, was the site where restoration success was not predicted by expert opinion even though the model predicts that success is possible. The higher NPI and abundance of epiphytes indicates water quality is not currently appropriate for eelgrass restoration this far west in Long Island Sound.

The trends in NPI among the six sites coupled with additional knowledge of the sites allows for the development of an initial recommendation for NPI values. When examining a site for possible restoration efforts, an NPI of less than 0.12 is desirable and a value less than 0.09 is highly advised. While eelgrass does survive at sites with higher NPI values, newly planted eelgrass often requires better water quality than established beds. Additional deployments to determine the potential confounding effect of alternate donor beds, length of deployment, and time of deployment are advised to further refine this estimate.

10 Summary

10.1 Utility of the Model

The EHSI Model is a useful tool for evaluating the suitability of a site for eelgrass restoration efforts. With additional site specific data, the EHSI Sub-Model will further refine the estimate of site suitability and can aid in choosing a specific location within in area targeted for restoration. The maps generated in this report can be used as a first approximation to examine the areas which are potentially suitable for eelgrass in general and for restoration efforts. For a more detailed examination of the model scores in a particular area and an investigation of the model scores associated with individual parameters, working with the GIS-based version of the model is advised. A user manual targeted towards people familiar with the operation of *ArcGIS* is provided in Appendix 2. The model is suitable for use by restoration specialists, the management community, and the academic community. The model may also be of interest to other LIS stakeholders, including educators, shellfish commissions, and community-based advocacy or monitoring groups.

While eelgrass may be supported in areas with model scores greater than 50, a target score of greater than 88 is recommended for restoration efforts (Section 6.5.1, page 48). To assess the error associated with extrapolating data from deeper areas of LIS into the shallow margin of the Sound, the LIS-wide HSI Model results were compared to the EHSI Sub-Model results which incorporated data collected within the sites. The EHSI Model is relatively skilled at predicting areas which are determined by the EHSI Sub-Model as suitable for eelgrass restoration, with the EHSI Model matching the EHSI Sub-Model scores 73% of the time at the threshold model score of 88. The EHSI Model is highly skilled at predicting areas which are determined by the EHSI Sub-Model as unsuitable for eelgrass restoration or natural eelgrass beds, with the EHSI Model matching the EHSI Sub-Model scores 86% of the time at the threshold model score of 50.

In addition to identifying potential sites for eelgrass restoration work, the model may also be used to identify the source of impairment in areas with model scores less than 88 or less than 50. Figures in this report may be used as a first approximation of impairments in a specific location (see Section 6.4.5, page 47 for a description of this process), but for in-depth exploration, the GIS-based version of the model is advised. In the GIS files, the user may zoom into an area of interest and toggle between the layers of model scores associated with each parameter to evaluate which parameter is causing the source of the impairment. No management actions exist which can affect temperature, if this parameter is the source of the impairment, but all other parameters may be affected by management actions. Dissolved oxygen and the light reaching the bottom reflect water quality issues (nutrients, organic matter, total suspended solids). The sediment characteristics (gran size as % silt & clay, organic content) also reflect water quality issues as the finer sediments and higher organic content are associated with greater delivery of organic matter and particles to the benthos. The difference between water column issues and benthic issues is the expected response time following management actions. Water column properties are highly likely to exhibit a much faster response time relative to changes in the benthos.

While the EHSI Model and the EHSI Sub-Model are useful tools in evaluating site suitability for restoration efforts, they are tools which should be used in conjunction with a suite of diagnostic approaches. The EHSI Model is useful for identifying new areas for restoration efforts, especially in areas west of where restoration has previously been attempted. A site evaluation by an experienced restoration specialist will allow for the evaluation of other factors which may exclude a site from consideration. These would include the presence of beneficial and detrimental organisms (macroalgae, invertebrates), proximity to competing uses (marinas, navigation channels, shellfish beds, public beaches, etc.), and an understanding of the potential for physical disturbance due to storms and winter weather. Additional data for the five parameters included in the model collected from a site of interest can be fed into the EHSI Sub-Model yielding higher resolution site maps and assisting with the choice of specific locations within a larger area targeted for restoration. The empirical tool evaluated, the Nutrient Pollution Indicator deployments of eelgrass to assess water quality suitability is an additional method for assessing sites identified by the model. The NPI captures effects not included as forcing factors in the model. Thus, it is especially useful in sites where all parameters look good in the model, but the restoration specialist has concerns over water quality.

The model can incorporate new data as they become available. This flexibility will allow the model to incorporate changing water quality in Long Island Sound, both improvements as further strides are made in the area of nutrient reductions from human sources, and worsening conditions as temperatures rise in response to climate change.

The EHSI Model can be readily transferred to other systems. The parameter values over which the model varies may be changed to reflect other seagrass species and the varying tolerances to the five parameters included in the model. Local data will be required from any new locations.

The current model accurately reflects the distribution of natural eelgrass beds in Long Island Sound and captures both the successful and unsuccessful restoration attempts. Future restoration efforts will be guided by model output, further verifying the model and highlighting any shortcomings in the model.

10.2 Identifying the Gaps

The development of the model has revealed gaps in the available data and yielded suggested additions to the model to improve accuracy of the model's ability to predict suitable sites.

10.2.1 Data Gaps for the Current Model

The development of the model has allowed for the identification of gaps in the data coverage. First and foremost, data from the shallow margin of Long Island Sound where eelgrass may grow is needed in all categories. Extrapolating data collected in the main stem of Long Island Sound can provide a good first estimate of the suitability of a site for eelgrass restoration, but additional site specific information can further improve the accuracy of the model, as demonstrated for the case study sites. While additional site specific data on all of the model input parameters would be helpful, the priorities are as follows.

The highest priority data need is for higher resolution bathymetry data which can be coupled with estimates of tidal range to better delineate the deep water edge and shallow water edge of suitable habitats for eelgrass. In the current model, it is assumed that eelgrass may grow up to the shoreline. This assumption was necessitated by the fact that there is little to no bathymetry data in areas where the mean water depth is 1.5 m or less. The shallow limit of eelgrass in Long Island Sound has been identified as equivalent to the mean tide level minus half the mean tidal range (Koch 2001). For example, in areas with a 1 m tidal range (equivalent to a 0.5 m tidal amplitude), the minimum depth will be 0.5 m below mean tide level. Inclusion of this minimum depth limit would eliminate some of the shallow shoals where eelgrass is unlikely to survive.

A comparison of data from the case study sites and the values estimated for the case study sites based on the LIS-wide datasets indicates that light and temperature are the two parameters also in need of additional data. These two parameters were identified by examining the model scores in the EHSI Sub-Model applied to the case study sites versus the EHSI Model score within the area of the case study sites. Both of these parameters exhibited a difference in average model score greater than 3 for most of the case study sites. The light parameter (percent of surface light reaching the bottom) is a function of

the light attenuation coefficient and the bathymetry of the site, thus better bathymetry data in shallow waters is a priority for this model term as well as for defining the shallow edge of suitable areas. The issue with both of these parameters is the need for a deployed instrument to monitor these values, which vary over a daily cycle and exhibit day-to-day variability. Deployments of inexpensive light and temperature sensors capable of recording every 15 minutes would assist with better characterizing these parameters.

All other parameters (oxygen, sediment grain size, sediment organic content) were similar among the EHSI Model and the EHSI Sub-Model, with an average difference in model score less than three for a majority of the case study sites (see Section 8.1, page 146 for a full discussion of this topic). While additional data for these parameters would increase the accuracy of the model output, the model is less sensitive to inaccuracies in these values. The oxygen values in coastal waters are not well known, the timing and duration of hypoxia and anoxia is important to evaluating a site for eelgrass but the LIS data may serve as a proxy for this parameter. Sediment characterization is also not required, but may be needed if sediment is thought to have changed since the last surveys for a particular area.

10.2.2 Suggested Additions to the Model

While the model appears to yield an accurate assessment of habitat suitability for eelgrass, delineation of the shallow limit for eelgrass suitability would improve the assessment of areas targeted for restoration. This involves the better resolution of bathymetry in shallow areas mentioned in the previous section, but also includes the issue of better defining the minimum depth requirement in light of physical disturbance to the area as a results of waves. Koch (2001) points out that while we know that wind-induced waves will have an effect on the bottom, no data are available for *how* waves in shallow waters are likely to affect eelgrass distribution. The inclusion of the effect of waves on the bottom requires data or modeling of the typical wind velocity and fetch associated with a site. These estimates of wave action on the bottom must be compared to the minimum depth distribution of current eelgrass beds to determine a threshold value over which eelgrass is unlikely to survive. It was our original intention to include wave exposure calculation data into our overall model but the inability of one of the original project partners to generate this data due to changes in staffing and eventually employment prevented this from happening.

The model presented in this report and available in a GIS platform includes the option of examining various sea level rise scenarios. The sea level rise scenarios predict a loss of potentially suitable eelgrass bed along the deep edge of the model domain. The possibility of expansion of eelgrass along the shallow edge of the model domain is not included because of the lack of shallow water bathymetry data and the need to estimate the shallow depth limit of eelgrass. This topic is discussed fully in Section 6.6 (page 56). Currently, the model domain extends to the shoreline, which thus overestimates the potential area suitable for eelgrass along the shallow margin of the model domain.

A suggested addition to the model that arose too late in the project timeline (two weeks before the final report was due) was to include estimates of future temperature increases to the sea level rise scenarios. While analysis of this additional effect on the extent of suitable habitat was not conducted, users of the

GIS model have the option of increasing temperature throughout the model domain and incorporating those increases into the sea level rise scenario.

10.3 Closing Remarks

- The EHSI Model provides a reasonably accurate representation of habitat suitability for eelgrass throughout Long Island Sound. Comparison of the model output with current eelgrass distribution, and the siting of successful and failed restoration attempts indicates the model will be useful when making future plans for restoration efforts.

- While the EHSI Model is one tool which may be used to make decisions regarding restoration, the final decision should include local knowledge of the site and a site evaluation by an experienced restoration specialist. An additional tool for evaluating site suitability is the Nutrient Pollution Indicator (NPI), which involves short deployments of eelgrass on floating racks. The NPI was a sensitive indicator and integrator of local water quality.

- Site specific data, as gathered for the case study sites, can further refine where to site a restoration bed within an area of interest. The EHSI Sub-Model can be applied to sites where additional data are available. This higher resolution model can assist restoration specialists with choosing the best location within a target area. While longer term data would be ideal, a single site visit in mid-summer is sufficient.

- While more data overall would improve model accuracy, the information of highest priority is shallow water bathymetry. Data on light and temperature from deployed instruments are also of high priority.

11 List of Appendices

Appendix 1 -

Eddings, J. 2012. Thesis: Geographic Information Systems Eelgrass (*Zostera marina*) Habitat Restoration Suitability Model, Long Island Sound, USA - A 'Sound-Wide' Model. Master of Science. University of Southern California. p. 9-12.

Appendix 2 -

Eddings, J., Brousseau, L. 2013. Eelgrass Habitat Suitability Index Model User's Manual. *draft.*

Appendix 3 -

QA/QC Report

12 Works Cited

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Geographic Information Systems Eelgrass (*Zostera marina*) Habitat Restoration Suitability Model

Long Island Sound, USA - A 'Sound-Wide' Model

By

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A Thesis Presented to the
FACULTY OF THE USC GRADUATE SCHOOL
UNIVERSITY OF SOUTHERN CALIFORNIA
In Partial Fulfillment of the
Requirements for the Degree
MASTER OF SCIENCE
(GEOGRAPHIC INFORMATION SCIENCE AND TECHNOLOGY)

December 2012

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Abstract

Eelgrass (*Zostera marina*) is an important benthic flowering plant used by many marine species as a nursery and food source; it also sequesters carbon, and the beds provide some protection for shorelines from coastal erosion by slowing water movement. In the past century, approximately 90% of eelgrass beds have been lost from natural and anthropogenic causes. Eelgrass was once a major component of the shorelines of Long Island Sound, USA, which has experienced many of these effects, including rain runoff carrying pesticide and fertilizer residues. Knowledge and analysis of the water quality parameters in Long Island Sound influencing eelgrass distribution will enhance restoration efforts in the future. A GIS model was created that estimates the habitat suitability for all areas in Long Island Sound with respect to key environmental variables. The habitat model has two parts. First, the study area was limited to regions where eelgrass growth is possible based solely on water depth, assuming that other conditions are suitable. Second, this suitable area was ranked by weighting each of 11 environmental parameters: percent light reaching bottom (0–30), sediment grain size (0–15), Chlorophyll *a* (0–10), Total Suspended Solids (0–10), Total Dissolved Nitrogen (0–5), Total Dissolved Phosphorous (0–5), surface temperature (0–10), salinity (0–5), pH (0–5), dissolved oxygen (0–5), and sediment percent organics (0–5). The resulting sum indicates the suitability of areas with a weighted sum of 100 being most suitable and 0 being least suitable. The model produced weighted sum scores ranging from 43 to 93.5. Areas that are scored higher than 75 within the suitable band should be locally tested to decide if the area is ready for habitat restoration to proceed. Regions below this threshold

should be further tested to identify which parameter scores reduced the overall score. This identification of the parameter contributing to the low score could help prioritize policies to reduce these influences in the future.

Chapter 1: Introduction

1.A. Overview

A century ago, eelgrass meadows (*Zostera marina*) dominated the shallow areas of the Long Island Sound, USA. Due to natural and anthropogenic variables, a great decline both in the Long Island Sound and worldwide of all seagrasses has been observed. Current decline and restrictions limiting growth of existing eelgrass are dominated by cultural eutrophication, i.e. nutrient enrichment from the application of fertilizers containing high amounts of phosphorous and nitrogen for improved lawn care in coastal residences, boating activities, and commercial marine events (Burkholder et al., 2007). Though not as prevalent today, an initial substantial die-off of seagrasses was observed by the spread of wasting disease in the 1930s (Godet et al., 2008). Global threats to eelgrass, including climate change, make it important to identify and minimize local threats (Waycott et al., 2007; Short et al., 2011).

Recent successful restoration efforts have occurred in the nearby, smaller Peconic Bay, New York (Pickerell et al., 2004) and along the north shore of Long Island, New York. A Geographic Information Systems (GIS) was used to model several key variables that influence the distribution of eelgrass in Long Island Sound, to predict areas that may be favorable to eelgrass restoration in the near future.

1.B. The Role of Eelgrass in Long Island Sound

Seagrass ecosystems are found worldwide and make-up 0.1–0.2% of Earth's oceans (Duarte, 2002). Worldwide, there are 50–60 species of seagrasses and they are an integral part of the dynamic near shore marine ecosystem (Hemminga et al., 2000). Seagrass is benthic vegetation that occurs only to depths where enough sunlight is available to support growth (Koch & Beer, 1996).

Expansive seagrass meadows, or beds, are home to many marine invertebrate and vertebrate species. The blades, which are upwards of 2 meters in length, serve as shelter and protection from predators for a multitude of marine organisms (Davis, 1999). The seagrass beds also control and mitigate the erosive nature of strong water currents (Fonseca et al., 1998). The long seagrass blades slow currents, allowing sediment being transported in the water column to settle to the bottom. Similar to the function of beach grasses on dunes, the seagrass' extensive root system keeps the seagrass attached to the bottom, reducing suspension of loose particles into the water column. As particles settle at the base of eelgrass beds, a dense, nutrient rich substrate is created which is ideal for microorganisms and invertebrates that inhabit these meadows, as well as for the eelgrass itself.

Eelgrass (*Zostera marina*) is the most common submerged aquatic vegetation species in Northeastern United States estuaries, including one of the nation's largest estuaries, Long Island Sound (LIS) (Beckwith Jr. et al., 2007). A century ago, eelgrass beds covered all the shorelines of Connecticut. But, as seen with seagrasses worldwide, eelgrass in Long Island Sound saw great decline beginning in the early 1900s, and

continued losses and lack of resurgence in eelgrass with the increase in human coastal inhabitance.

Eelgrass is not just a shelter for marine organisms, but also a major food source for migratory waterfowl, such as Brant (*Branta bernicla*). LIS supports a large shellfish industry, the success of which can be dependent on eelgrass. Scallops are known to frequent eelgrass beds for shelter from predators (Fonseca et al., 1998). Crustaceans inhabit these meadows and take advantage of the protective blades; some even suspending from the blades to capture small prey (Schmidt et al., 2011). The blades are shed every year and as they decay, they are consumed by many types of decomposers, which make up much of the bottom of the estuarine food web (Short et al., 1995). Recent work has revealed that eelgrass beds sequester a substantial amount of carbon in the sediment; more so than terrestrial vegetation (Fourqurean et al., 2012).

The Long Island Sound is approximately 3,420 square kilometers and has an average depth of 19.2 meters (Long Island Sound Study, 2012). Salinity varies from 35 ppt to 23 ppt from east to west, while tides range from 0.67 meters in the east to 2.25 meters in the west (NOAA Tides and Currents, 2012). The surface temperature ranges from 3˚C in the winter, to 21˚C in the peak summer months (see Long Island Sound Study, "By the Numbers"). The Long Island Sound experiences semidiurnal tides, which means 4 tides per day (2 high and 2 low tides) (NOAA Tidal Datum, 2012). These features help exemplify the great variability present in this estuarine ecosystem. This may also raise the question, if eelgrass has survived previously in these conditions, why

has its extent receded so greatly in the past century? And, which parameters may show the greatest influence on the eelgrass reduction in localized areas of Long Island Sound?

The conditions of several environmental variables have been declining over the last century and are implicated in the decline of eelgrass beds (Short et al., 2011; van Katwijk et al., 2009). These include influences on water clarity and quality such as increased algal blooms from nutrient enrichment, and sediment loading from trawling and dredging activities. These trends and the likely culprits are also evident in Long Island Sound (LIS), where eelgrass thrived over a century ago (Koch & Beer, 1996). Identifying the most critical factors that are reducing eelgrass beds in the LIS is very important to mitigating the problems through the enforcement of coastal policies and best management practices for implementation of a successful restoration effort.

Human impacts have had detrimental effects on eelgrass distribution, primarily with the ever-growing development of coastal residence, introducing physical and chemical stressors to the nearby waters. As people have progressively inhabited coastal regions, they continue to construct bulkheads. A retaining structure, usually constructed of concrete or steel, is installed along coastal residents' shorelines, allowing easy access to deeper water from their property, usually for boats, rather than a gradual sloping beachfront that may erode over time. Bulkheaded properties have eliminated beach slopes associated with natural shorelines, creating a rapid increase in depth in the intertidal zone.

Eelgrass has a relatively high light requirement for photosynthesis, thus a maximum suitable depth is established based on the light reaching the bottom. Eelgrass

has been recently observed during dives in LIS at a depth of 9.2 meters which is considered the threshold depth in this study (Pickerell personal comments, 2012; Yarish, 2012). Dives deeper than 9.2 meters showed no existent eelgrass, so any deeper is considered unacceptable primarily because of lack of sufficient sunlight reaching the benthic plant for the photosynthesis process. Additionally, runoff from residences may carry fertilizer, increasing the levels of nitrogen and phosphorous in the water column which can lead to algal blooms. Algal blooms will shade the eelgrass intercepting the sunlight, causing the eelgrass to die-back as a result. Also, with the increase in coastal populations has come a surge in boat activity. Boat propellers scour the bottom of shallow regions, leaving shredded eelgrass blades in the wake. Further, boat moorings typically involve long chains that connect a surface buoy and bottom anchor, which, at low tides and high currents or wind, extirpating eelgrass as they drag across the bottom.

1.C. Motivation for this Research

It is apparent from research over the past century (see for example, Setchell et al., 1929; Burkholder et al., 2007, Waycott et al., 2009) and restoration management guidelines now in place (U.S. NOAA Coastal Services Center, 2001) that eelgrass is recognized as a vital submerged aquatic vegetation to the estuarine ecosystem. This research aims to assist in that important restoration effort by providing an assessment of potentially suitable restoration areas throughout LIS and identifying the causal factors in areas where restoration is predicted to be unsuccessful.

1.D. Key Parameters Affecting Eelgrass Survival

The model uses knowledge on the conservation, management and restoration of eelgrass and other benthic flora in similar coastal environments. Considerable research into submerged aquatic vegetation restoration has been conducted worldwide. Data specific to LIS was received from the Connecticut Department of Energy and Environmental Protection (CT DEEP). CT DEEP collected data for a large number of parameters over the past 20 years. These data and data from other reputable resources – United States Geologic Survey, Long Island Sound Resource Center, National Oceanic and Atmospheric Agency – are available to the public with metadata. These datasets were reviewed in collaboration with colleagues who have years of experience in the field of eelgrass restoration and ecology from several organizations including Cornell Cooperative Extension (CCE)[1] and University of Connecticut (UConn)[2]. Thirteen parameters were used in the development of a 'Sound-wide' model for potential eelgrass restoration (Table 1).

[1] Chris Pickerell of Cornell Cooperative Extension is an eelgrass specialist with 20 years of experience around the waters of Long Island, NY, including a number of successful local restoration sites existent in Long Island Sound.

[2] Dr. Jamie Vaudrey and Dr. Charles Yarish of University of Connecticut have conducted several studies of the marine environment of Long Island Sound and analyzed several parameters that are critical to eelgrass survival.

Table 1: Environmental Parameters for Habitat Restoration - 13 Parameters are identified and summarized as to their importance in the eelgrass restoration project

Parameter	**Summary**
Bathymetry	This data is critical to identifying the shallow regions in which eelgrass can survive.
Tidal Amplitude	Tidal amplitude varies throughout the shallows of LIS and is influential of the bathymetry analysis.
Chlorophyll *a*	Addresses phytoplankton levels in the water column which largely affect water clarity.
Total Dissolved Nitrogen	The affect of nutrients available in the water column can influence algal blooms.
Total Dissolved Phosphorous	The affect of nutrients in the water column can influence algal blooms.
Total Suspended Solids	Stormwater runoff can carry high levels sediment particles into rivers, emptying into larger water bodies.
pH	Seawater is typically around a pH of 8. Variations from this value can influence marine fauna and flora survival.
Salinity	Long Island Sound is an estuary where ocean water from the Atlantic combines with rivers and estuaries that accept freshwater runoff from rivers and storm water runoff.
Percent Silt and Clay	The type of sediment can impact the survival of benthic flora and influence the success of a species that attempts to root in this sediment
Surface Temperature	Temperatures in the water column may exceed the thermal tolerance for eelgrass and result in reduction of photosynthesis and growth rates or lead to death
Benthic Sediment Percent Organics	Existing eelgrass beds have relatively organic rich sediment due to settling and trapping of particles. Restoration of eelgrass indicates much lower organic content is preferred by beds in the process of establishment.
Photosynthetically Active Radiation (PAR)	Maintaining a sufficient PAR level is crucial for eelgrass survival
Dissolved Oxygen (DO)	Eelgrass requires sufficient oxygen in the water column. Sufficient oxygen reduces the levels of reduced compounds which can be toxic to eelgrass plants (e.g. hydrogen sulfide, ammonium).

The habitat restoration project is expected to last well beyond the development of the Sound-wide model presented here. This work represents the development of the Sound-wide model that will be validated by future work.

Chapter 2: Data Sources

Several data sources were identified and the data from each was downloaded and reviewed for usefulness to the habitat restoration project for Long Island Sound (LIS). This chapter begins with a brief description of the study area, and then discusses in detail each of the parameters used in the analysis. The parameter datasets are divided into the Suitability Parameters, and the Scored and Weighted Parameters.

2.A. The Study Area

The study area encompasses the entire LIS and adjoining tributaries. Hydrography data for the study area were downloaded from the New York State (NYS) GIS Clearinghouse and Connecticut Department of Energy and Environmental Protection (CT DEEP) (Figure 1).

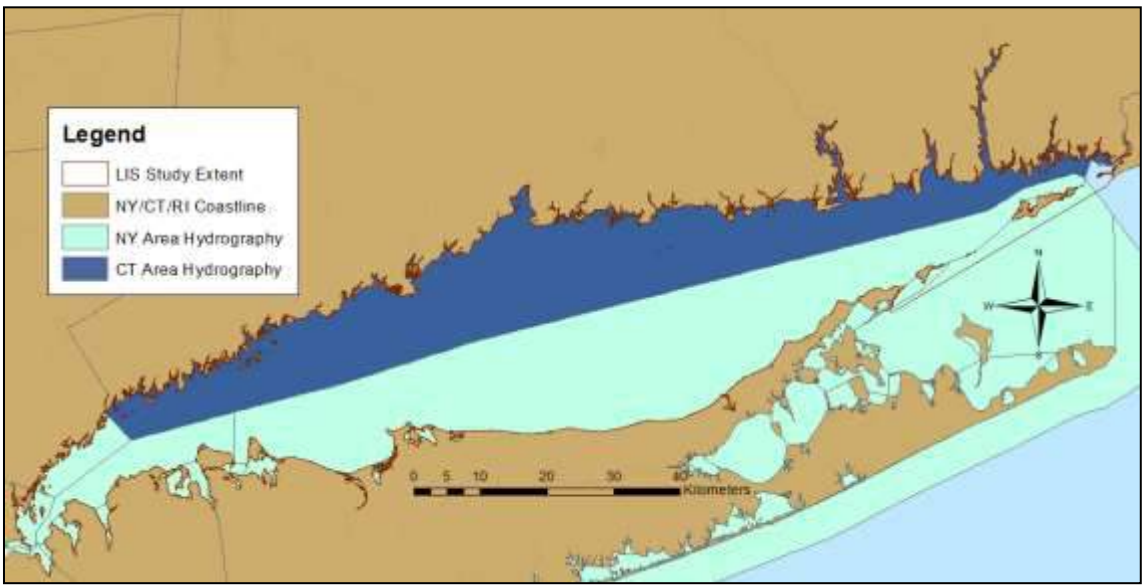


Figure 1: New York and Connecticut Area Hydrography - Area hydrography polygons displayed in GIS. The polygons were selected and merged to create the Long Island Sound study extent.

