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

Long Island Sound, USA - A ‘Sound-Wide’ Model

By

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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).

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[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 effect of nutrients available in the water column can influence algal blooms.
Total Dissolved Phosphorous	The effect 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).

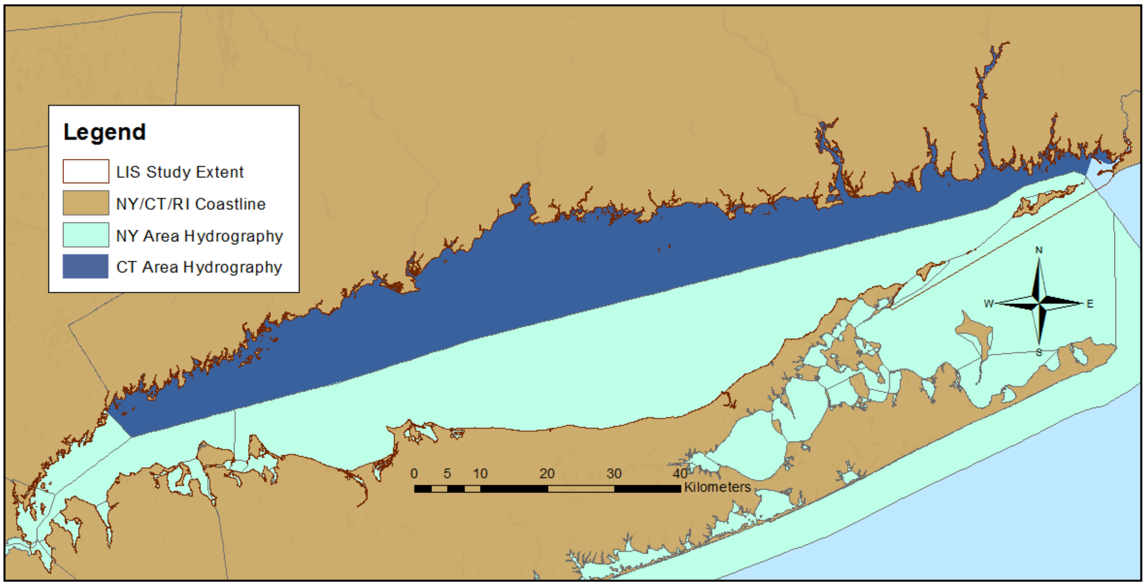


Figure 1: New York and Connecticut Area Hydrography - Area hydrography polygons displayed in GIS. The polygons were selected and merged to create the Long Island Sound study extent.

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.