The two datasets employed different coordinate systems so conversion to a common coordinate system was necessary to accomplishing all later work in the habitat restoration project. The Projected and Geographic coordinate systems were selected from the Connecticut Area Hydrography feature class and applied to the environmental settings for all other GIS layers (Figure 2).

Projected Coordinate System:
NAD_1983_StatePlane_Connecticut_FIPS_0600_Feet
Projection: Lambert_Conformal_Conic
False_Easting: 999999.99999600
False_Northing: 499999.99999800
Central_Meridian: -72.75000000
Standard_Parallel_1: 41.20000000
Standard_Parallel_2: 41.86666667
Latitude_Of_Origin: 40.83333333
Linear Unit: Foot_US

Geographic Coordinate System: GCS_North_American_1983
Datum: D_North_American_1983
Prime Meridian: Greenwich
Angular Unit: Degree

Figure 2: Projected and Geographic Coordinate Systems - Coordinate systems applied throughout the habitat restoration project. These coordinate systems were originally used in the Connecticut Area Hydrography dataset.

A base layer for the study area was created by merging the NYS and CT Area Hydrography features within the study extent and applying the above coordinate systems (Figure 3). Once the merge was complete, the polygon was extended at the mouth to the Atlantic Ocean manually using the editing toolset. Vertices were added so the shorelines of Fishers Island, Little Gull Island, Big Gull Island, and Plum Island were completely contained (Figure 4). Since Fishers Island was part of eelgrass restoration efforts in the past, its inclusion is useful when analyzing the model results with regards to the location

of successful restoration efforts. To help determine the appropriate length to extend the study area, NY and CT Orthoimagery databases were used.

Figure 3: Study Extent for Long Island Sound - Data in the form of polygons was displayed from NYS and CT Area Hydrography and merged.

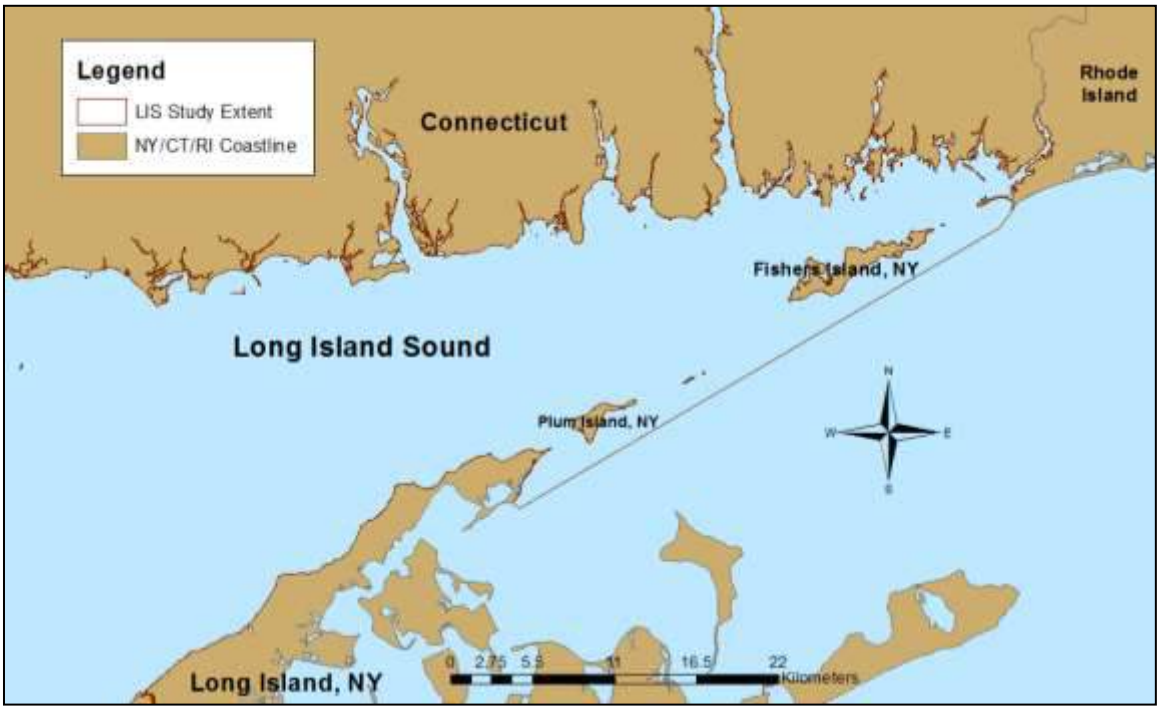


Figure 4: Mouth of LIS to the Atlantic Ocean - Study Extent is extended here to encompass all shorelines of the nearby islands including Fishers and Plum Islands.

Tributaries in the study area were also reviewed for relevance to the study area. Known eelgrass beds have existed in the Thames River, Connecticut, for example, well north of the mouth to Long Island Sound. Tributaries that extend further inland from the LIS were individually assessed by using the potential extent of eelgrass survival in each tributary as an indicator of how far the model should extend up the tributary. Colleagues familiar with this area provided information on both current and historical eelgrass extent (Figure 5).

Figure 5: Study Extent and River Connections - The connecting rivers from Connecticut to Long Island Sound, Connecticut River and Thames River, were assessed and end points of the two waterways were identified and manually extended from the Sound.

2.A.1. Limiting Study Area by Depth

The study area for the habitat suitability model was limited by depth, which is unlikely to change in the short run as a result of human or natural actions. For eelgrass,

the high light requirement of the plant limits the depth to which the plant can occur. On the shallow edge, tidal amplitude will limit how shallow the plant can occur, as it is typically sub-tidal in LIS. The exclusion of areas that are too deep for survival even under the best water quality conditions focuses the analysis on a much more tractable study area. Review of several sources for bathymetry layers found both contour lines at varying intervals; 1 m and 5 m intervals. Additionally, DEM bathymetry layers with a 30 m and 76 m resolution were available. These covered a majority of LIS. However, both the contour lines and DEM's bathymetry layers do not include a small but significant area, in the eastern LIS; from about the center of Fishers Island, NY, east.

The –1 m interval contour line bathymetry data collected by the United States Geologic Survey (USGS) (managed by Long Island Sound Resource Center (LISRC)) was selected as the most suitable for this analysis. This data was originally extracted from hardcopy maps from 1984, 1986 and 1989 of lower low tide bathymetry data that were digitized and published by USGS. According to the USGS metadata, the dataset is intended for "science researchers" and should not be applied in navigational purposes (USGS, LISBATHY Metadata, 2002).

The –1 m contour line data ends at an east-west line across the LIS about halfway across Fishers Island (Figure 6). Additionally, there are some connecting rivers that are not covered by these bathymetry lines.

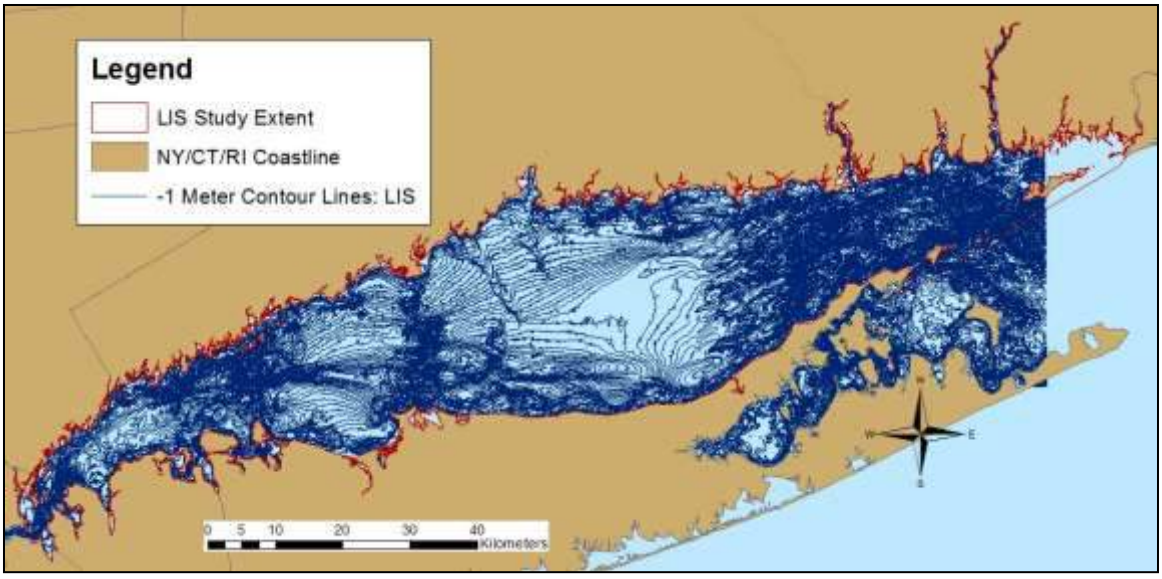


Figure 6: –1 m Contour Lines for Long Island Sound (LISRC, 2012) - The contour lines range from 0 to -98 meters depth and extend only as far as Fishers Island, though the study extent clearly extends further.

Because this study extent ends at the west Rhode Island border, additional data were collected from the NOAA Charts Catalog: Raster Navigational Charts (RNCs). RNCs are regularly updated by NOAA and the relevant RNCs for the uncovered regions of Long Island Sound, including rivers and the eastern portion of LIS, were downloaded and projected in GIS (Figure 7).

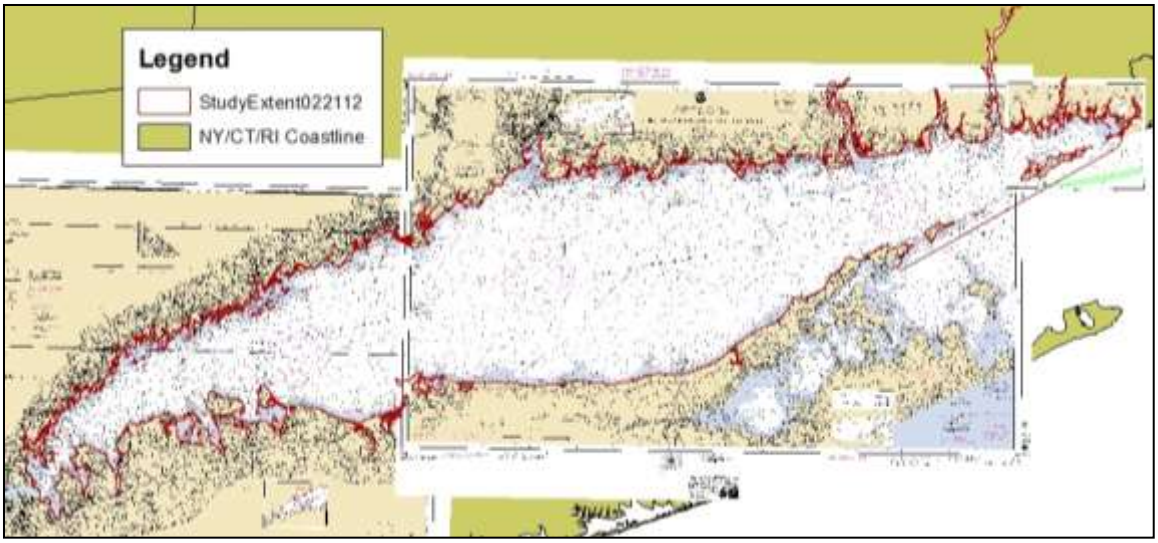


Figure 7: NOAA Raster Nautical Charts – Charts were downloaded and imported to GIS to fill depth values in areas that are exempt of depth data in the –1 m contour lines.

The data in the RNCs were displayed as raw depth values measured in feet, so it was necessary to create data manually in a point feature class for the raw depth values. An additional manual change to the bathymetry files was applied to the shoreline line segments of New York, Connecticut and Rhode Island. For the shoreline, the study extent polygon was also applied as a 0 meter depth value at each vertex before further processing of this data for a complete bathymetric layer.

2.B. The Ranked Parameters

The term "ranked parameters" refers to all applicable environmental variables that affect eelgrass survival in Long Island Sound (LIS). Data used for these parameters must cover the full extent of LIS. Data for the ranked parameters were obtained from the Connecticut Department of Energy and Environmental Protection (CT DEEP), Long Island Sound Resource Center (LISRC) and the Woods Hole Oceanographic Institute (WHOI).

First, a large number of parameters were received from the CT DEEP in the form of an Access Database. Each parameter was processed to project the data in GIS. The nine parameters that were found relevant to the study area and of importance in eelgrass survival are shown below.

CT DEEP: Parameters

1. Chlorophyll a
2. PAR for Kd: Percent light reaching the bottom
3. Total Dissolved Nitrogen
4. Total Dissolved Phosphorous
5. pH
6. Salinity
7. Low Oxygen
8. Total Suspended Solids
9. Temperature

Each data value in these datasets is associated with a recorded station name and location given in latitude and longitude for each sampling event. For this reason, values are clustered around stations. For this study, values were averaged in Microsoft Excel or MatLab and projected in GIS to produce mean values that are associated with each respective station point per parameter.

Of the data obtained from CT DEEP, which spans upwards of two decades for some parameters, only data from 2009 to 2011 were extracted for this study. Due to policies influencing water quality in LIS enacted in both Connecticut and New York, data prior to 2009 for these parameters can influence the results inaccurately for current conditions (Vaudrey, 2012; Yarish, 2012). With the continued influence of new best management practices and policies, many of these parameters are expected to remain constant or to continue improving with respect to water quality in the future.

In addition, sediment total organic carbon content was available from Long Island Sound Resource Center and sediment grain size data was available from the Woods Hole Oceanographic Institute GIS Libraries. Both datasets covered the entire study area densely enough to be deemed useful in this study. These parameters are especially important when considering restoration efforts, as lower levels of organic carbon in the sediment and a sandier bottom is likely to provide greater success for restoration plantings. The data for these parameters were analyzed and interpolated in GIS.

In total, eleven parameters were identified as useful for the study of water quality with regards to eelgrass survival in LIS. Because the parameters were collected as point data, the data were further analyzed to produce estimates throughout the study area as estimated values.

Chapter 3: Development of the Sound-Wide Model

The process of creating a Sound-wide model was broken down into two key stages: conducting the suitable area procedure, and conducting the scored and weighted rankings procedure. Suitable parameters were processed and applied to the study extent to define those areas which are either true - the Suitable - or false - the Unsuitable. The parameters selected for the Long Island Sound (LIS) study extent were water depth and tidal range. These environmental variables are not controlled by humans and are extremely important for eelgrass primarily with respect to light for survival.

The ranked parameters were each analyzed by their suitable range of values for successful eelgrass restoration. The results were scored before each parameter was weighted as to its importance of eelgrass survival within the Suitable area. Mapped results are provided with each parameter's analysis.

3.A. The Suitable Procedure

This section describes the processes used to create the bathymetry surface and identify the maximum depth suitable for eelgrass with the application of the tidal amplitude dataset.

3.A.1. Construction of the LIS Bathymetric Surface

The Contour Line bathymetry data at –1 meter interval were used in this analysis. Additional sources of contour line data were found to be too coarse in format or lacked data in particular near shore regions of the study extent that would require additional resources for a complete bathymetric surface of LIS. The contour line vertices were extracted using the "Feature Vertices to Points" tool to a new point feature class with the

associated depth values in a new 'Float' field called "DepthFloat" using the Field Calculator equation:

'DepthFloat' = 'Depth'

Data were downloaded from NOAA Raster Navigation Charts (RNCs) which display depth values of the uncovered areas, including the eastern Long Island Sound and connecting tributaries to complete empty areas of the study extent (see example, Figure 8). The data from each RNC was digitized to create point features with the associated depth values (in positive feet). Similar to the contour points feature class, a new 'Float' field was added with the bathymetry data processed from positive feet to negative meter depth values using the Field Calculator with the following equation:

'DepthFloat' = –('Depth(ft)' * 0.3048)

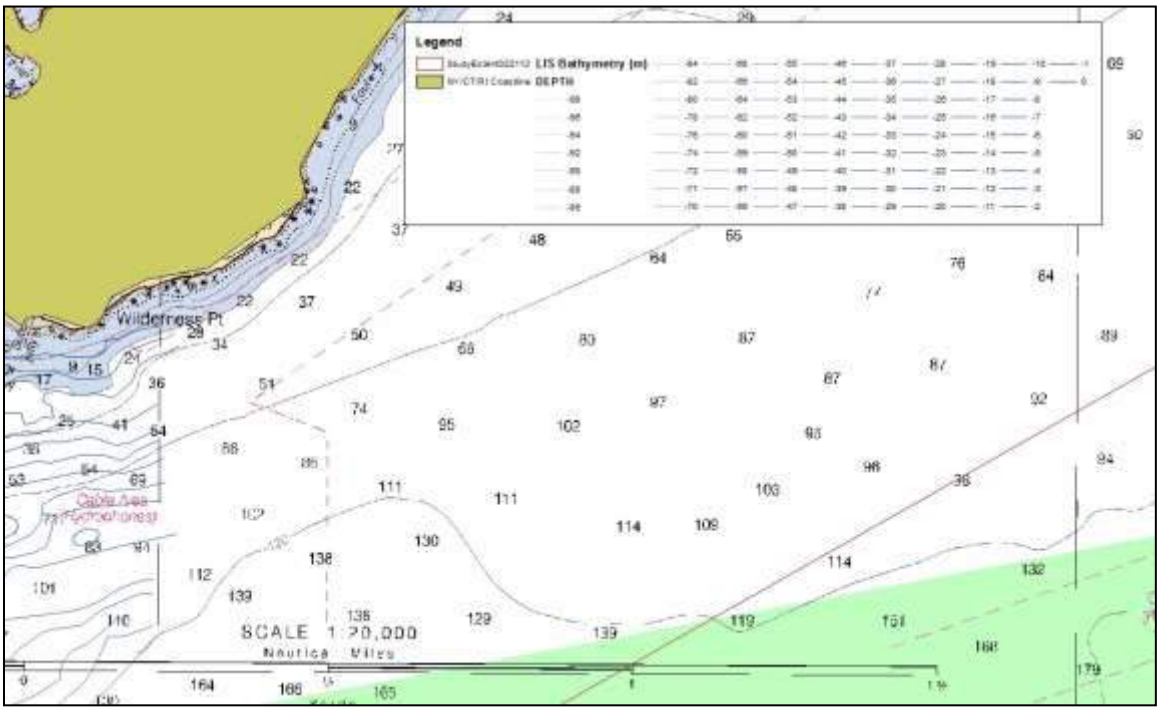


Figure 8: –1 m Contour Lines and Raster Nautical Chart - A zoomed in display of the contour lines extent just south of Fishers Island on the left and the RNC depth values (in feet) which were manually compiled as point data at each depth value location.

The study extent is a polygon clipped and merged from the Area Hydrography feature classes for both CT and NY that contain the entire LIS and adjoining tributaries. The study extent defines the shoreline for New York, Connecticut and a small portion of Rhode Island which serves in this study as a 0 depth feature. Shoreline segments were clipped from the study extent polygon and the vertices were extracted using the "Feature Vertices to Points" tool to a new point feature class. A similar 'Float' field was created with all point values set to 0 meters:

'DepthFloat' = '0'

The three point feature sets with associated depth values - extracted contour points, points from RNCs, and extracted shoreline points - were appended to a single file producing 640,481 points for interpolation of the raster bathymetry grid (Figure 9).

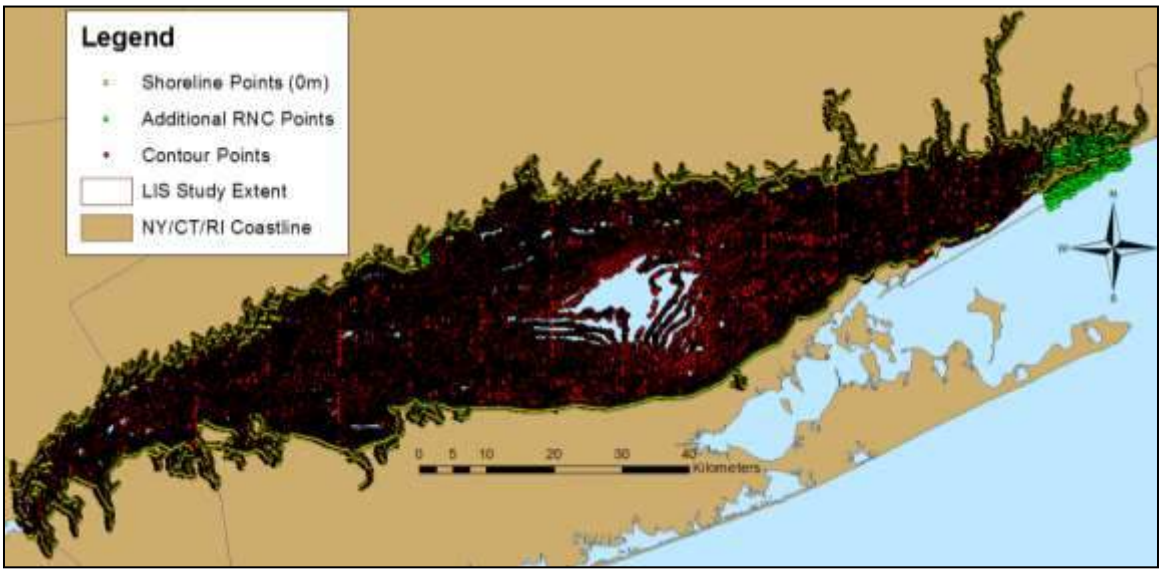


Figure 9: Bathymetry Point Datasets - Contour vertices, RNC digitized points, and shoreline vertices before interpolation with the IDW tool.

The Inverse Distance Weighted (IDW) technique was chosen as the most appropriate interpolation tool. IDW applies a linearly weighted equation to calculate cell

values of a select number of available points (see "How IDW Works" in http://help.arcgis.com). This raster analysis technique assigns near true values to cells at existing point locations and interpolated values which are determined by a set number of nearby points to all other cells. The settings used in this analysis were:

- Power of: 2
- Cell Size: 100'
- Variable search: 6 points
- Barrier: 'Shoreline'
- Analysis Mask: 'Mask020212' (this polygon is comprised of a 150' buffer around the shorelines combined and a 2000' buffer at the mouth of LIS)

It was confirmed by colleagues that a 100 ft resolution interpolated raster cell size was adequate for defining the area accurately enough that plus or minus 50 ft had a low impact on the results for such a large area. The result is a detailed bathymetric grid map of LIS (Figure 10).

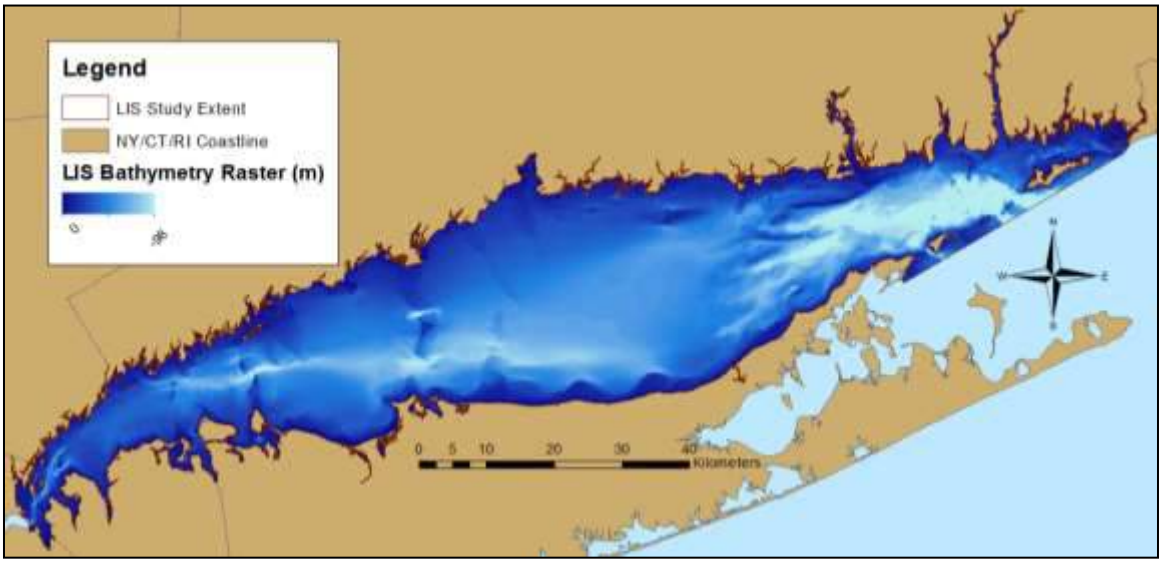


Figure 10: Long Island Sound Bathymetry Raster - The output bathymetry raster for the Long Island Sound study extent. The depth ranged from 0 to –98 meters.

3.A.2. Determination of the Maximum Suitable Depth Band

Eelgrass survives only within a limited range of water depth. For this study, a control maximum depth value of –9.2 meters was applied (Yarish, 2012). This value was determined by colleagues and is based on the known minimum light requirements of 10% surface light penetration and water clarity expressed as a Kd value 0.25/m (Vaudrey, 2012). Kd quantifies the percentage of light penetrating the entire water column, and 0.25/m expresses a realistic high water clarity value. The rationale for applying tide and depth to determine a maximum depth suitability band is:

i. The effect of new policies and advancements in the reduction of point source pollutants including nitrogen, have improved the overall water clarity of LIS over the last decade.
ii. Several areas, primarily in western LIS, may continue to show improvements in the future. These areas may meet suitable depth and tidal variables but would not be included currently as suitable growing areas given present water clarity values.
iii. This value will capture known deeper beds.
iv. Tidal amplitude cannot be controlled and is inconstant throughout the LIS.

LIS has high variability from east to west of its mean tide value. Since high tide level increases the effective depth of the water column, it is necessary to determine the average thickness of the water column at every location as this is the depth value that impacts eelgrass growth. The goal is to identify the furthest extent from the shoreline (here called the Maximum Suitable Depth Band) suitable for eelgrass in an ideal environment with regard to water quality and clarity.

To create the Maximum Suitable Depth Band, data from 73 tide stations were compiled in an Excel spreadsheet containing mean tide values and spatial data (latitude and longitude). This table was projected in GIS as a point feature class. A new 'Float'

field was created and the field calculator was used to generate maximum depth values at each tide station using the following equation:

"Maximum Depth for Eelgrass"= [–9.2m – "Mean Tide Value (negative meters)"]

Next, an IDW interpolation was run to estimate the maximum suitable depth for eelgrass throughout LIS:

- Power of: 2
- Cell Size: 100'
- Variable Search: 4 points
- Analysis mask: Mask020212 (this polygon is comprised of a 150' buffer around the main shoreline combined with a 2000' outer buffer along the south shores of the Islands in the mouth of the Sound)

The result of this process was a raster that was snapped to the same cell extent as the Bathymetry raster, and displays the Maximum Depth suitable for eelgrass in each cell throughout the study area.

Appropriately, a division of the study area into suitable areas where eelgrass could survive if all additional parameters are also suitable, and unsuitable areas where even if all parameters meet the requirements for eelgrass restoration, its survival is still impossible. Using the previous output, the Maximum Depth Band was created using the Raster Calculator. The following logic equation was applied in this raster calculation:

If "LIS Bathymetry" >= "Max Suitable Depth Value" then 1, else 0

All cells that are true are returned with a cell value of 1, while all cells that are false are returned with a value of 0.

Processing Examples:

- –5.3 >= –8.7: True or 1, as the depth at this location is truly –5.3m and the maximum depth at that location is –8.7m
- –48 >= –9.1: False or 0, as the depth at this location is truly –48m and the maximum depth at this location is –9.1m.

The result is a 'Suitable Band' which extends from the shoreline to the maximum allowable depth as defined by the maximum depth value in that area, as well as any shallow areas such as shoals where the true depth is shallower than the maximum depth for eelgrass (Figure 11).

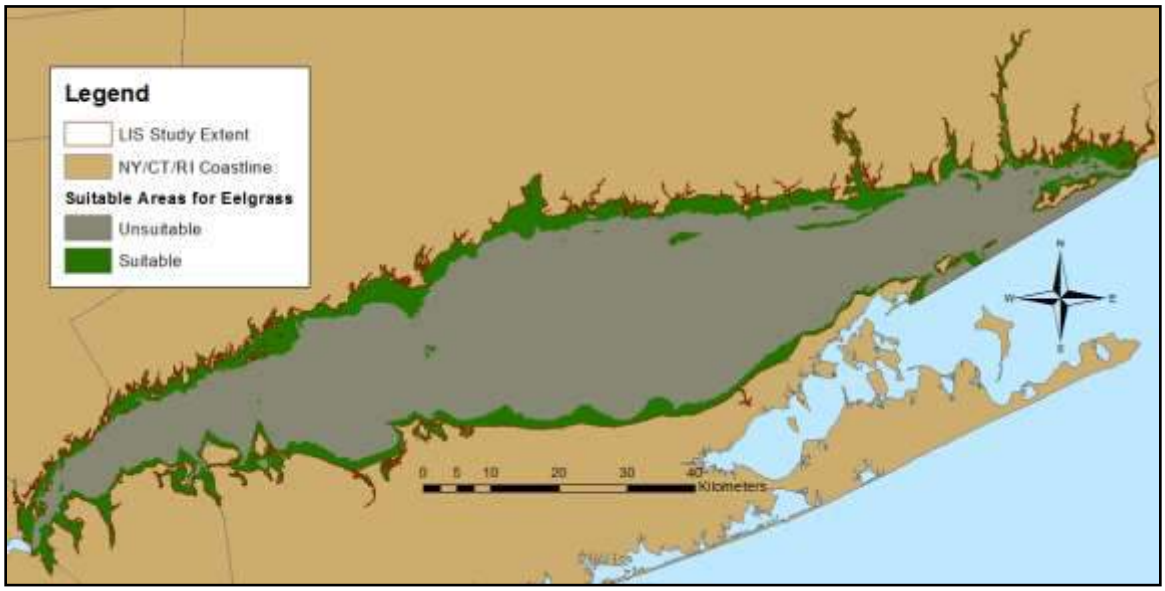


Figure 11: Suitable Band for Eelgrass by Depth - The division between areas where eelgrass can survive and areas that are too deep for eelgrass even if all environmental parameters are ideal

3.B. Scoring Ranked Parameters Procedure

With the separation of suitable and unsuitable areas completed, further analysis of the water quality and benthic parameters were applied in the next phase. By analyzing additional key variables that are integral to eelgrass survival in LIS, scientists can acquire

a sense of the more suitable areas where habitat restoration efforts may begin. Several parameters were scored throughout the LIS to reflect their influence on eelgrass growth. The scores were based on individual parameter values and were scaled from 0 to 10.

As stated in Chapter 2, Section B, parameters available from CT DEEP, LISRC and WHOI were assessed for usefulness in this habitat restoration project. The eleven parameters deemed applicable for habitat restoration were analyzed within the following temporal ranges defined with assistance from colleagues (Table 3).

Table 2: Environmental Parameters for Ranking – The top row in this table indicates the temporal limits applied to each of the parameters below.

1964–2010	**1974–1997**	**2009–2011**	**2009–2011 Growing Season**	**2009–2011: July and August**
Bottom Sediment: Percent Silt and Clay	Total Organic Carbon (Uncorrected for salt)	Total Dissolved Nitrogen	PAR to Kd Value for Percent light reaching bottom	Temperature at 2–3 meters depth
		Total Dissolved Phosphorous	Total Suspended Solids	Dissolved Oxygen
		Salinity	Chlorophyll *a*	
		pH		

Once processed, the data was projected in GIS and interpolated using the Inverse Distance Weighted (IDW) spatial analysis tool, similarly to the Suitable Procedure. For each parameter, the IDW applied a number of points to process an estimated value at each cell in the study extent.

By scoring the values for each parameter on a scale from 0 to 10, each parameter could be visualized (Table 4). The parameters were scored by an assigned range at an equal interval with the combined assistance of scholarly articles (Duarte, 2002; Touchette, 2007; Wazniak et al., 2007), and the knowledge of colleagues. The specified

ranges are selected in reference to successful eelgrass restoration. Each parameter was scored using the Reclassify spatial analyst tool in GIS and the processing output revealed the scores from 0 to 10.

Table 3: Scoring Criteria for Environmental Parameters - This table shows the scoring range for each parameter and the range of each interval between scores 0 and 10, rounded to one or three decimal places as appropriate. Cells labeled "n/a" indicate that the value of the parameter is not expressed in the raw data or the interpolated range.

Parameter	0	1	2	3	4	5	6	7	8	9	10
ChlA (ug/L)	>15	15–13.9	13.9–12.8	12.8–11.7	11.7–10.6	10.6–9.4	9.4–8.3	8.3–7.2	7.2–6.1	6.1–5	<5
Grain Size (% Silt & and clay)	>20	20–18	18–16	16–14	14–12	12–10	10–8	8–6	6–4	4–2	<2
& Light to Bottom	<46	46–47	47–48	48–49	49–50	50–51	51–52	52–53	53–54	54–55	>55
Oxygen (mg/L)	<3	3–3.3	3.3–3.7	3.7-4	4–4.3	4.3–4.7	4.7–5	5–5.3	5.3–5.7	5.7–6	>6
pH	>9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	<8.8
Salinity (ppt)	<10	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	>10
%Total Organic Carbon	>5	10–8.9	8.9–7.9	7.9–6.8	6.8–5.8	5.8–4.7	4.7–3.7	3.7–2.6	2.6–1.6	1.6–0.5	<0.5
Total Dissolved Nitrogen (mg/L)	>0.47	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.423–0.417	0.417–0.41	<0.41
Total Dissolved Phosphorous (mg/L)	>0.08	0.08–0.074	0.074–0.069	0.069–0.063	0.063–0.058	0.058–0.052	0.052–0.047	0.047–0.041	0.041–0.036	0.036–0.03	<0.03
Temperature (˚C)	>25	24.6–25	24.1–24.6	23.7–24.1	23.2–23.7	22.8–23.2	22.3–22.8	21.9–22.3	21.4–21.9	21–21.4	<21
Total Suspended Solids (mg/L)	>30	26.7–30	23.3–26.7	20–23.3	16.7–20	13.3–16.7	10–13.3	6.7–10	3.3–6.7	0–3.3	0

3.B.1. Percent Light Reaching Bottom

Being a benthic plant, the percent light reaching the bottom is one of the most critical parameters to the survival of seagrasses. CT DEEP recorded light in Photosynthetically Active Radiation or PAR, µmol photons m^{-2} s^{-1}. PAR readings were taken at descending depths at 0.2 m interval from the surface to the bottom on each visit. The light data were processed to estimate a Kd (m^{-1}) value for each cast at each station using MatLab (Vaudrey, 2012). The values for Kd at each station were interpolated using the IDW tool within the study extent. Kd did not account for the depth of the water column as it is a per meter value. The Kd value was combined with the water depth to yield an estimate for the percent light reaching the bottom within each grid. To best quantify the percent light reaching the bottom, the raster was converted to center points of the cells as was the Bathymetry raster, and a Spatial Join was applied to merge the overlain values. A new field was added to process the depth and Kd value collectively, called "PctToBottom" (Table 5).

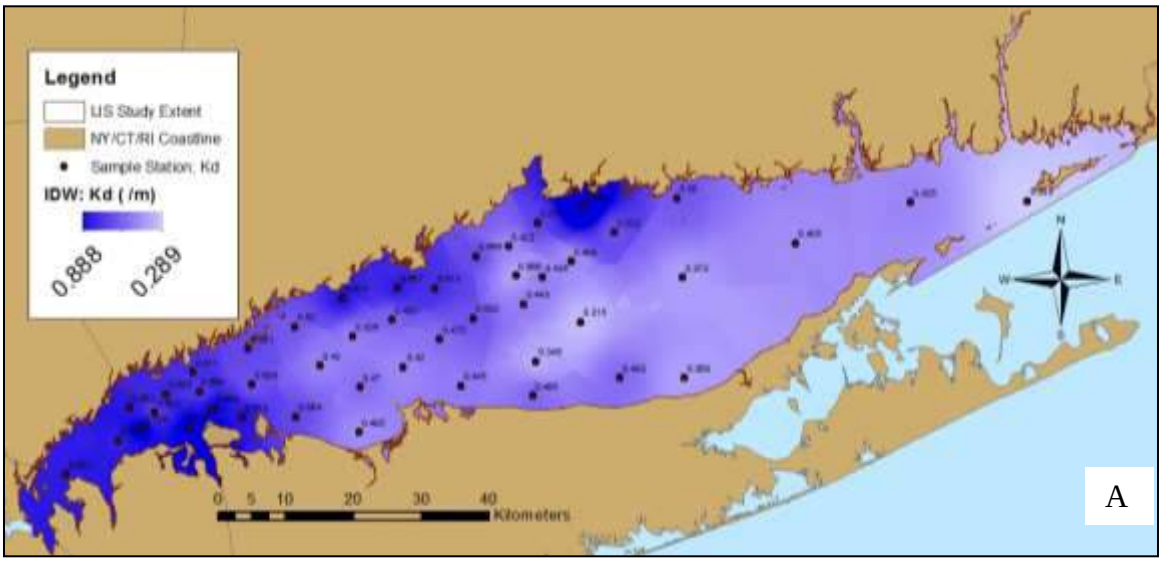
Table 4: Spatial Join Depth and Kd Value Attribute Table - Fields from the spatial join of converted bathymetry points and Kd value points, also converted from the Kd raster. Additional field to calculate the % light reach bottom.

Depth (m)	Kd (m^{-1})	PctToBottom
–0.239	0.356	91.858
–0.044	0.356	98.434
0	0.356	100
–5.908	0.357	12.102
–7.433	0.357	7.019
–7.887	0.357	5.969
-87.355	0.356	0

The following equation in the Field Calculator to measure the percent light reaching the bottom was applied with 'e' being the base of the natural logarithm:

'PctToBottom' = e^(kd*'Depth')

The points were converted back to a raster surface of the percent light reaching bottom, ranging from 0 to 100% throughout LIS (Figure 12).



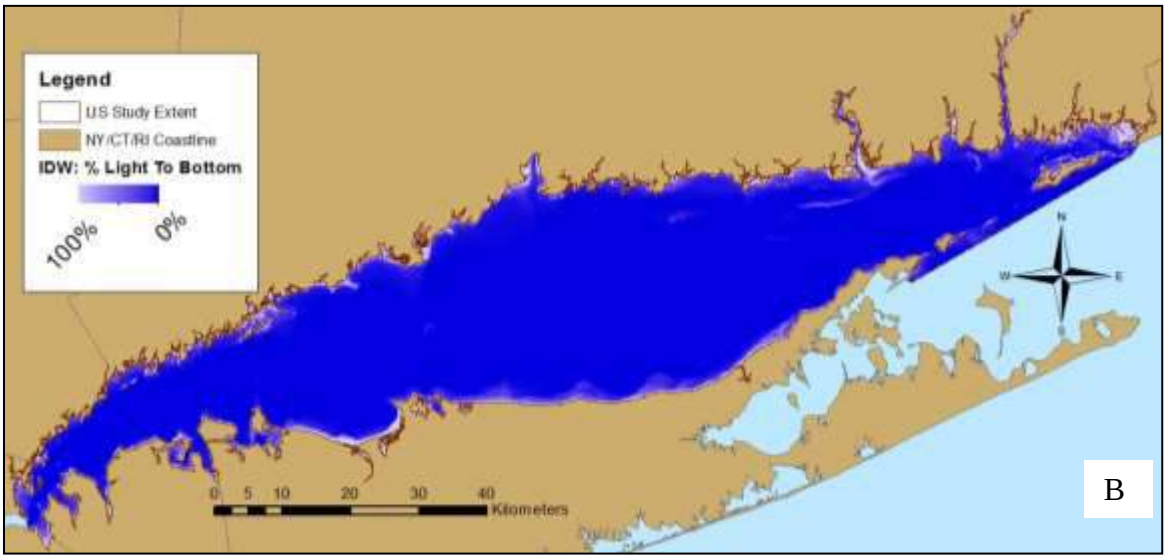


Figure 12: Interpolated Kd and Percent Light Reaching Bottom Raster - A. Kd values are estimated throughout LIS using the IDW tool and the average Kd value at each station during the growing season. B. Once processed, the Percent light reaching bottom was returned as a raster from a point feature class.

The percent light reaching bottom was ranked based on desired levels for restoration efforts (Table 4); the result is a raster which displays the score of the dataset from 0 to 10 (Figure 13).

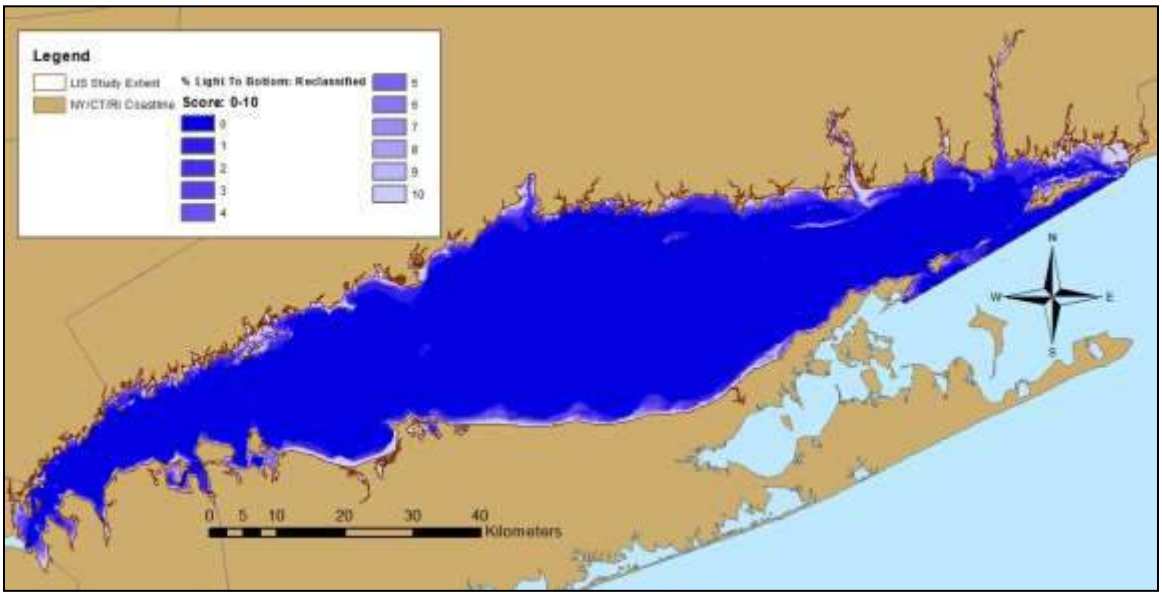


Figure 13: Percent Light Reaching Bottom Reclassified Raster - Percent light reaching the bottom is reclassified with a score from 0 to 10.

3.B.2. Surface Temperature

In the CT DEEP data, temperature was recorded every 0.2 meters at descending depths at each station location by a CTD (Conductivity-Temperature-Depth) probe. The most critical time of year is during the months of July and August, when the highest surface temperature is reached, thus only data from this range of months were used. CT DEEP data are from the main stem of LIS. The depths most applicable to the shallow eelgrass habitat are from the surface of the water column profiles. To quantify temperature accurately, the data were averaged on each visit for only those temperatures from 2 to 3 meters deep. The number of sampling days varied per month. In order to avoid assigning more weight to those periods with more sampling records, the data were

averaged monthly in Excel and the resulting values were projected in GIS. The data were again averaged to the associated station with the Mean Center tool, generating the overall average for July and August. The station results were processed using IDW to avoid estimating values out of the range of the low or high end of the results (Figure 14).

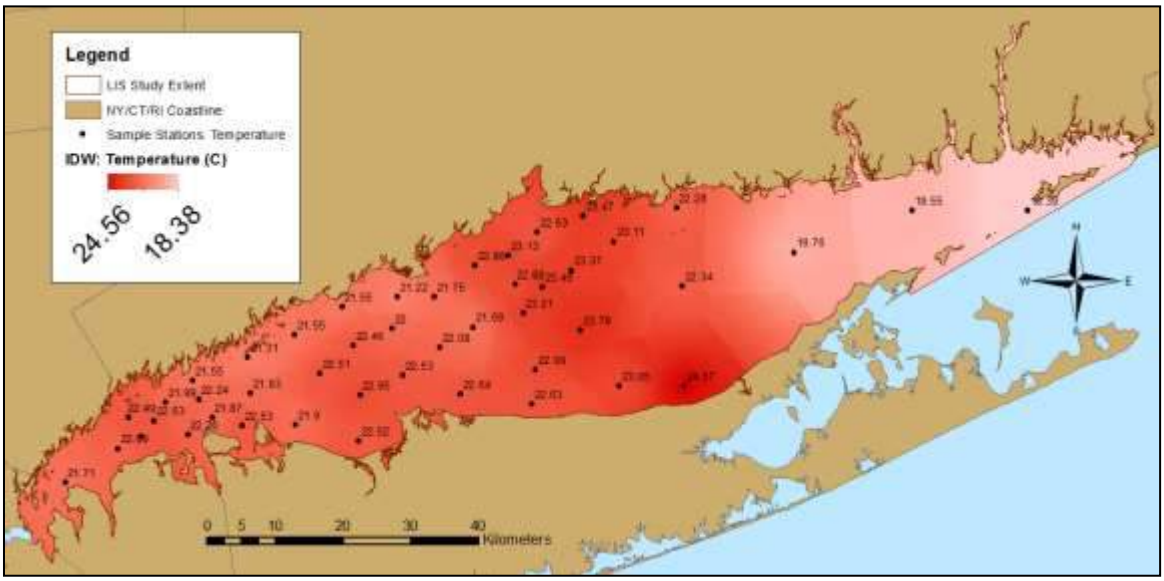


Figure 14: Interpolated Surface Temperature Raster - Surface temperature averaging the last meter of data in July and August, 2009 to 2011 and interpolated using the IDW tool.

The result was an interpolated raster with estimated surface temperatures throughout LIS. Next, the surface temperature value was scored over the identified ecologically significant range (Table 4) using the Reclassify tool and the result is a raster that displays the score of the dataset from 0 to 10 (Figure 15).

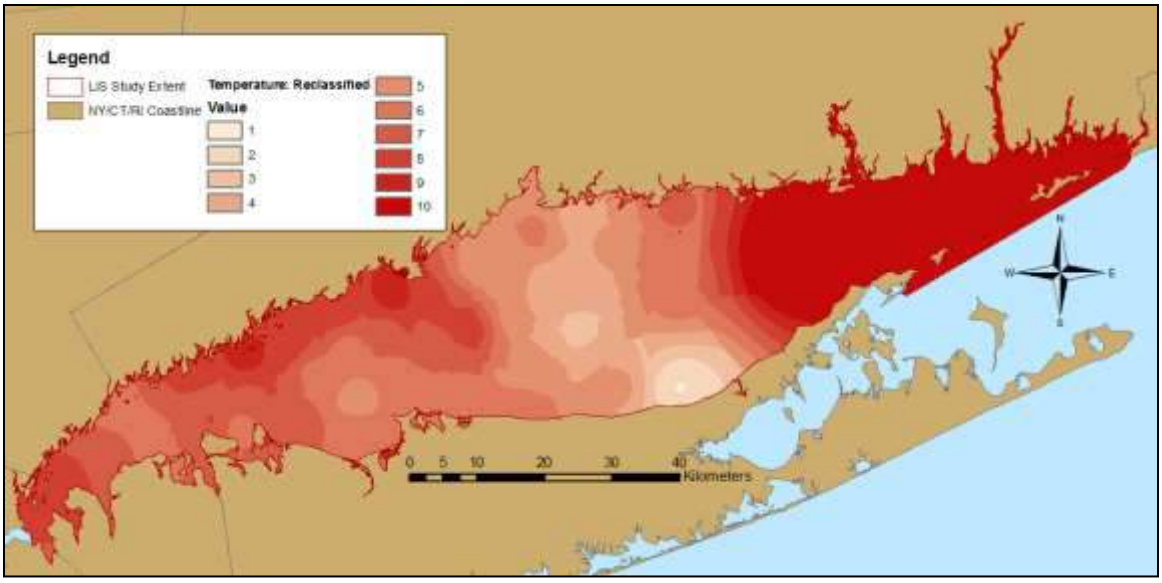


Figure 15: Surface Temperature Reclassified Raster - Surface temperature is reclassified with a score from 0 to 10.

3.B.3. Dissolved Oxygen

Sufficient dissolved oxygen is important to maintain a chemical composition in the water column suitable for eelgrass. Under low oxygen conditions, some compounds typically found in the water column will change their chemical species to their reduced form and can become toxic to eelgrass (e.g. sulfate, SO_4^+ converts to hydrogen sulfide, HS^-). Measurements were taken at the surface, bottom and occasional depths in between. July and August see the lowest levels of dissolved oxygen in the water column so only data from these months were processed. Minimum O_2 levels were isolated from the July and August data per station in MatLab and projected in GIS. The sample station point values were interpolated using the IDW tool to avoid estimations outside the range of low O_2 (Figure 16)

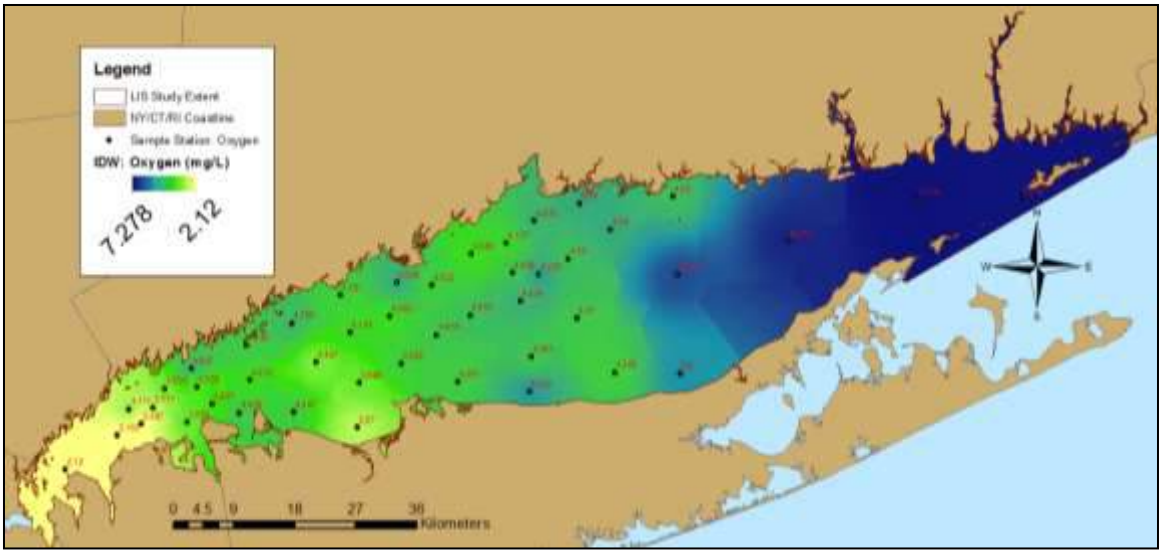


Figure 16: Low O_2 Interpolated Raster - Dissolved oxygen levels averaged at each mean center station for 2009 to 2011 and interpolated to estimate the values throughout LIS using the IDW interpolation tool. 46 stations were analyzed for dissolved oxygen.

The result was a low O_2 interpolated raster throughout LIS. Next, the low O_2 value was scored over the identified ecologically significant range (Table 4) using the Reclassify tool and the result is a raster which displays the score of the dataset from 0 to 10 ().

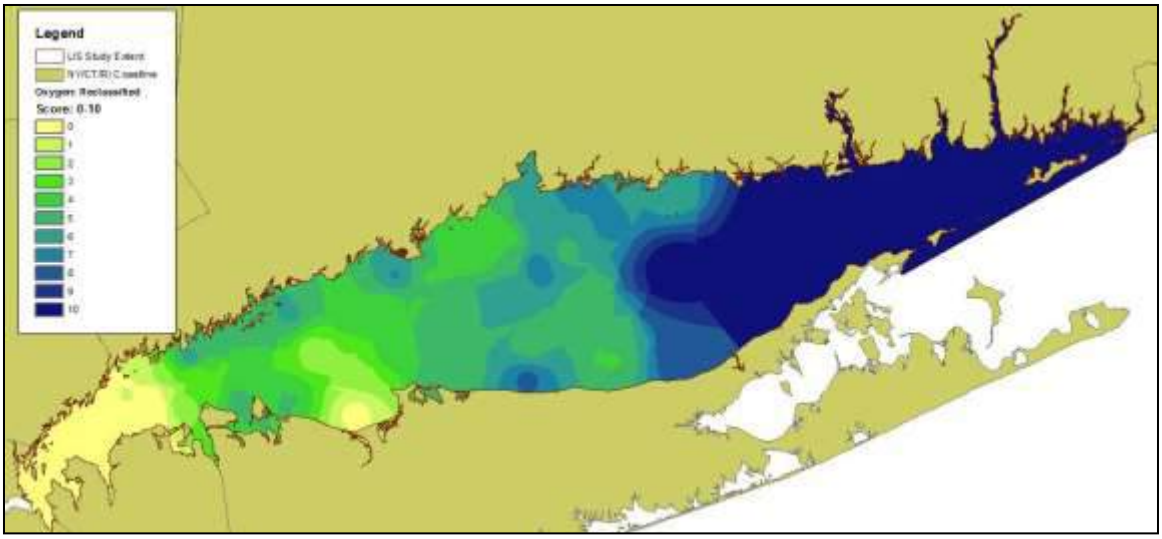


Figure 17: Low O2 Reclassified Raster - Low O2 is reclassified with the score from 0 to 10.

3.B.4. TDN/TDP/Salinity/pH

The parameters in this section are identified as year-round parameters. Although there are seasonal variations in the parameters, literature suggested ranges are based on annual averages (Wazniak et al., 2007). For equal influence from month to month throughout the calendar year, the data for these 4 parameters were averaged per month per station in the Excel spreadsheet.

Table 5: Total Dissolved Phosphorous Excel Processing – Data from the CT DEEP was imported to an Excel spreadsheet and processed using the If and AverageIf functions for per station and per month values

Cruise-Stn	Month-Stn	Depth Code	Result	PerVisit_Avg	Avg_Month_Stn	DD_Lat	DD_Long
BOLDA0901	AUG-01	S	0.05			40.96333	–73.6235
BOLDA0901	AUG-01	B	0.061	0.0555		40.96333	–73.6235
BOLDC0901	AUG-01	S	0.058			40.96333	–73.6237
BOLDC0901	AUG-01	B	0.057	0.0575		40.96333	–73.6237
BOLDE0901	AUG-01	B	0.061			40.9635	–73.6233
BOLDE0901	AUG-01	S	0.061	0.061		40.9635	–73.6233
BOLDH0901	AUG-01	B	0.055			40.96333	–73.6233
BOLDH0901	AUG-01	S	0.053	0.054		40.96333	–73.6233

Table 5, Continued

Cruise-Stn	Month-Stn	Depth Code	Result	PerVisit_Avg	Avg_Month_Stn	DD_Lat	DD_Long
BOLDJ0901	AUG-01	S	0.054			40.96333	–73.6228
BOLDJ0901	AUG-01	B	0.062	0.058		40.96333	–73.6228
BOLDL0901	AUG-01	B	0.061			40.963	–73.6245
BOLDL0901	AUG-01	S	0.054	0.0575	0.05725	40.963	–73.6245
BOLDA0902	AUG-02	B	0.085			40.93467	–73.6013
BOLDA0902	AUG-02	S	0.049	0.067		40.93467	–73.6013
BOLDD0902	AUG-02	B	0.078			40.93433	–73.6008
BOLDD0902	AUG-02	S	0.065	0.0715		40.93433	–73.6008
BOLDF0902	AUG-02	S	0.086			40.93467	–73.601
BOLDF0902	AUG-02	B	0.076	0.081		40.93467	–73.601
BOLDH0902	AUG-02	S	0.068			40.93467	–73.6012
BOLDH0902	AUG-02	B	0.075	0.0715		40.93467	–73.6012
BOLDJ0902	AUG-02	B	0.082			40.9345	–73.6008
BOLDJ0902	AUG-02	S	0.064	0.073		40.9345	–73.6008
BOLDL0902	AUG-02	S	0.064			40.935	–73.601
BOLDL0902	AUG-02	B	0.073	0.0685	0.0720833	40.935	–73.601

The following functions were applied to the above spreadsheet to average the data ‘per visit’ and then ‘per month per station’:

‘PerVisit_Avg’ = IF(Cruise-Stn2=Cruise-Stn3,"",AVERAGEIF(Cruise-Stn$2:Cruise-Stn$1059,Cruise-Stn2,Result$2:Result$1059))

‘Avg_Month_Stn’ = IF(Month-Stn13=Month-Stn14,"",AVERAGEIF(Month-Stn$2:Month-Stn$1059,Month-Stn13,PerVisit_Avg$2:PerVisit_Avg$1059))

The ‘per month per station’ values were projected by the associated Latitude/Longitude coordinate data in GIS. The data for each parameter were averaged to the sampling stations throughout the study area, and the spatial data were centered using the Mean Center tool. The results were each processed using the IDW to avoid estimating values out of the range of each parameter. The outputs were interpolated rasters with estimated TDN, TDP, Salinity, and pH values throughout LIS (Figures 18–21).

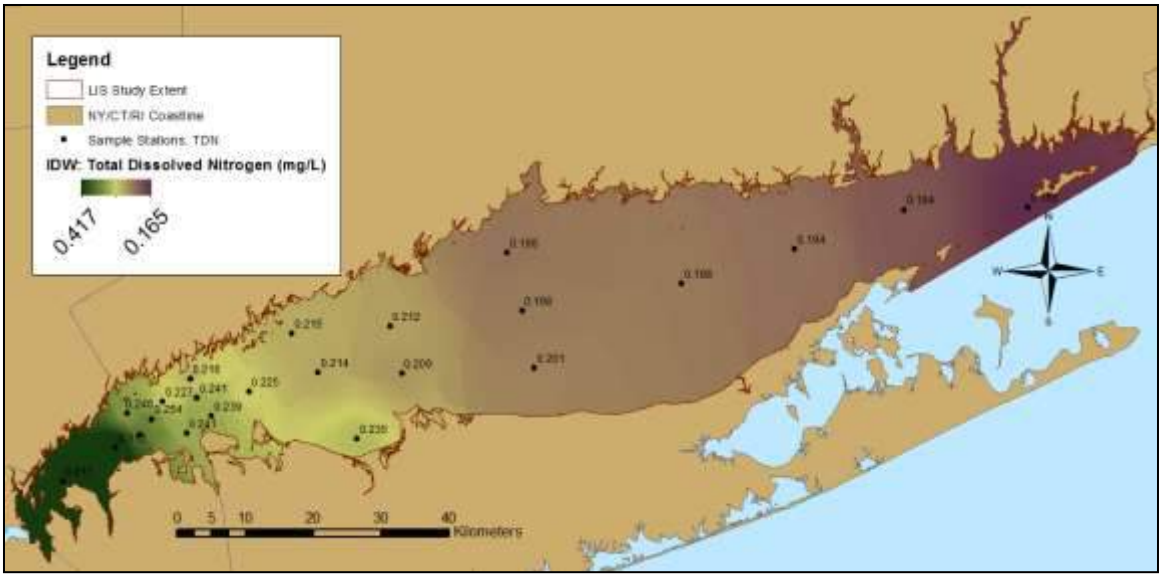


Figure 18: Total Dissolved Nitrogen Interpolated Raster - TDN averaged at each mean center station for 2009 to 2011 and interpolated to estimate the values throughout LIS using the IDW tool. 23 stations were analyzed for TDN.

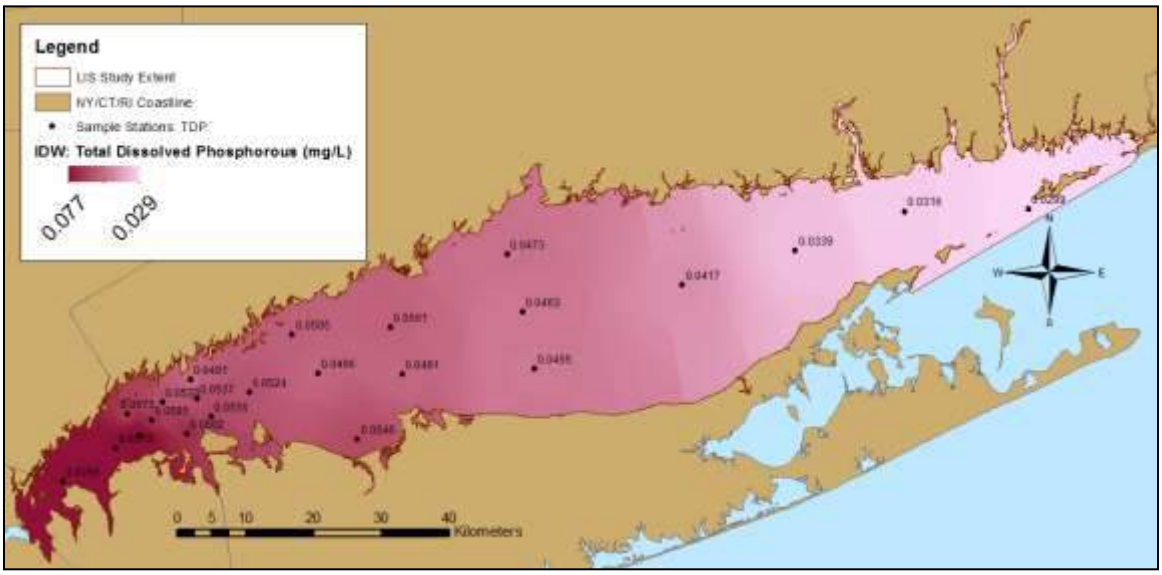


Figure 19: Total Dissolved Phosphorous Interpolated Raster - TDP averaged at each mean center station for 2009 to 2011 and interpolated to estimate the values throughout LIS using the IDW tool. 23 stations were analyzed for TDP.

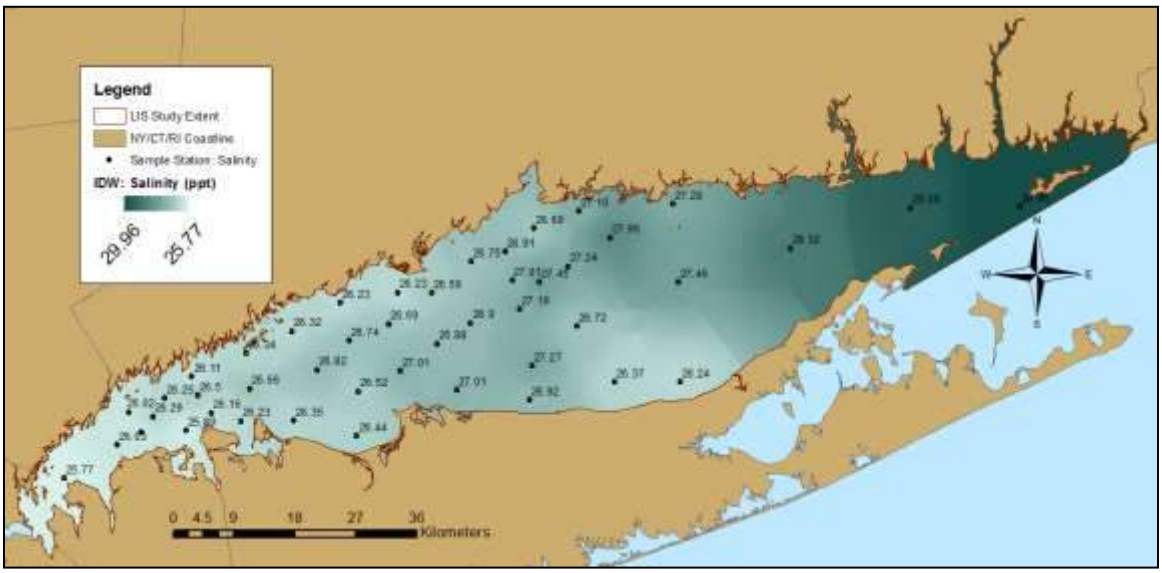


Figure 20: Salinity Interpolated Raster - Salinity average at mean center station from 2009 to 2011, year round and interpolated using the IDW tool. 46 Stations were analyzed for salinity.

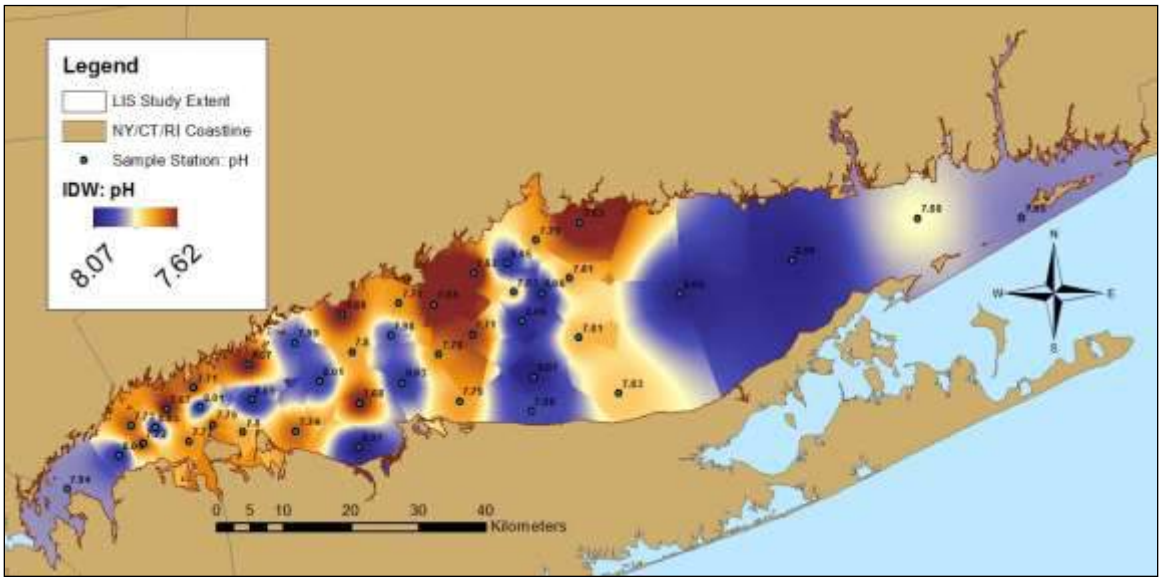


Figure 21: pH Interpolated Raster - pH averaged at each mean center station from the 2009 to 2011 year round data and interpolated using the IDW tool. 43 Stations were analyzed for pH.

Next, each parameter was ranked based on desired levels for restoration efforts by the above criteria (Table 4); the resulting rasters were all scored on an equal interval from 0 to 10 (Figures 22–25).

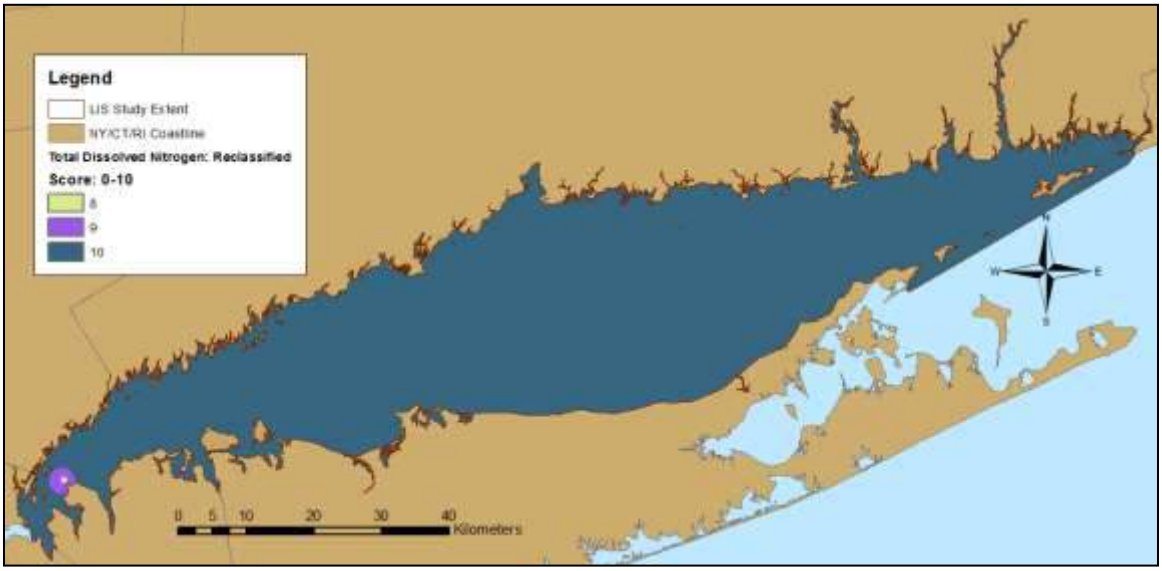


Figure 22: Total Dissolved Nitrogen Reclassified Raster - TDN is reclassified with the score from 0 to 10.

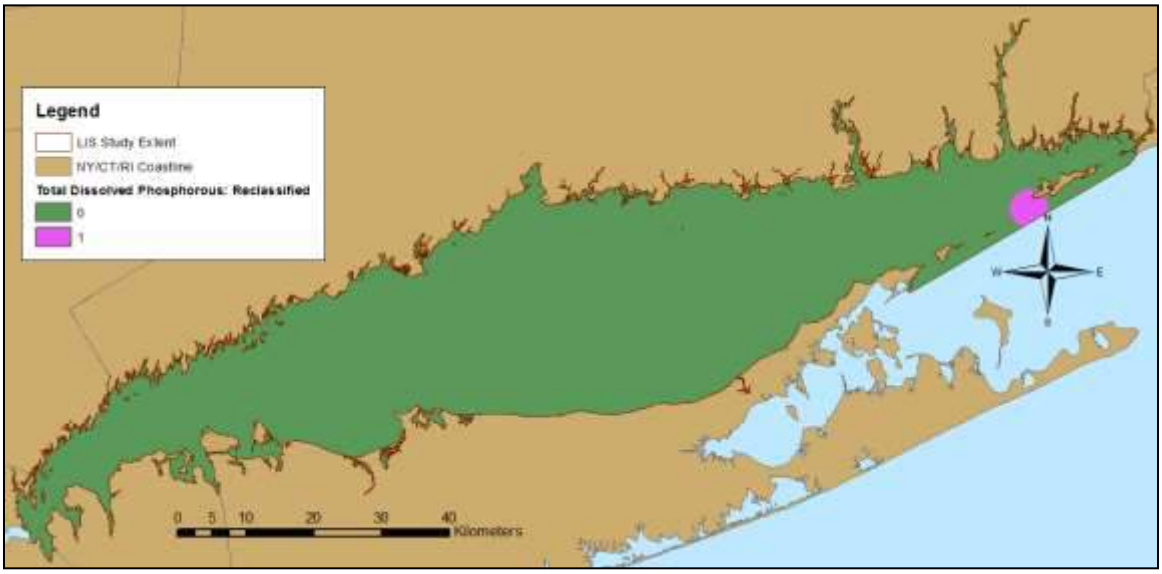


Figure 23: Total Dissolved Phosphorous Reclassified Raster - TDP is reclassified with the score from 0 to 10. TDP is included in the Chesapeake Bay based submerged aquatic vegetation parameter ranges to account for the freshwater and brackish water species. It does not really apply for LIS, which is estuarine.

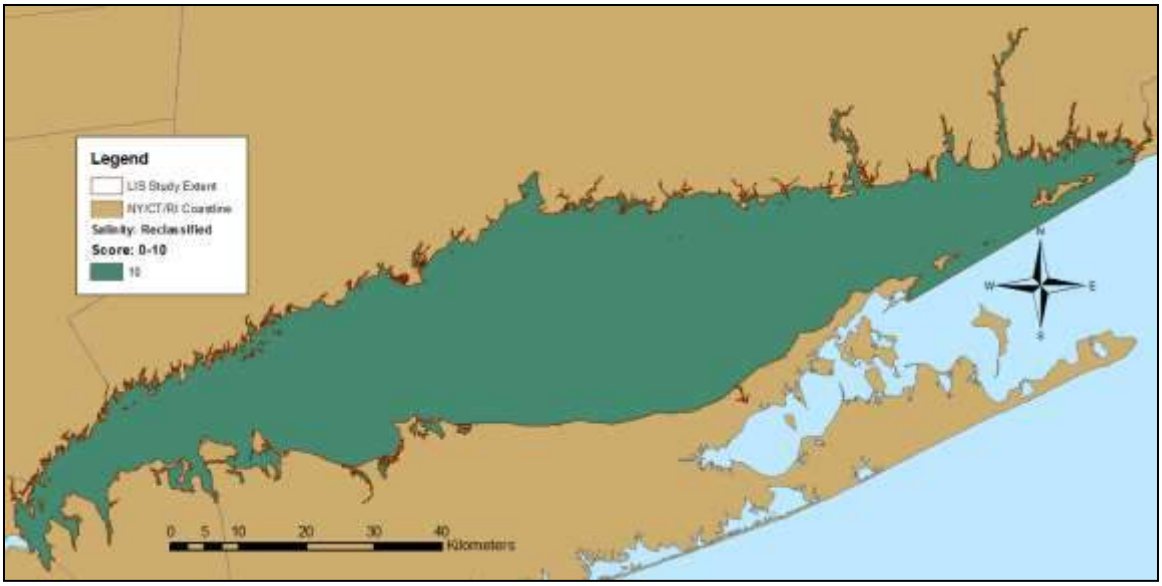


Figure 24: Salinity Reclassified Raster - Salinity is reclassified with the score from 0 to 10. Salinity range does not exceed the maximum threshold of 10ppt at any station in LIS.

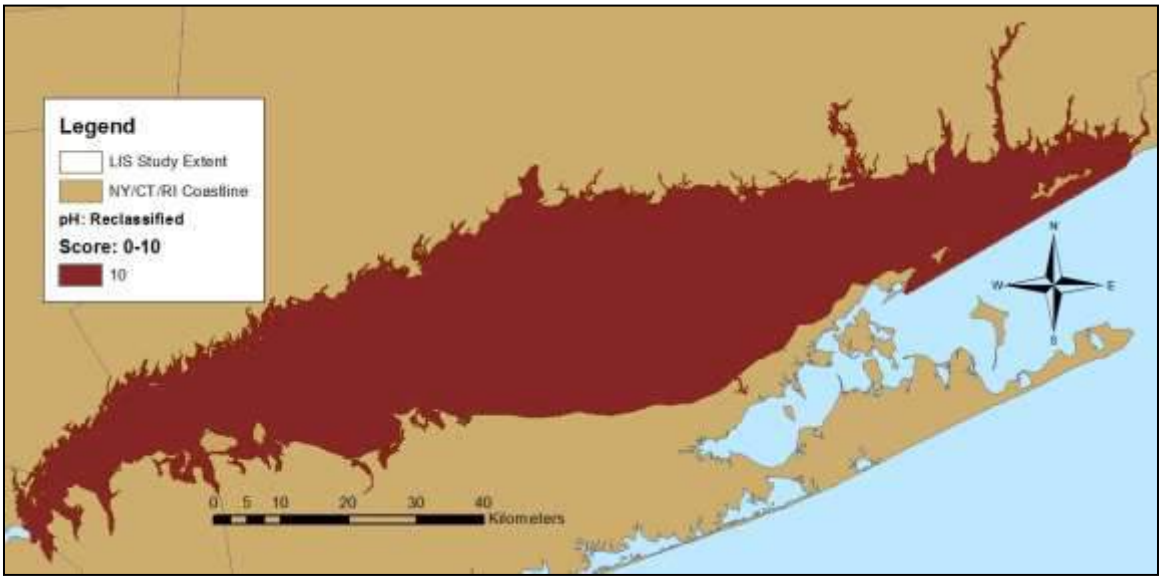


Figure 25: pH Reclassified Raster - pH is reclassified with the score from 0 to 10. pH does not exceed the maximum threshold of 8.8 at any station in LIS.

3.B.5. Chlorophyll *a*/Total Suspended Solids

Chlorophyll *a* (ChlA) and Total Suspended Solids (TSS) both play important roles in water clarity. For this reason, data for each parameter were extracted during the

growing season. The datasets were further processed per visit per month in Excel to avoid seasonal variation and were each displayed in GIS (See TDP Example, Table 5). Each parameter was averaged to the associated station, and the spatial data were centered using the Mean Center tool. The results were each processed using the IDW to avoid estimating values out of the range of each parameter (Figures 26–27).

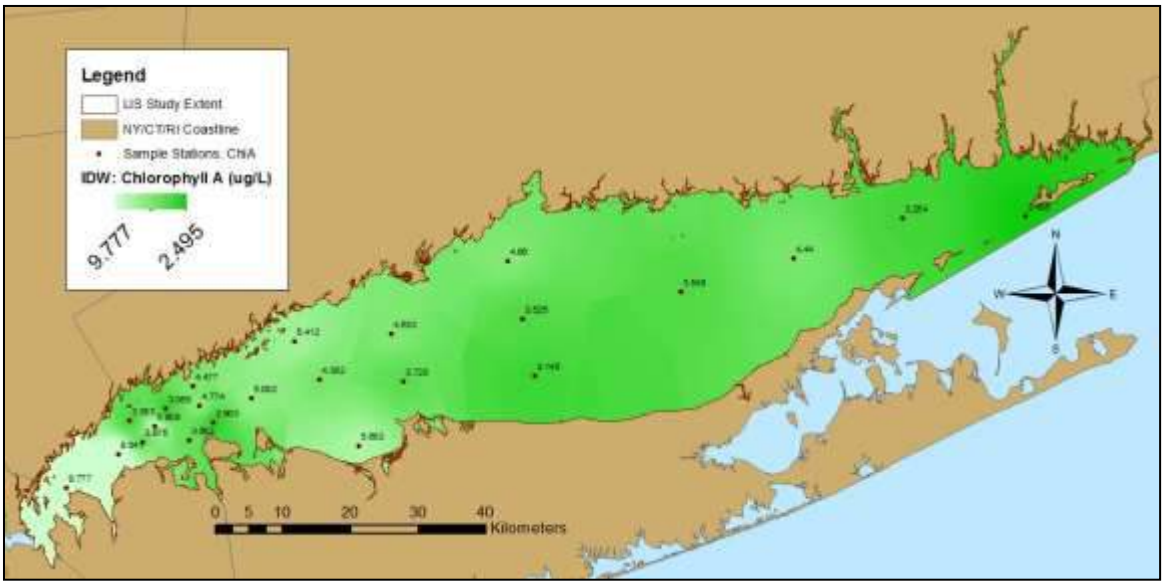


Figure 26: Chlorophyll *a* Interpolated Raster - Chlorophyll *a* values at 23 stations throughout LIS averaged data from 2009 to 2011 growing season and produced estimates using the IDW interpolation tool. 23 Stations were analyzed for Chlorophyll *a*.

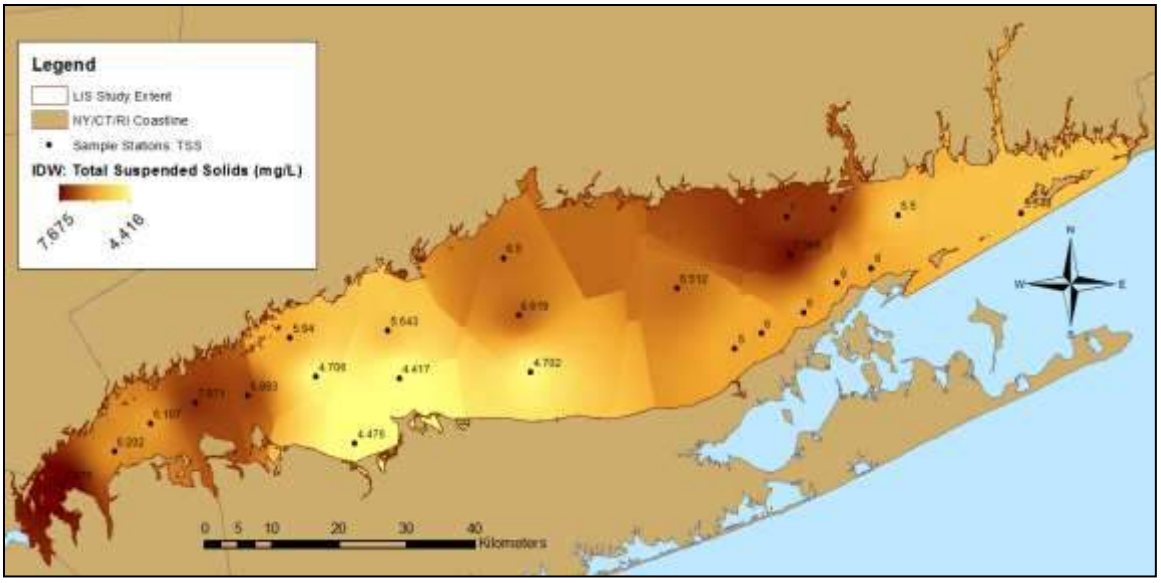


Figure 27: Total Suspended Solids Interpolated Raster - Total Suspended Solids averaged at 17 mean center stations during the growing season, 2009 to 2011. Data were interpolated using the IDW tool. 24 Stations were analyzed for Total Suspended Solids.

The results were interpolated rasters with estimated ChlA and TSS throughout LIS. Next each parameter was ranked based on desired levels for restoration efforts by the above criteria (Table 4); the output rasters were scored from 0 to 10 (Figures 28–29).

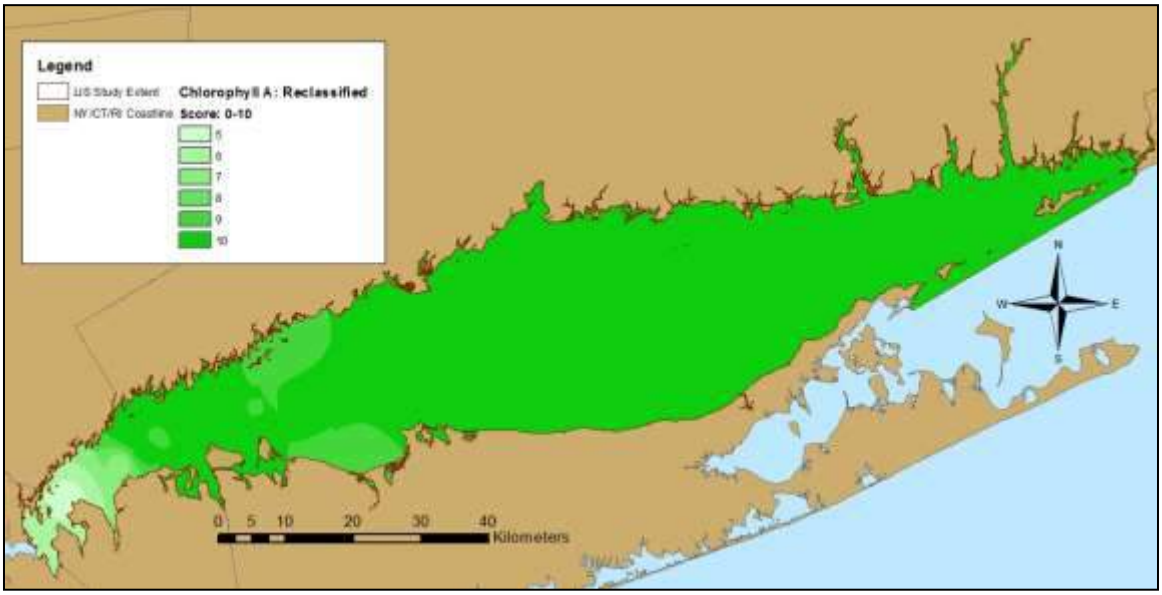


Figure 28: Chlorophyll *a* Reclassified Raster - Chlorophyll *a* reclassified raster with a ranked score from 0 to 10.

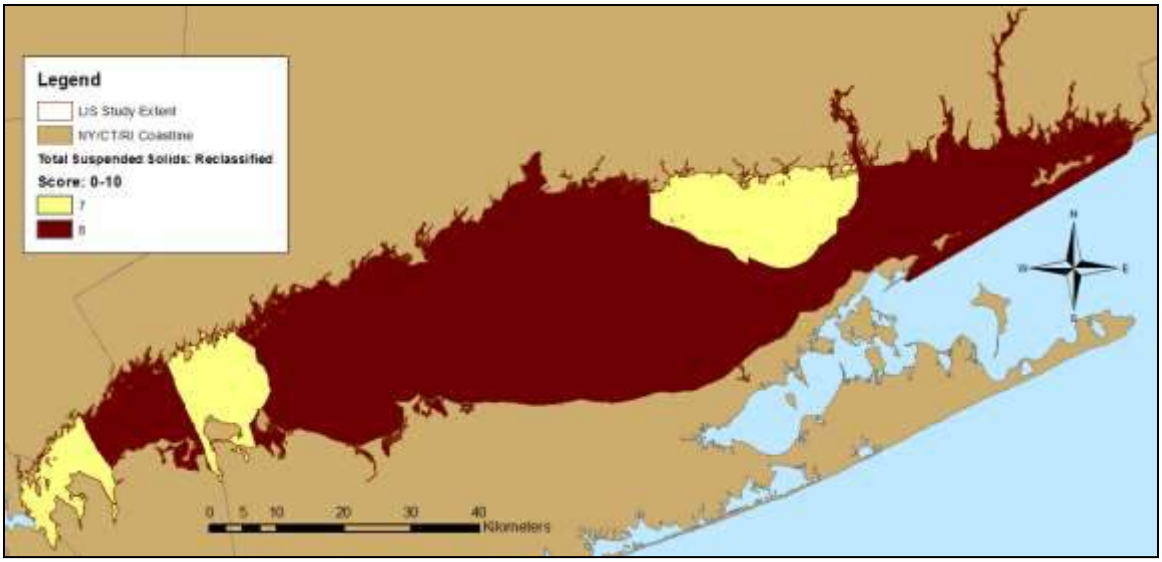


Figure 29: Total Suspended Solids Reclassified Raster - Total suspended solids is reclassified with a ranked score from 0 to 10.

3.B.6. Grain Size: Percent Silt and Clay

Data collected and made available to us by the Woods Hole Oceanographic Institute (WHOI) contained a large amount of bottom sediment data at locations throughout LIS in a shapefile. The data were projected in GIS and a new field was added to combine the existing "%Silt" and "%Clay" fields using the Field Calculator:

'Percent Silt & Clay' = '%Silt' + '%Clay'

The resulting field value for 'Percent Silt & Clay' was interpolated using the IDW tool and the result is an estimated % Silt and Clay raster surface covering the entire LIS (Figure 30).

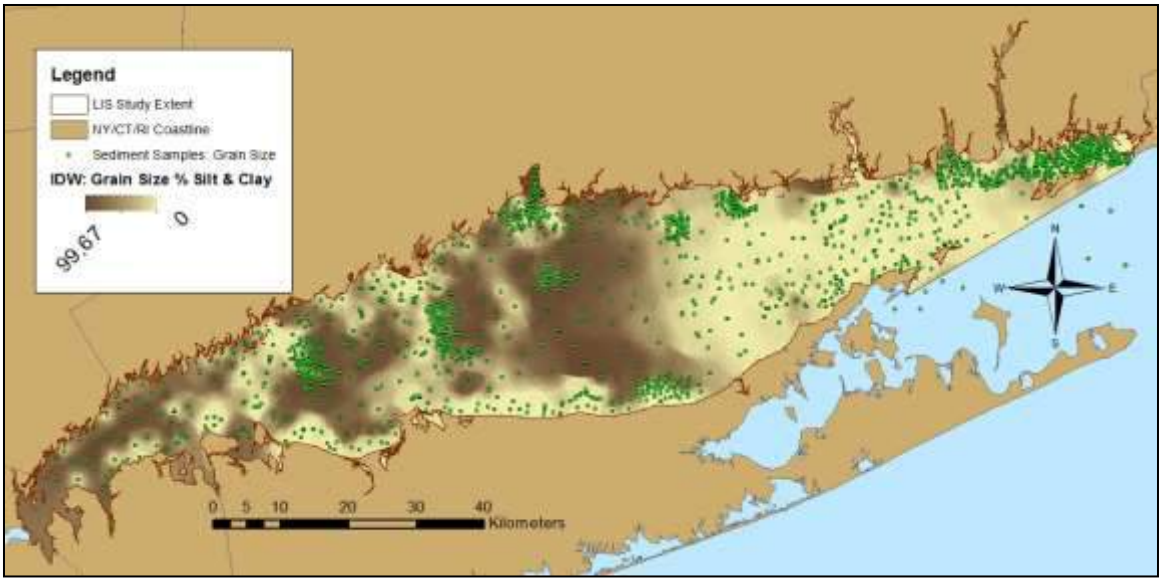


Figure 30: Percent Silt and Clay Interpolated Raster - Grain size analysis with data collected by WHOI for LIS and interpolated using the IDW tool. 2214 Samples were analyzed for Percent Silt and Clay.

Next, the output raster was ranked based on desired levels for eelgrass restoration efforts by the above criteria (Table 4); the result is a raster with the data scored from 0 to 10 (Figure 31).

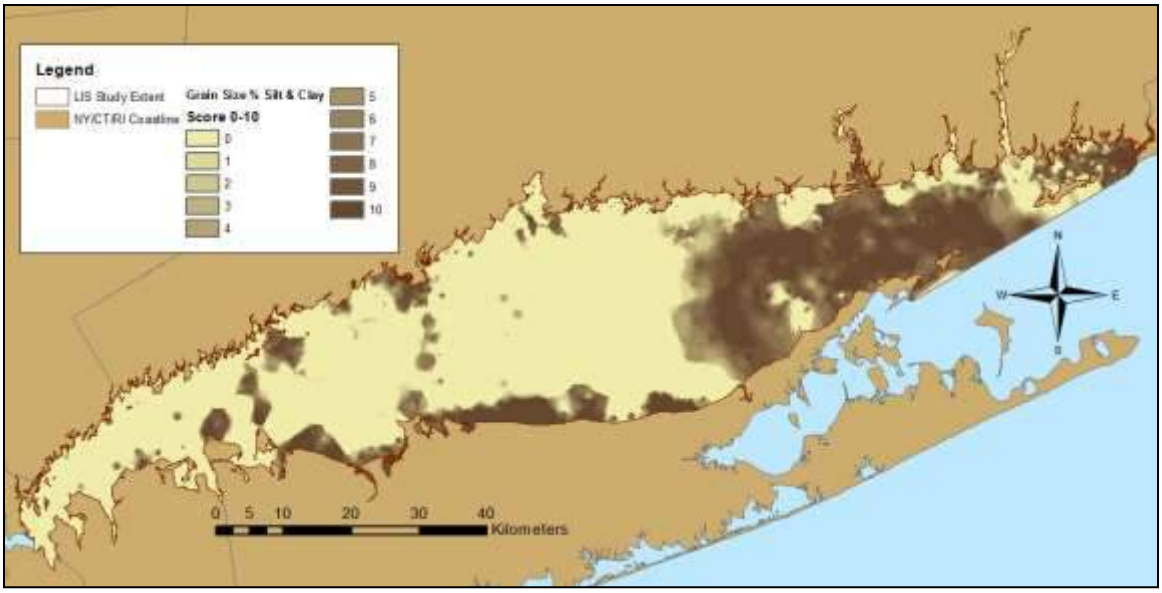


Figure 31: Percent Silt and Clay Reclassified Raster - Percent silt and clay reclassified to account for sandy and rocky bottoms where new eelgrass seed can develop a strong root structure.

3.B.7. Sediment Total Organic Carbon

Total Organic Carbon (TOC) was made available by the LISRC, extracted from the feature "seddata_g83" shapefile with values uncorrected for salt content. TOC is the total organic carbon in the sediment samples. The sediment percent organic ranges developed for eelgrass habitat suitability include TOC, total organic nitrogen, and total organic phosphorus, as well as any other organic compounds in the sediment. Thus, the use of TOC is an underestimate of the percent of total organic material in the sediments. Colleagues are working to develop an appropriate conversion for TOC values to sediment percent organics. For the purpose of initial model development, TOC is assumed to represent the majority of the sediment percent organics and is used without modification. All points containing TOC values were exported to a new feature class before the data were interpolating using the IDW tool (Figure 32).

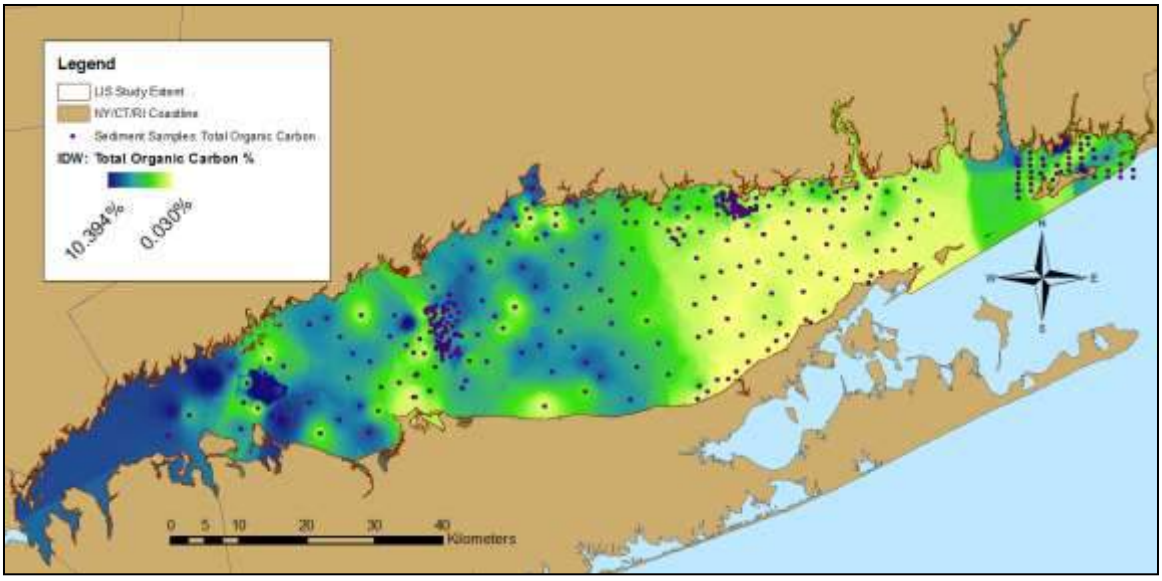


Figure 32: Sediment Total Organic Carbon Interpolated Raster - For Sediment Percent Organics, TOC value uncorrected for salt at each location throughout LIS was interpolated using the IDW tool. 406 Samples were analyzed for TOC.

Next, the parameter raster was ranked based on desired levels for restoration efforts by the above criteria (Table 4); the result is a raster with the data scored from 0 to 10 (Figure 33).

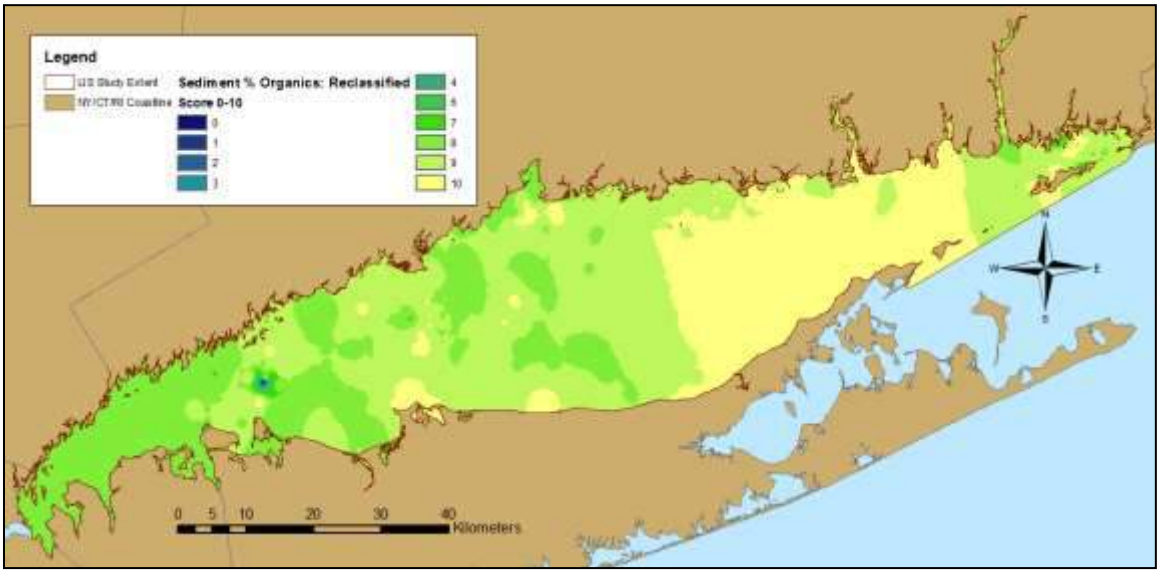


Figure 33: Sediment Total Organic Carbon Reclassified Raster - Sediment Percent Organic is reclassified with the score from 0 to 10.

3.C. Weighted Sum of Scored Parameters

With the knowledge of colleagues and multiple scholarly articles (Koch and Beer, 1996; Beer, 2001; Davis, 1999; Wazniak et al., 2007), the importance of each parameter in the successful restoration of eelgrass in Long Island Sound is weighted (Table 7). First, being a benthic plant, the percent light reaching the bottom is a critical parameter to the survival of any submerged aquatic species so this parameter is given 30% of the weighting in the habitat restoration project. Additionally, Chlorophyll *a* and TSS are important factors influencing light in the water column and so each parameter is weighted 10% of the sum of weighted parameters. To express the importance of light for the benthic plant, the first 3 parameters make up 50% of the weighted sum of the parameters.

The year round 2009 to 2011 parameters, TDN, TDP, Dissolved Oxygen, Salinity and pH, play important roles in water quality with indirect influence on water clarity. TDN and TDP would be better quantified instead by load values. Salinity and pH do not exceed the parameter ranges, so the estimated values for these parameters, although they are important to eelgrass, have low influence on habitat restoration. Each parameter was weighted equally as 5% of the sum of weighted parameters.

Sediment percent organics and sediment grain size are the major components of the bottom habitat. Although higher levels of organic compounds in the sediment can be found around existing eelgrass beds, new areas suitable for eelgrass restoration are characterized by low amounts of total organic carbon. This parameter may be partially influenced by the sediment grain size in the area. Appropriate sediment grain size is a major indicator of habitat suitability for restoration work. Sediment percent organics was

weighted as 5% and grain size was weighted as 10% of the sum of all ranked parameters. The results of the weighted rankings are portrayed further in Chapter 4.

Chapter 4: Results

In this chapter the suitable band was combined with the ranked parameters on a weighted scale, identifying areas that are ready for localized water quality analysis to begin, followed by eelgrass restoration efforts in the near future.

4.A. Weighting Ranked Parameters Results

All parameters were summed using the Raster Calculator by their reclassified score (0–10) (Figure 34).

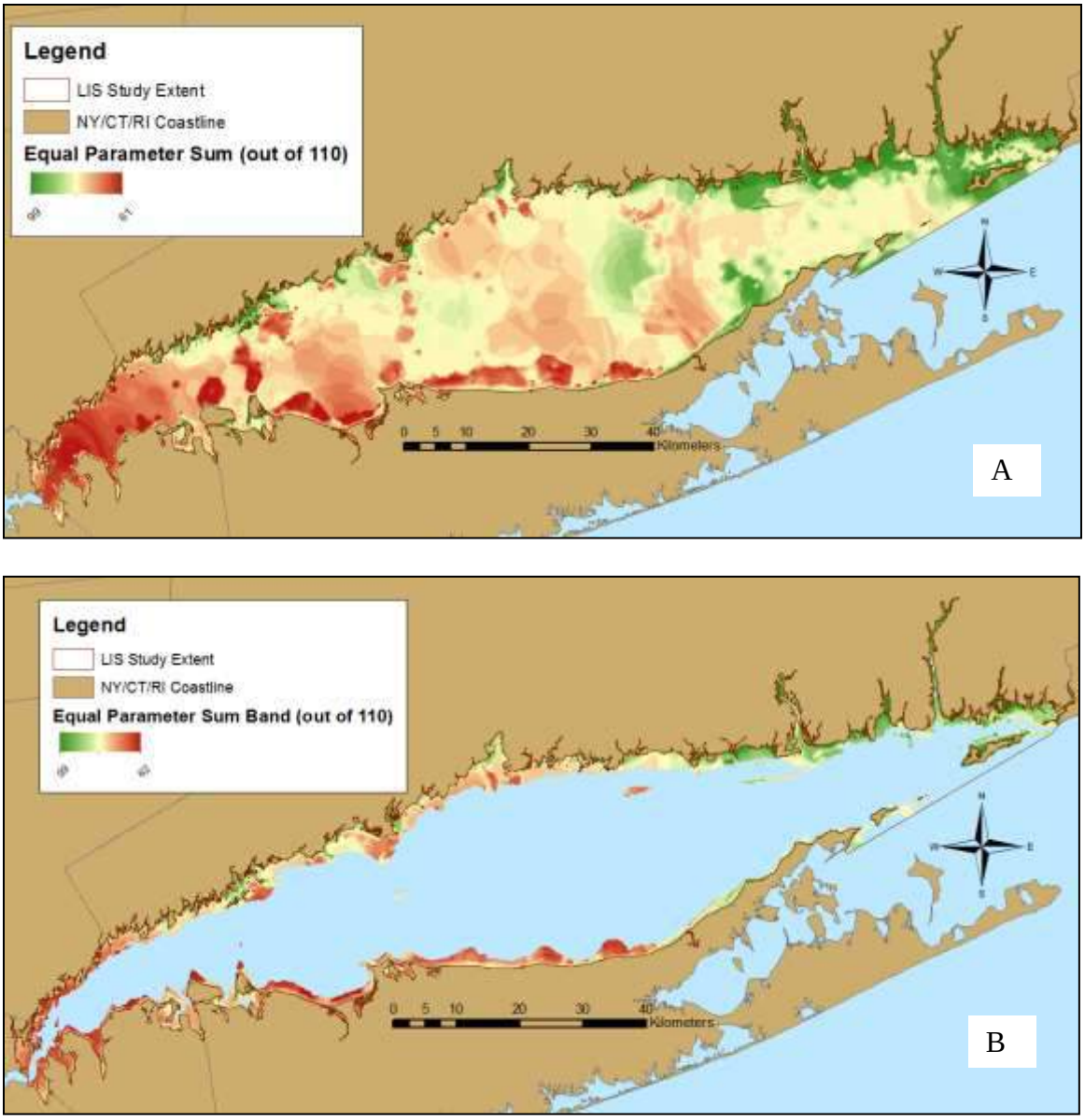


Figure 34: Equal Sum Parameters and Equal Sum Band – the reclassified parameters were A. summed using the Raster Calculator and B. then clipped within the suitable band.

If the scoring of 0 to 10 for each parameter were weighted equally, the parameters with a greater effect on eelgrass success (e.g. light) would not have as much influence in the model as what is seen in the field data. The parameters, once weighted using the

Weighted Sum tool, produces the overall sum of the parameters on a range from 0 to 100 (Table 6, Figure 35).

Table 6: Weighting Criteria for Environmental Parameters - The weighting of each parameter identifies each parameters importance in eelgrass restoration. All scores sum to 100.

Parameter	Weighted Score
Chorophyll A	0–10
Percent light reaching bottom	0–30
Total Dissolved Nitrogen	0–5
Total Dissolved Phosphorous	0–5
pH	0–5
Salinity	0–5
Dissolved Oxygen	0–5
Total Suspended Solids	0–10
Percent Total Organic Carbon	0–5
Surface Temperature	0–10
Bottom Sediment: Percent Silt and Clay	0–10

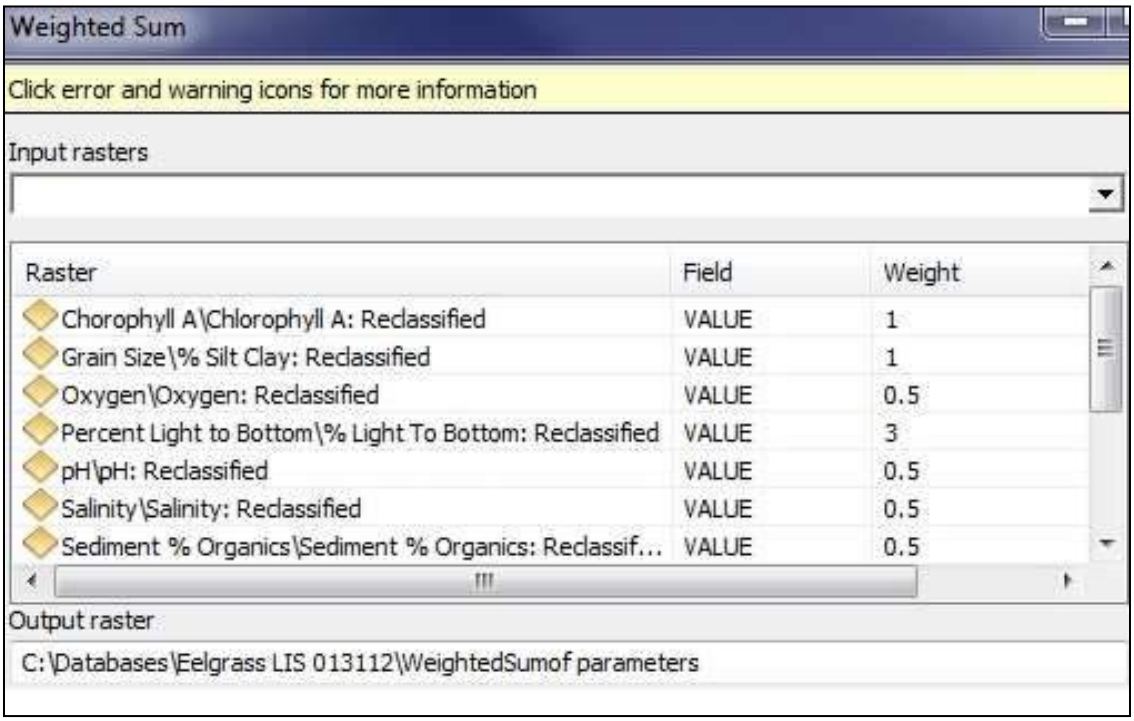


Figure 35: The Weighted Sum Tool – The Weighted Sum tool was applied to the reclassified values with weights given to each value. Each original score was multiplied by its weight, and all of the weights sum to 100.

The resulting raster was summed with the maximum depth band using the Raster Calculator to clip the raster. All cells within the Suitable Band were scored as 100.

'Weighted Sum Band' = 'Weighted Sum' + 'Suitable Band'

With all eleven ranking parameters reclassified to a weighted value, the suitable band was scored to identify the most suitable areas for further water quality analysis and potential eelgrass restoration efforts. By weighting the parameters using the Weighted Sum tool within the Suitable Band, the results express a range from 43 to 93.5 (Figure 36). Further review of the resulting band found that the highest scores are located near shores with greater emphasis on eastern LIS (see Figures 36B and 36C).

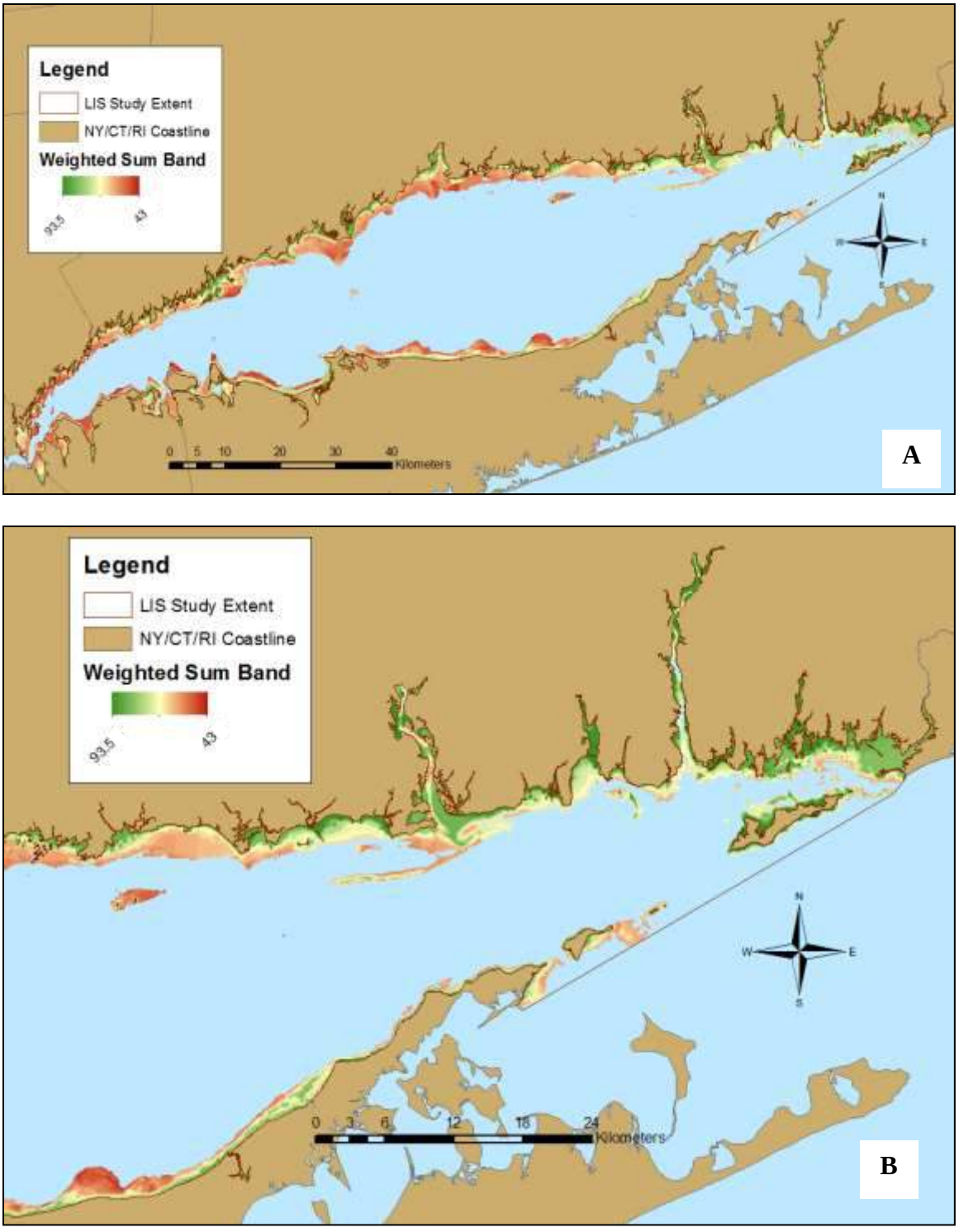


Figure 36: see caption on next page

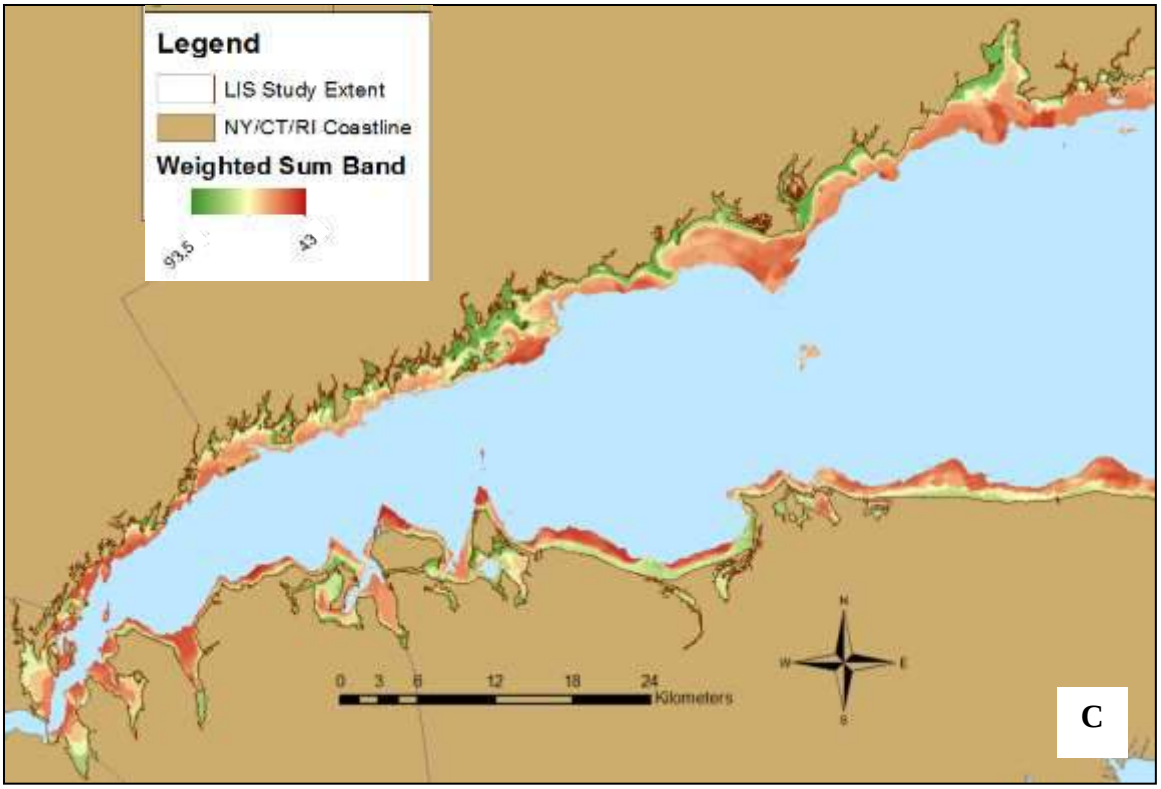


Figure 36: Weighted Sum Parameters Band - Weighted sum of ranked parameters within the Suitable Band has scores ranging from 43 to 93.5. A. Full study extent; B. Eastern LIS; C. Western LIS.

4.B. Intersect With Existing Eelgrass

The datasets were highly variable regarding the density of the number of stations in the study extent. Several ranked parameters had a low number of station values, primarily in eastern LIS. The reclassified raster surfaces for each parameter was overlain with the 2009 existing eelgrass bed data available by CT DEEP using a custom model (Figure 37). The results showed that more suitable values for eelgrass for all parameters were common in many parts of the existing eelgrass areas (see examples Figure 38).

The resulting intersect values were analyzed using the statistics tool in the attribute table for each parameter as well as categorically symbolizing the points by their

reclassification scores. Scored values were near 10 in all parameters which helps validate the estimated output of the IDW interpolation tool.

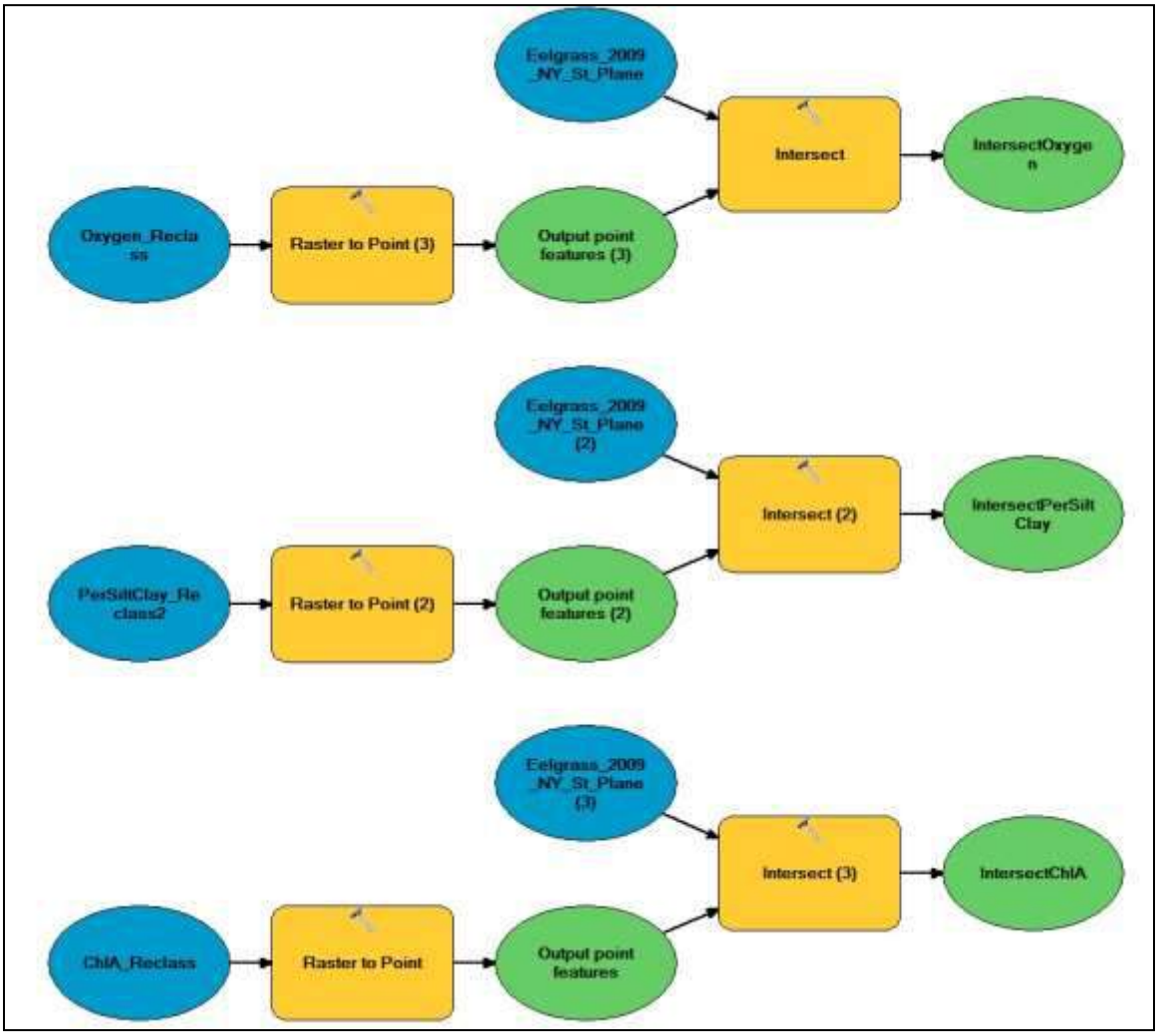


Figure 37: Intersect Model with 2009 Existing Eelgrass – The model inputs the reclassified parameter rasters, converts the raster to points, and intersects the points with 2009 Existing Eelgrass Bed data polygons. The result is a number of points from the original parameter that are overlain with the existing eelgrass data.

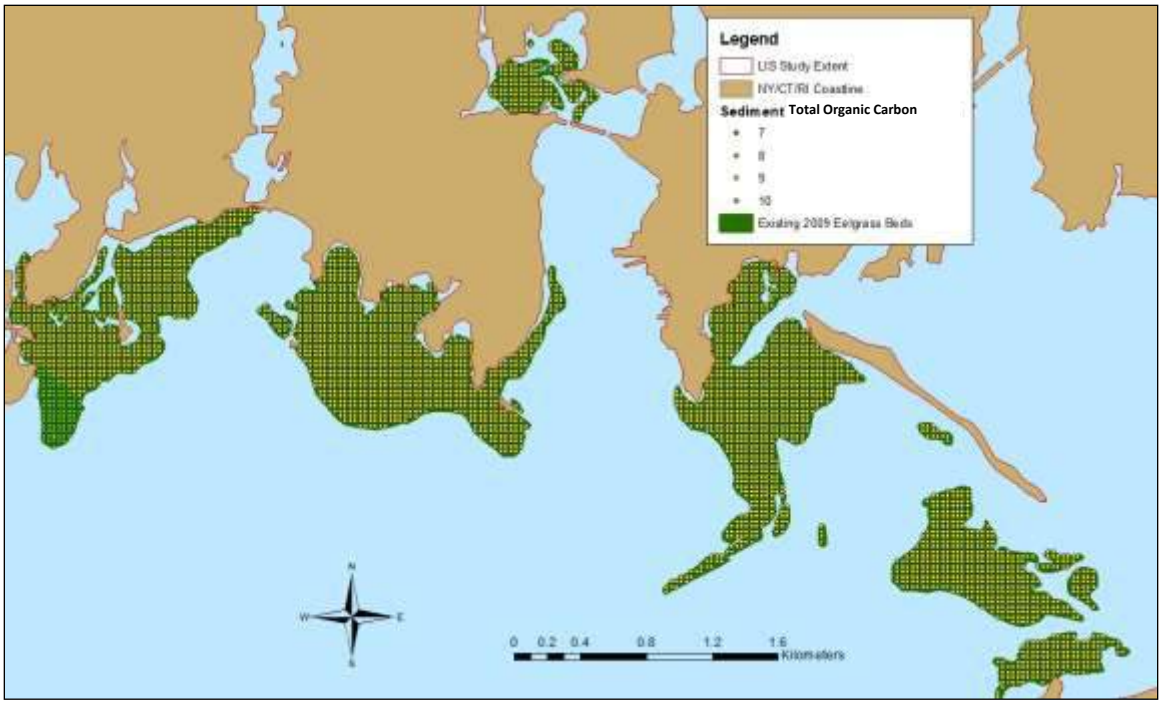


Figure 38: Sediment Total Organic Carbon Intersect with 2009 Existing Eelgrass - A view of the intersect of the total organic carbon scores with the 2009 existing eelgrass bed data (CT DEEP). The scores intersecting the existing eelgrass beds here are Yellow for 9 and Green for 10.

The above results from the model do not validate the model but rather help to understand the application of habitat restoration near existing eelgrass beds and the influence existing beds might have on the environmental parameters. One example of this might be the ranked score range from 0 to 10 for Grain Size: Percent Silt and Clay in the existing areas due to reduced current energy and particles settling to the bottom over time. Following further validation of the model, restoration will require high model output scores which may be present in regions of existing beds.

The weighted sum intersect with the existing eelgrass bed features helped again to understand the usefulness of the weighting scheme used in the habitat suitability project

(Figure 39). The statistics and frequency distribution of the intersect results calculated a range from 62.5 to 93.5 and an average of 87.59.

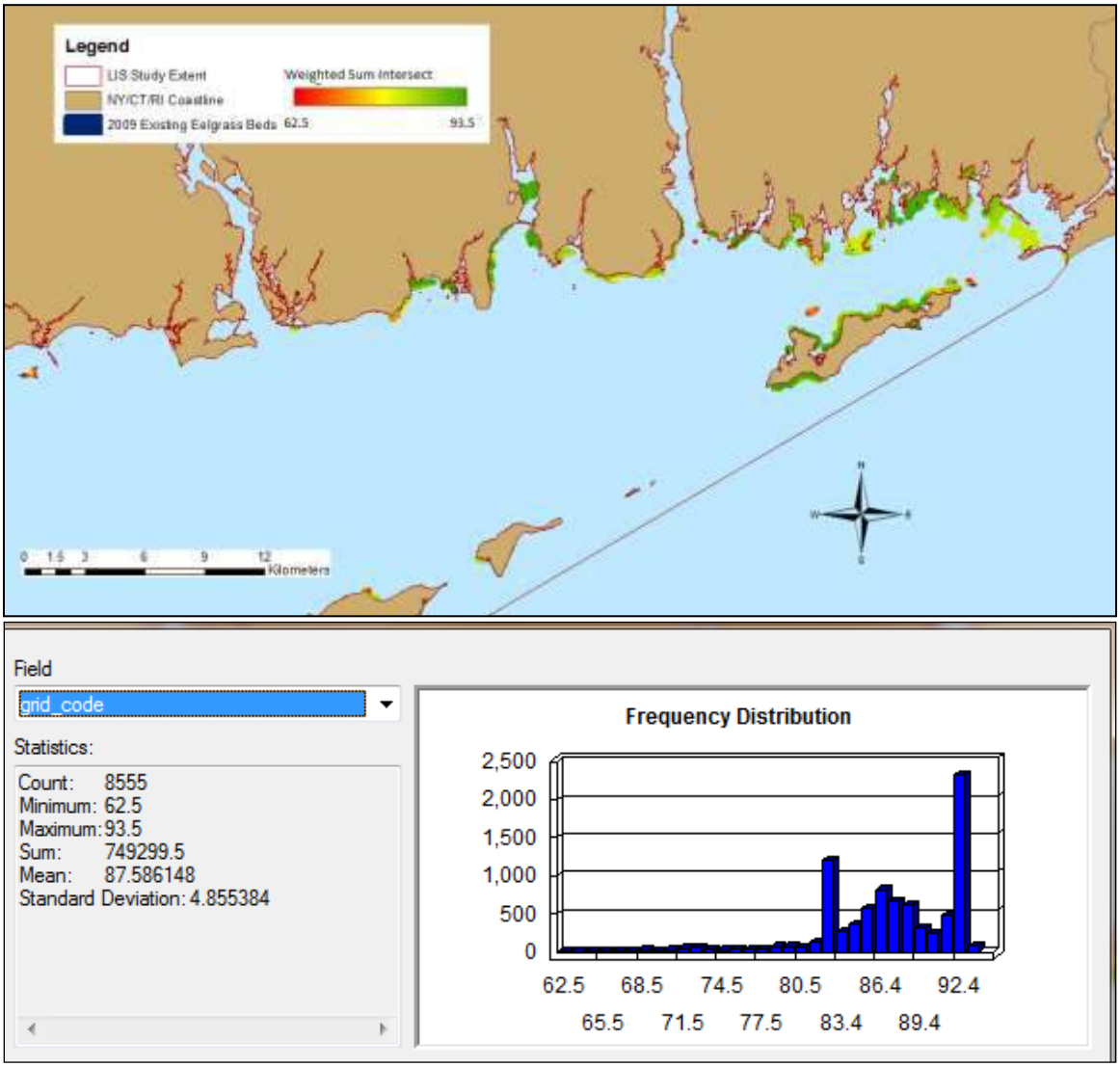


Figure 39: Weighted Sum Intersect with 2009 Existing Eelgrass - the range of the Weighted Sum band when overlain with the 2009 Existing Eelgrass beds (CT DEEP) is from 62.5 to 93.5 with an average score of 87.59.

Chapter 5: Discussion and Conclusion

Eelgrass (*Zostera marina*) in Long Island Sound (LIS), USA, has had difficulty recovering on its own from historic and recent losses, reflecting what is occurring worldwide. For habitat restoration efforts to occur and be sustainable into the future, it was important to analyze the most recent, influential environment parameters within a GIS model.

5.A. Processing Issues

While there were some initial processing problems, once the study extent, coordinate system, analysis mask, and raster snap environmental parameters were established, processing ran smoothly with very few setbacks with regards to the overlay of multiple weighted rasters.

While it appears that the eastern LIS is more suitable for eelgrass restoration in the future, it will be important to continue monitoring water and sediment quality for as many of the parameters as possible in and around the suitable band. The number of sampling stations in the study extent and the distance of stations to the Suitable Band varied from parameter to parameter. Stations near the Suitable Band had higher accuracy of the estimated values in the band, primarily in the western Long Island Sound. Stations which were further from the Suitable Band, although they were the nearest for interpolation purposes, increased the likelihood that the estimated value is not as accurate in eastern LIS relative to the densely sampled western LIS.

The Suitable Band was created from a very dense dataset of bathymetric points and a less dense but equally important mean tide dataset. Mean tide throughout LIS has

some variability as a result of the extreme tidal amplitude seen in the western LIS in contrast to the eastern LIS. While the data is less dense with regards to maximum depth of eelgrass, the values express a near linear regression with regard to the locations distance to the mouths of LIS at the east and west ends. Interpolation tools were assessed prior to the start of the study. Kriging and Spline tools were found to produce estimate values outside the range of the raw data so they were discarded. The IDW interpolation tool produces values without exceeding the upper or lower limits of the data range. IDW allowed a variable search type and for the number of points (stations) to be. This prevented stations in the western LIS from influencing areas in the east end. Data received from the CT DEEP contained a lower numbers of stations in the eastern LIS relative to the western LIS.

Additional accuracy was measured following completion of the study to identify where rasters intersect with recent observations of known eelgrass beds displayed as polygons (CT DEEP, 2009). The data were statistically analyzed in ArcMap 10.0, and the scores for each parameter - except TDP (which showed low values throughout LIS) - were in the upper score limit.

With regards to the overall result of the weighted ranked parameters, this model output layer identifies areas that are ready for eelgrass restoration efforts to occur in the near future as well as key areas that, while they may fall in the suitable band, have poor water quality and require further best management practices (BMPs) to improve conditions to a point where restoration is feasible (e.g. enforcement of new policies including waste management, fertilizer and pesticide use, or sediment dumping).

5.B. Conclusion

The goal of this study, to analyze water quality data to assist in the future habitat restoration efforts in LIS, has been successfully achieved. The model output yields weighted scores for eelgrass restoration suitability ranging from 43 to 93.5 out of possible 100, which would estimate the most suitable areas. The weighted scores show variability throughout the suitable band of Long Island Sound. Further studies will be conducted within and near the Suitable Band, primarily in those areas with scores greater than 80 to validate that estimated ranked parameters agree with field data. A suggested range from 80 to 93.5 to identify ideal areas for case studies is further confirmed as a suitable range by the intersection of the weighted sum values with the existing eelgrass data (Figure 39). Here, the scores range from 62.5 to 93.5 and the average is 87.59.

Further model analysis may include additional criteria such as boat traffic, mooring fields, and commercial fishing regions; all of which adversely affect restoration success. These may further our understanding of the overall quality of the highly scored areas. Water quality sampling during these events will verify the estimated values interpolated with the IDW tool for each parameter. The IDW may be rerun with adjusted variables so the estimated values in these areas can be better quantified. It may be useful to also update the depth values of LIS if new depth data is made available; maybe in the application of accurate Pictometry data.

By generating a Suitable Band and quantifying a score for the area by several weighted environmental variables, scientists are able view the LIS as it pertains to habitat restoration efforts. The habitat restoration model can be manipulated as new case study

data is conducted in priority areas. The model may also serve as a template for other regions that have experienced similar loss, to estimate the regional data on a full scale and indicate the areas of importance for future restoration efforts.

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Appendix

Tidal Amplitude and Maximum Depth Data

This data is supplied by NOAA Coastal Data and recorded in an Excel spreadsheet. The data processed to measure the Maximum Depth of Eelgrass at each tidal station and is projected in GIS.

Station_ID	Mean_Range__m_	Mean_Tide__m_	DD_Lat	DD_Long	Max_Depth__m_
Little Gull Island	0.67056	0.39624	41.20667	–72.1102	–8.8038
Silver Eel Pond, Fishers Island, NY	0.710184	0.417576	41.25667	–72.03	–8.7824
Watch Hill Point	0.79248	0.42672	41.305	–71.86	–8.7733
West Harbor, Fishers Island	0.762	0.42672	41.26674	–71.9998	–8.7733
Noank, Mystic River Entrance	0.70104	0.42672	41.31674	–71.9834	–8.7733
Niantic, Niantic River	0.786384	0.438912	41.325	–72.1867	–8.7611
New London, State Pier	0.780288	0.448056	41.36	–72.0917	–8.7519
Plum Gut Harbor, Plum Island	0.79248	0.4572	41.17167	–72.205	–8.7428
Westerly, Pawcatuck River	0.79248	0.4572	41.38167	–71.8317	–8.7428
Millstone Point	0.82296	0.4572	41.29992	–72.1666	–8.7428
Stonington, Fishers Island Sound	0.82296	0.4572	41.33334	–71.9001	–8.7428
Yale Boathouse	0.832104	0.478536	41.43	–72.0933	–8.7215
Essex	0.9144	0.51816	41.34833	–72.385	–8.6818
Connecticut River, Saybrook Point	0.97536	0.54864	41.28333	–72.35	–8.6514
Truman Beach	1.03632	0.54864	41.14041	–72.3229	–8.6514
Connecticut River, Lyme, highway bridge	1.008888	0.557784	41.32167	–72.35	–8.6422
Connecticut River, Saybrook Jetty	1.0668	0.6096	41.26333	–72.3433	–8.5904
Horton Point	1.2192	0.64008	41.08334	–72.45	–8.5599
West Brook, Duck Island Roads	1.24968	0.67056	41.27333	–72.475	–8.5294
Hashamomuck Beach	1.28016	0.70104	41.095	–72.3983	–8.499
Duck Island	1.3716	0.73152	41.25	–72.4834	–8.4685
Madison	1.49352	0.79248	41.27	–72.6033	–8.4075

Appendix, continued

Mattituck Inlet	1.58496	0.85344	41.015	–72.5617	–8.3466
Guilford Harbor	1.764792	0.862584	41.27167	–72.6667	–8.3374
Sachem Head	1.64592	0.88392	41.245	–72.7083	–8.3161
Falkner Island	1.64592	0.88392	41.21667	–72.6502	–8.3161
Northville	1.64592	0.896112	40.98167	–72.645	–8.3039
Money Island	1.70688	0.9144	41.25	–72.7502	–8.2856
Herod Point	1.79832	0.94488	40.96667	–72.8333	–8.2551
Branford, Branford River	1.78308	0.96012	41.26167	–72.8183	–8.2399
Mount Sinai Harbor	1.8288	0.97536	40.96333	–73.04	–8.2246
Stony Brook, Smithtown Bay	1.85928	0.97536	40.91673	–73.15	–8.2246
Lighthouse Point, New Haven Harbor	1.865376	1.002792	41.25167	–72.905	–8.1972
New Haven Harbor Entrance	1.88976	1.00584	41.23334	–72.9168	–8.1942
New Haven Harbor, New Haven Reach	1.87452	1.011936	41.28333	–72.9083	–8.1881
Milford Harbor	1.926336	1.039368	41.21833	–73.055	–8.1606
Housatonic River, Sniffens Point	1.959864	1.054608	41.18667	–73.1133	–8.1454
Cedar Beach	1.959864	1.054608	40.965	–73.0433	–8.1454
Port Jefferson Harbor entrance	2.01168	1.0668	40.96667	–73.0833	–8.1332
Stratford Shoal	2.01168	1.0668	41.06666	–73.1	–8.1332
Setauket Harbor	2.04216	1.0668	40.94994	–73.1001	–8.1332
Housatonic River, Stratford, I-95 bridge	2.005584	1.075944	41.20333	–73.1117	–8.1241
Port Jefferson	2.014728	1.075944	40.95	–73.0767	–8.1241
Bridgeport	2.054352	1.100328	41.17333	–73.1817	–8.0997
Black Rock Harbor Entrance	2.10312	1.12776	41.15008	–73.2167	–8.0722
Lloyd Harbor, Huntington Bay	2.139696	1.146048	40.91	–73.4317	–8.054
South Norwalk	2.16408	1.15824	41.09833	–73.415	–8.0418
Rowayton, Fivemile River	2.161032	1.15824	41.065	–73.445	–8.0418
Throgs Neck	2.1336	1.15824	40.805	–73.795	–8.0418
Nissequogue River Entrance	2.1336	1.15824	40.89998	–73.2332	–8.0418
Hewlett Point	2.16408	1.15824	40.83344	–73.7501	–8.0418
Saugatuck River Entrance	2.1336	1.15824	41.10008	–73.3666	–8.0418
Long Neck Point	2.185416	1.164336	41.03833	–73.48	–8.0357

Appendix, continued

Kings Point	2.182368	1.176528	40.81	–73.765	–8.0235
Oyster Bay, Cold Spring Harbor	2.215896	1.176528	40.87333	–73.47	–8.0235
Northport, Northport Bay	2.2098	1.176528	40.9	–73.3533	–8.0235
Glen Cove, Hempstead Harbor	2.215896	1.179576	40.86333	–73.655	–8.0204
Rye Beach	2.221992	1.182624	40.96167	–73.6717	–8.0174
Willets Point	2.17932	1.182624	40.79333	–73.7817	–8.0174
Stamford	2.19456	1.18872	41.03833	–73.5467	–8.0113
Cos Cob Harbor	2.19456	1.18872	41.01667	–73.5967	–8.0113
New Rochelle	2.221992	1.18872	40.89333	–73.7817	–8.0113
Oyster Bay Harbor	2.22504	1.18872	40.88333	–73.5333	–8.0113
Eatons Neck Point	2.16408	1.18872	40.95333	–73.4	–8.0113
City Island	2.19456	1.18872	40.85011	–73.7835	–8.0113
Davids Island	2.19456	1.18872	40.88337	–73.7666	–8.0113
Execution Rocks	2.22504	1.18872	40.88328	–73.7334	–8.0113
Mamaroneck	2.22504	1.18872	40.93338	–73.7334	–8.0113
Great Captain Island	2.22504	1.18872	40.98333	–73.6167	–8.0113
Greens Ledge	2.19456	1.18872	41.05	–73.4501	–8.0113
Port Washington	2.221992	1.194816	40.83167	–73.7033	–8.0052
Oyster Bay, Bayville Bridge	2.246376	1.200912	40.90333	–73.55	–7.9991
Greenwich	2.25552	1.2192	41.01669	–73.6167	–7.9808

Eelgrass Habitat Suitability Index Model User's Manual (v. 20Nov2013)

-- a revised version of the User's Manual is available with the ArcGIS files

- Eelgrass Habitat Suitability Index Model Tool (Soundwide Model Tool)
    - Identified the study area by available hydrography polygon datasets
    - Measured the suitable area by depth, tides and % light reaching the bottom in raster format (cell size 30.48 m)
    - Identify relevant and domain-wide parameters available for analysis within the study area
    - Interpolate the parameters within the area of interest
    - Weight the interpolated parameters based on ranges detailed in specific literature on scores for 0-X, which sums to a total possible score of 100.
- Eelgrass Habitat Suitability Index Sub-Model Tool (Mini Model Tool)
    - Identify the study area by available hydrography polygon datasets, aerial orthoimagery, and the location of data points to be analyzed.
    - Identify relevant parameters collected during the study and any additional parameters that may be pertinent to further analysis.
- Sea Level Rise Model Tool
    - Effects both the suitable band by depth and % Light reaching the bottom (a value determined by Kd and Depth).
    - Apply a predicted sea level rise value to the study area

Eelgrass Habitat Suitability Index Model Tool (Soundwide Model Tool)

1. Open ArcToolbox and launch the Soundwide Model Tool.
2. Enter the Output cell size value (Figure 1). The default cell size is 100 feet.

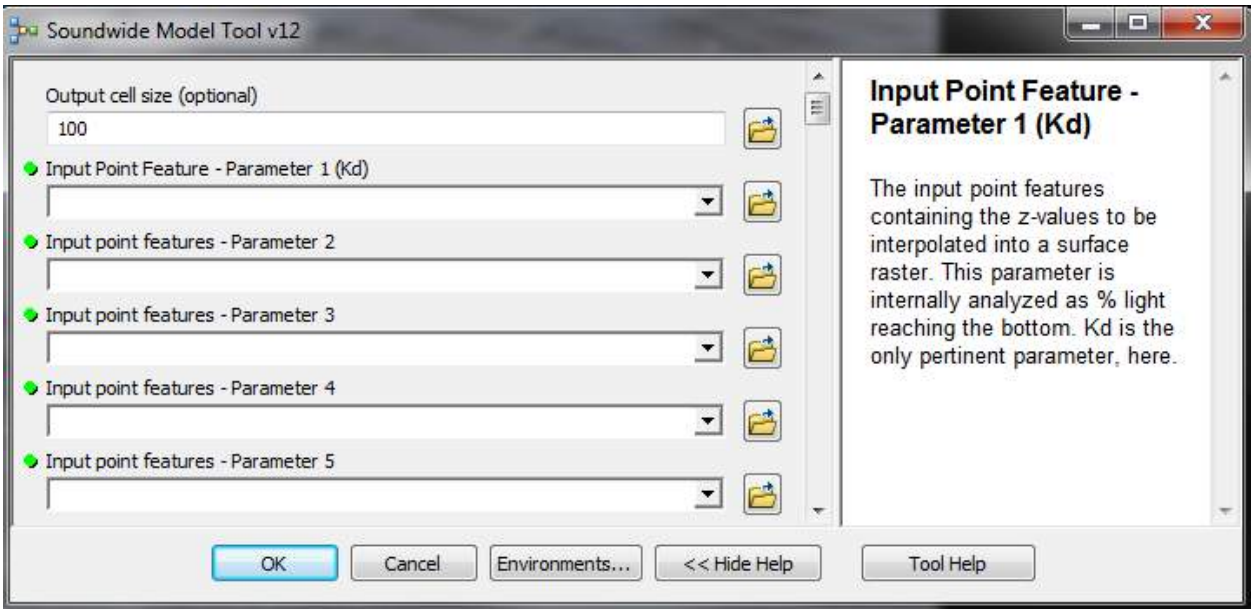

Figure 1: Output cell size and Input Point Features for parameters.

3. Enter the Input Point Feature for the 5 parameters (Figure 1). These are data points within the area of interest
    a. Parameter 1 is internally set to analyze Kd, measuring % Light Reaching the Bottom. Parameters 2-5 all run similar functions and are locked to one particular variable
4. Select a suitable search radius to be applied to the Inversed Distance Weighted interpolation. The default is Variable, 12 points (Figure 2).
    a. Visual analysis of each point feature class in ArcMap can help decide how many points are suitable to estimate the interpolated values. For instance, if points appear dense then select 6 or 8 points because more points can influence the output value. If points appear sparse or not regularly dense throughout the area of interest then estimate based on the sparsest of areas, usually 3 points so additional points that are further away are not influential on the result.

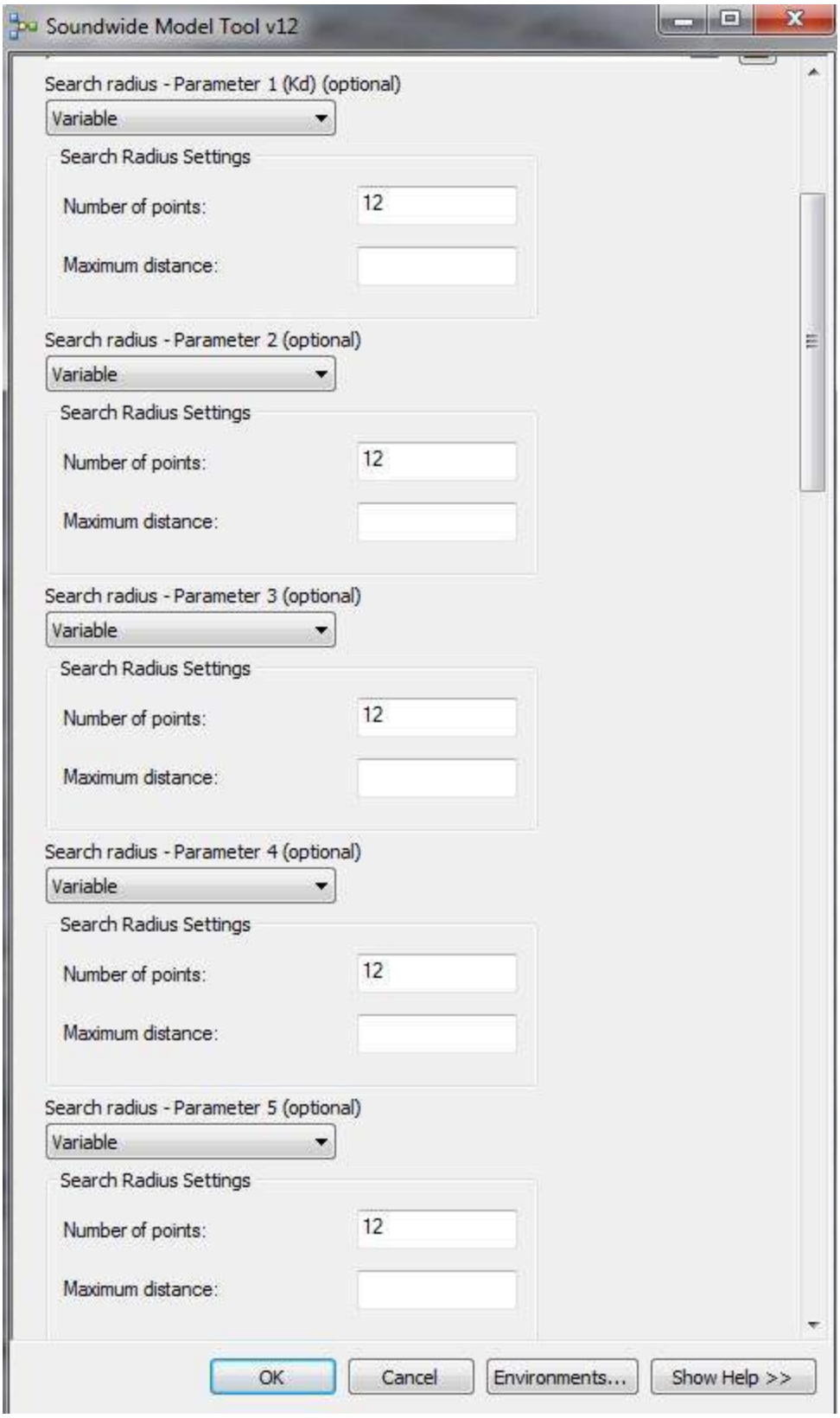

Figure 2: Search radius for IDW interpolation.

5. Select the Z value field for each parameter (Figure 3).

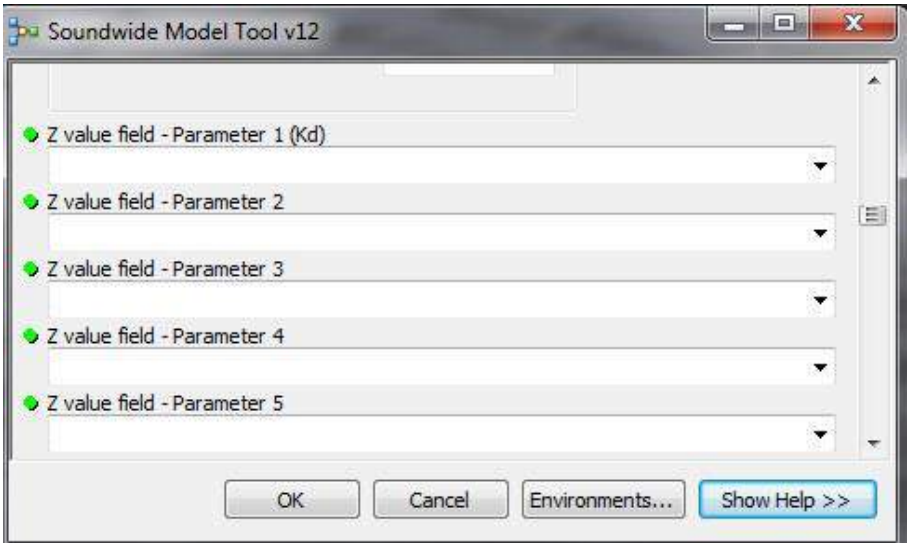

Figure 3: Z value field for IDW interpolation.

6. Enter the Soundwide IDW parameter output location and name (Figure 4).

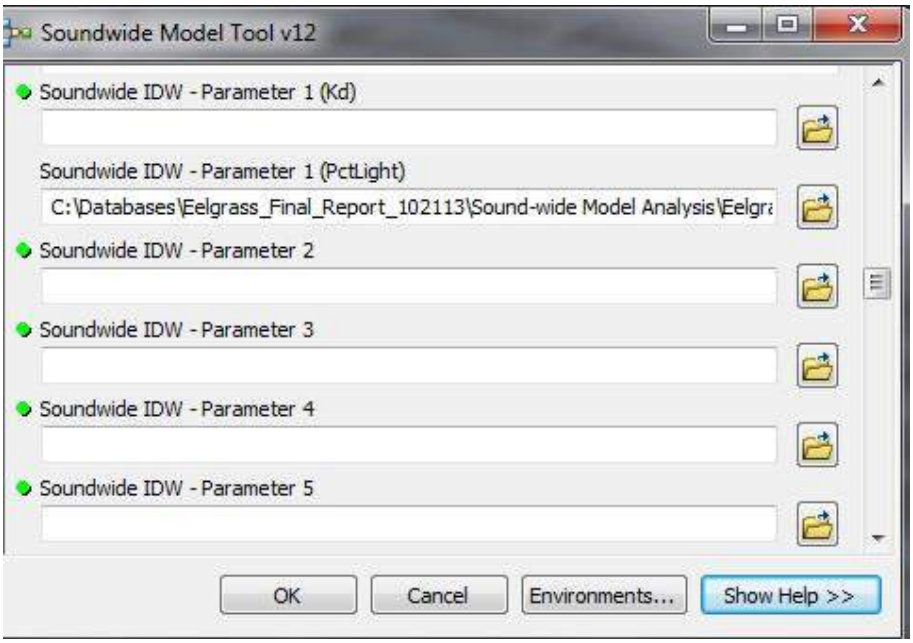

Figure 4: Soundwide IDW interpolation output path and name.

7. Load and create a Reclassification table for each parameter (Figure 5).
    a. There are several created reclassifications for each parameter available in the Model Weighting folder that can be applied from the Load… button. Reclassification tables can also be manually created or edited.

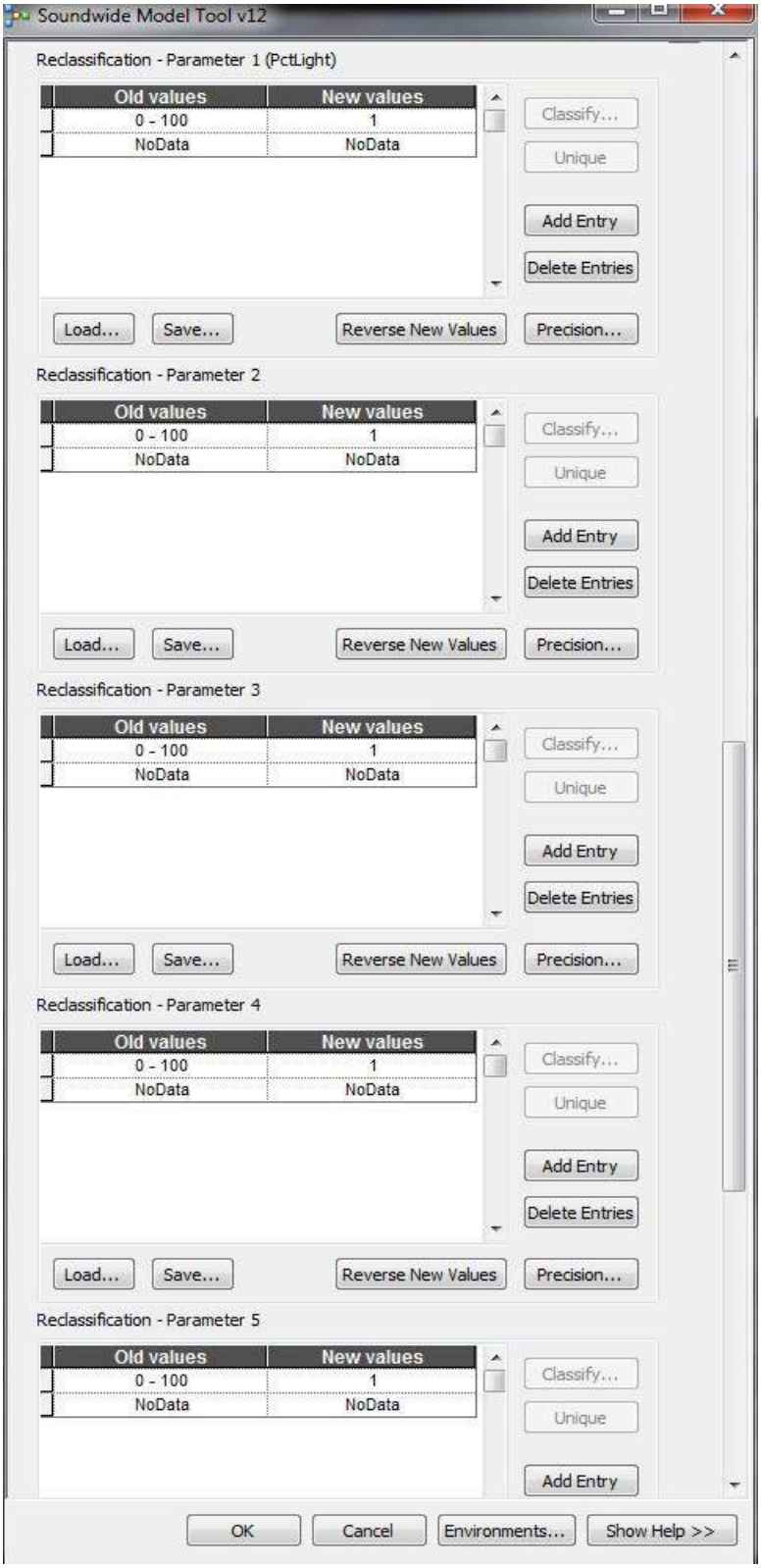

Figure 5: Reclassification tables for parameters.

8. Enter the Exclusive Band Reclass parameter output location and name (Figure 6).

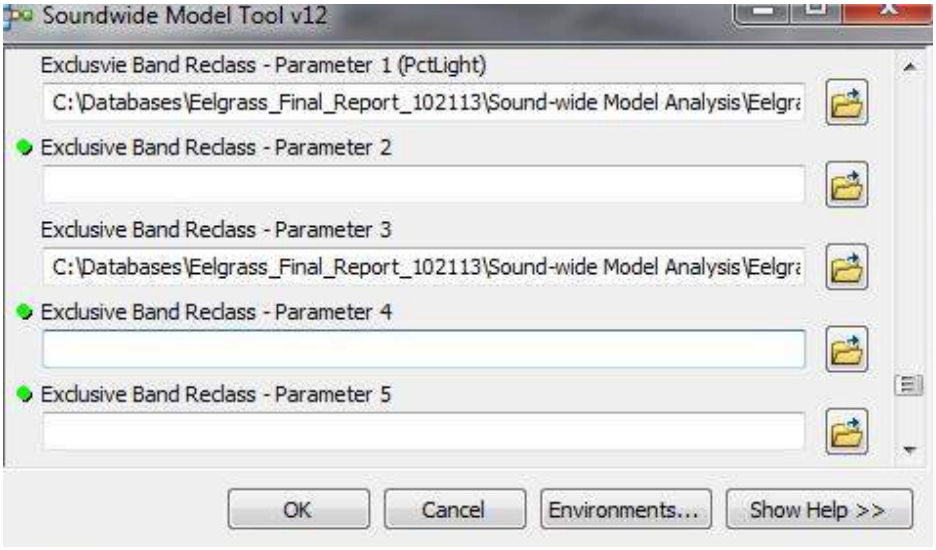

Figure 6: Reclassified parameter output path and name.

9. Select the Bathymetry Point Data feature (Figure 7).
    a. This feature is applied internally with the Kd output to calculate the % Light Reaching the Bottom. The equation applied in the tool is:

% Light Reaching the Bottom = e^(Kd * Depth)

e is the log of the natural algorithm and depth is applied in negative meters.

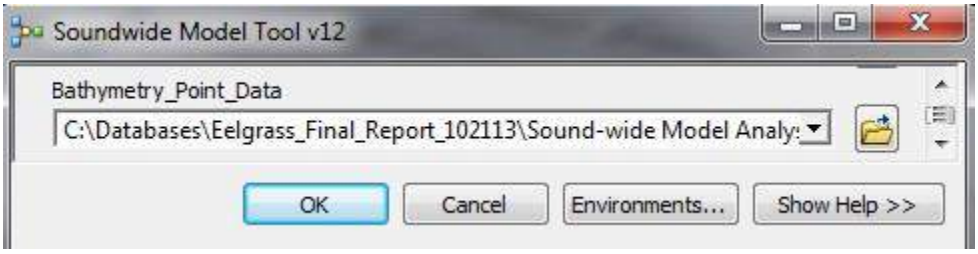

Figure 7: Bathymetry Point Data.

10. Enter the Soundwide – Sum Weighted Parameters raster calculator output location and name (Figure 8).

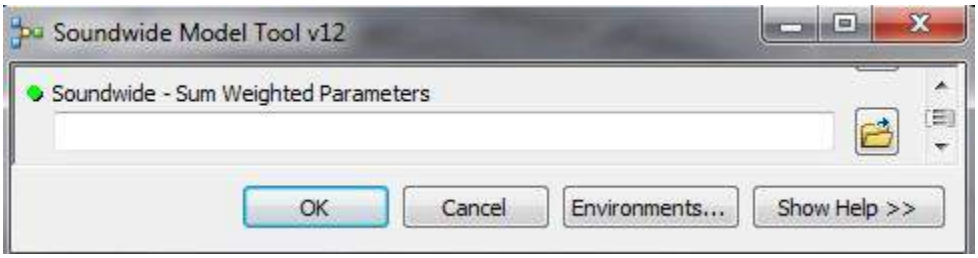

Figure 8: Raster Calculator output path and name.

11. Select the processing extent. The default is the StudyExtent022212 polygon feature (Figure 9).
    a. The polygon feature is applied as a mask clipping the processing area to only be contained within the area of interest.

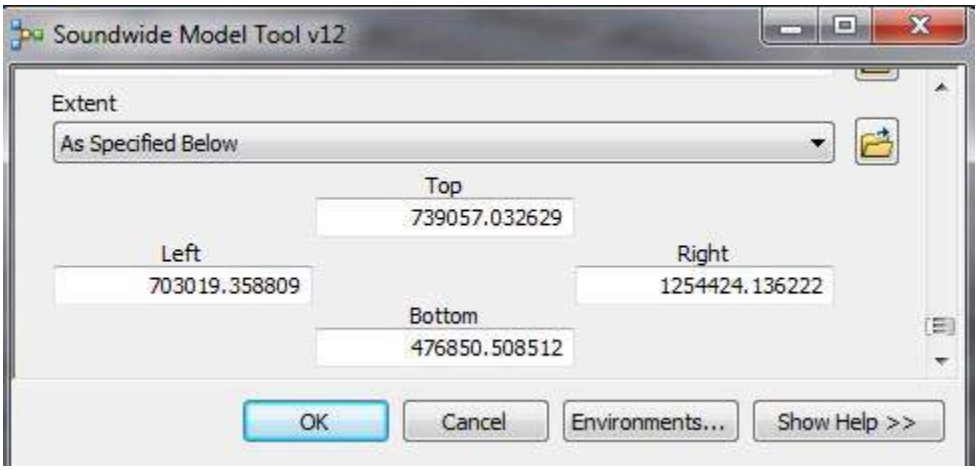

Figure 9: Environment Settings, Extent

12. Select the field that is applied to the Raster to Point tool. The default is Value (Figure 10).

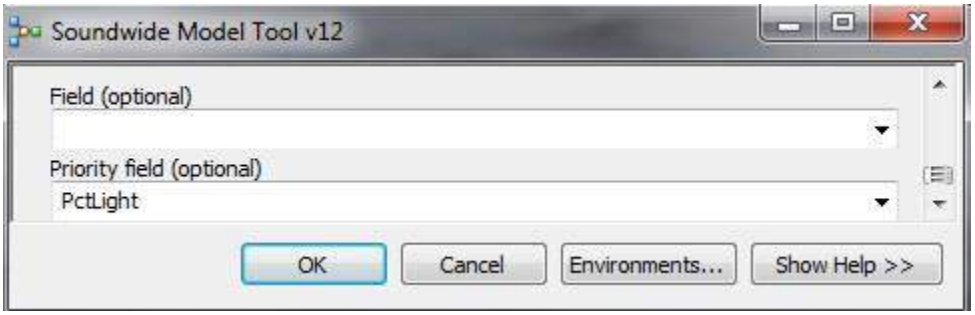

Figure 10: Field and Priority field for processing of Kd to produce % Light Reaching the Bottom outputs.

13. Select the Priority Field that is applied to the Point to Raster tool. The default is PctLight (Figure 10).
14. Check Environment Settings.
    a. Workspace: The Current Workspace and Scratch Workspace have been set to the Eelgrass_Soundwide_Model.gdb (geodatabase).
    b. Output Coordinates: Same as input.
    c. Processing Extent: the Extent is set to Default because this setting is set in the processing tool (Step 11). The Snap Raster default is the LISBathymetry022212 raster.
    d. Raster Analysis: The cell size is set to 100. The Mask is left blank.

Eelgrass Habitat Suitability Index Sub-Model (Mini Model Analysis Tool)

1. Open ArcToolbox and launch the Mini Model Analysis Tool.
2. Select the Barrier feature that will be applied to the Spline with Barrier tool and Extent environment setting for all tools. All processing will be conducted within this area of interest.
3. Enter the output Cell Size. The default is 25 feet.
4. Enter the Input point feature for the parameter.
    a. Parameter 1 is internally set to analyze Kd, measuring % Light Reaching the Bottom.
5. Select the Z-value field that will be applied to the Spline with Barrier tool.
6. Enter the Spline output location and name.
    a. Parameter 1 includes an output for Kd and % Light Reaching the Bottom (Pct Light).
7. Load or create a Reclassification table for the parameter.
    a. There are several created reclassifications for each parameter available in the Model Weighting folder that can be applied from the Load… button. Reclassification tables can also be manually created or edited.
8. Enter the parameter Reclass output location and name.
9. Repeat steps 4 through 8 for the remaining five parameters.
10. Select the Bathymetry Point Data for the area of interest.
11. Enter the Bathymetry Spline tool output location and name for the area of interest.
12. Enter the SumWeightedParameters raster calculator output location and name.
13. Check Environment Settings.
    a. Workspace: The Current Workspace and Scratch Workspace have been set to the Eelgrass_Mini-Model.gdb (geodatabase).
    b. Output Coordinates: Same as input.
    c. Processing Extent: The extent is set to Default. It may be changed the area of interest processing polygon extent, which is also applied as the Barrier in Step 2 and set to all the internal processes.
    d. Raster Analysis: The cell size is set to 25. The mask is left blank.
14. Click OK to run the tool.

Sea Level Rise Tool

QA/QC Report

The following quality assurance section of the report summarizes the measurement error estimates for the various data types collected as part of the field work associated with this project. The QA/QC associated with the collection of data for inclusion in the GIS layers for model input are addressed in the metadata associated with the GIS files, as is typical for these types of datasets. All data collected for use in *ArcGIS* followed requirements laid out in the QAPP.

Water Column Profiles

Water column profiles of temperature, salinity, and light were conducted at each station. The number of points in the vertical ranged from 2 to 22, dependent upon the depth of the station. A profile was collected at every station, with no loss of data. The meters were calibrated according to manufacturer guidelines prior to each deployment, readings in the calibration bath reflected known values.

Light profiles were conducted at all stations for all sites. In profiling mode (UCONN), a minimum of six readings in the vertical direction were collected for each of three profiles per station. Light attenuation (K_d) is calculated as the slope of the regression of a light parameter (-ln(Iz/Io)) on depth. The values from a single profile must have an $R^2 \geq 0.9$ for the estimate of K_d from the profile to be accepted; values from the Connecticut sites ranged from 0.93 to 1.0. The variability among the estimates of K_d were originally identified in the QAPP as needing to have a standard error ≤ 10% of the average for the station. While over half of the profiles met this criteria, 34% of the stations did not (Table 1). While values were variable, as discussed in Section 7.3.3.1, all standard error values were ≤ 21% of the average. Due to the importance of these values, the natural variability in the environment, the good agreement with typical values, and the still relatively low error (≤ 21%), these values were considered valid.

Table 1: Light Profile Error Values

The K_d is the light attenuation coefficient, calculated form profiles of light in the water column. Stations above 10% for standard error as a percent of the average are indicated in bold.

station ID	location	Average Kd (1/m)	StDev Kd (1/m)	Std Err / Avg	station ID	location	Average Kd (1/m)	StDev Kd (1/m)	Std Err / Avg
1	Petty's Bight, NY	0.70	0.07	4	1	Clinton Harbor	1.14	0.28	**14**
2	Petty's Bight, NY	0.86	0.15	7	2	Clinton Harbor	0.62	0.07	6
3	Petty's Bight, NY	0.60	0.31	**21**	3	Clinton Harbor	0.49	0.09	10
4	Petty's Bight, NY	0.68	0.31	**19**	4	Clinton Harbor	0.54	0.05	5
5	Petty's Bight, NY	0.60	0.21	**14**	5	Clinton Harbor	0.65	0.05	4
6	Petty's Bight, NY	0.78	0.36	**19**	6	Clinton Harbor	0.78	0.03	2
1	St. Thomas, NY	0.74	0.05	3	1	Cockenoe Island	0.58	0.03	3
2	St. Thomas, NY	0.64	0.24	**15**	2	Cockenoe Island	0.46	0.14	**18**
3	St. Thomas, NY	0.74	0.25	**14**	3	Cockenoe Island	0.57	0.02	2
4	St. Thomas, NY	0.57	0.23	**16**	4	Cockenoe Island	0.55	0.02	2
5	St. Thomas, NY	0.66	0.18	**11**	5	Cockenoe Island	0.59	0.02	2
6	St. Thomas, NY	0.65	0.21	**13**	6	Cockenoe Island	0.76	0.04	3
1	Duck Pond Point	0.56	0.11	8	2	Niantic Bay	0.40	0.02	3
2	Duck Pond Point	0.53	0.10	8	3	Niantic Bay	0.43	0.07	9
3	Duck Pond Point	0.49	0.10	8	4	Niantic Bay	0.40	0.09	**13**
4	Duck Pond Point	0.52	0.05	4	5	Niantic Bay	0.45	0.03	3
5	Duck Pond Point	1.03	0.38	**15**	6	Niantic Bay	0.45	0.03	4
6	Duck Pond Point	0.34	0.07	8	7	Niantic Bay	0.44	0.00	1
7	Duck Pond Point	0.41	0.09	9	8	Niantic Bay	0.60	0.02	2
8	Duck Pond Point	0.44	0.07	6					
9	Duck Pond Point	0.37	0.11	**12**					

Nutrients

The EPA approved QAPP for this project indicated that four stations from every site would be sampled for dissolved inorganic nutrients (ammonium, nitrate, nitrite, phosphate). At Duck Pond Point and St. Thomas Point, only three stations were sampled due to the small area of these sites compared to the other case study sites. At the time of the authoring of the QAPP, the size of the case study sites had not been determined, as those choices had to be informed by the initial GIS model. All other sites had a minimum of four stations sampled for nutrients (Petty's Bight, 4; Niantic Bay, 7; Clinton Harbor, 6; Cockenoe Island, 6).

The nutrients were analyzed on a Westco SmartChem autoanalyzer at the University of Connecticut, Avery Point campus. Methods for this instrument follow the standard methods below, with the modification of reduced sample sizes as determined by Westco for the SmartChem autoanalyzer. Analytical methods for nutrient and chlorophyll analyses:

Ammonium: SmartChem 200 Method 210-201B based on Standard Methods 4500-NH3-G [19th, 20th, and 21st Edition] and 4500-NH3-H [18th Edition].

Nitrate and Nitrite: SmartChem 200 Method 375-100E-1 based on USEPA 353.2. Revision 2.0, (1993) and Standard Methods Method 4500 NO3 F. 18th and 19th Editions.

Phosphorus (Ortho-phosphate): SmartChem 200 Method 410-3651 based on EPA 365.1 Rev. 2.0 (1993), and Standard methods 4500-P-F 18th, 19th Editions.

For each field sample, four replicates were collected. Two were analyzed and two reserved in the event reanalysis was necessary. The QAPP indicated an analytical replicate would be conducted every six field replicates analyzed. In actuality, all field replicates were analyzed in duplicate. If the relative percent difference between analytical replicates was greater than 15%, the samples were reanalyzed. The RPD of field replicates were all less than 30% or were less than ten times the method detection limit.

The practical detection limits (PDL), which is the highest value out of the method detection limit, lowest standard used for calibration, and the instrument detection limit were:

- Ammonium = 1 μM
- Nitrate = 1.2 μM
- Nitrite = 1.2 μM
- Ortho-Phosphate = 0.525 μM

As noted in Section 7.3.3.2, the nutrient concentrations in the water column are expected to be below the detection limit at a number of stations. Nitrate, nitrite, and ortho-phosphate were often below the PDL. For nitrate, sampled at surface and bottom, only 14 samples out of 29 were above the PDL. None of the 29 field samples were above the PDL for nitrite. For both ammonium and phosphate, 19 of the 29 samples were above the PDL.

The efficiency of nitrate conversion to nitrite was 104.30% and 99.84% for the two lab analysis days.

For nutrient analyses, certified reference material and a blank were analyzed periodically in each queue. An RPD from the certified reference concentration of more than 10% requires further investigation of the run. A difference greater than 15% results in a failure (unless the average of the two samples is less than 10 times the method detection limit). The results for the reference material are provided in Table 2, all sample runs passed the requirements for RPD of the standard reference material.

Laboratory fortified matrix samples (field sample with a reference material spike) were also used to assess the accuracy and bias of the nutrient analyses. Acceptable recoveries were in the range of 85% ≤ recovery ≤ 115%. Recoveries on samples which were below the PDL were not included in the calculation of statistics on recoveries. Recoveries for spiked ammonium analyses ranged from 105.1% to 116.1% with an average of 111.1.0%. Recoveries for spiked phosphate analyses ranged from 89.8% to 118.1% with an average of 103.1%. One phosphate spiked sample had a recovery of 122% and was eliminated from the analysis, it occurred mid-run. Both nitrate and nitrite field samples which were spiked were all under the PDL of 1.2 μM. Recoveries ranged from 128% to 140% for nitrate and nitrite. The fact that recoveries were higher support that the samples were below the detection limit. The

expected value for these samples was unknown as the sample concentration was not accurate, hence the large recoveries.

Table 2: Quality Checks on the Standard Reference Materials for Nutrient Analysis
Values are shown by sample analysis day, the name of the .xlsx file in the heading identifies each run.

Ammonium	01312013_recalculated.xlsx	020613_recalc_samples.xlsx
µM of Standard, known	5	2.5
µM of Standard +/- Std Dev, as sampled	5.53 ± 0.56	2.88 ± 0.66
µM difference of known and actual	0.53	0.38
RPD of standard relative to the actual concentration	10.05	14.03
µM MDL	1.00	1.00
%, maximum allowable RPD	15	15
RPD = OK, Not OK, <10x MDL	OK	OK
Nitrate	021913_NO3_samples.xlsx	022013_NO3_samples.xlsx
µM of Standard, known	12.5	3
µM of Standard +/- Std Dev, as sampled	7.47 ± 1.84	3.18 ± 0.73
µM difference of known and actual	5.03	0.18
RPD of standard relative to the actual concentration	50.38	5.80
µM MDL	1.00	1.00
%, maximum allowable RPD	15	15
RPD = OK, Not OK, <10x MDL	<10x MDL	OK
Nitrite	021913_NO2_samples.xlsx	022013_NO2_samples.xlsx
µM of Standard, known	12.5	3
µM of Standard +/- Std Dev, as sampled	12.43 ± 0.1	3.07 ± 0.01
µM difference of known and actual	0.07	0.07
RPD of standard relative to the actual concentration	0.58	2.18
µM MDL	1.00	1.00
%, maximum allowable RPD	15	15
RPD = OK, Not OK, <10x MDL	OK	OK
PHOSPHATE	010713_recalc_samples.xlsx	010813_sample.xlsx
µM of Standard, known	2.625	2.625
µM of Standard +/- Std Dev, as sampled	2.6 ± 0	2.6 ± 0
µM difference of known and actual	0.02	0.02
RPD of standard relative to the actual concentration	1.90	1.90
µM MDL	0.16	0.16
%, maximum allowable RPD	15	15
RPD = OK, Not OK, <10x MDL	OK	OK

Benthic Characteristics

A video camera or still camera was used to capture images of the bottom in order to estimate coverage by bare sediment, macroalgae, and eelgrass. The camera images were analyzed by three different technicians for percent cover. The three estimates agreed within a relative percent difference of 5% or the analysis was re-run.

Percent cover of the benthos is variable in some stations, for example, 43 bottom images collected in Niantic Bay exhibited an average coverage roughly equally divided between the three categories (bare sediment, eelgrass, macroalgae) with standard deviations as large as the percentages (e.g. macroalgae: 30.7 % ± 30.6 %). Due to this high variability at some stations, biomass estimates collected via a grab are known to under sample the area. Variability in the grab samples was not calculated, these samples were used primarily to identify and sample dominant macrophytes and sediment.

For each sediment sample, sediment organic content and sediment grain size were analyzed in triplicate. The relative percent difference (RPD) among the three replicates was less than 30%. If RPD was greater, the samples were reanalyzed in triplicate. When samples did not agree within 30%, it was usually due to variability in the gravel and sand fractions. Photos of sediment samples were logged to verify that samples were truly variable due to large grain sizes. For the silt and clay fraction, which were used in the model, samples always agreed within an RPD of 40% except for one sample with large gravel and shells (Petty's Bight, station 4). Sediment organic content was also affected by the presences of gravel and shells, in some cases exhibiting RPDs of 39% to 97% at five of the 29 stations. In all cases, the samples were re-run and the photos were examined to confirm that larger grain sizes were the source of the problem. The choice of RPD of 30% for sediment grain size and sediment organic content in the QAPP was too restrictive. A more realistic expectation is 70%, as used in other EPA approved QAPPs.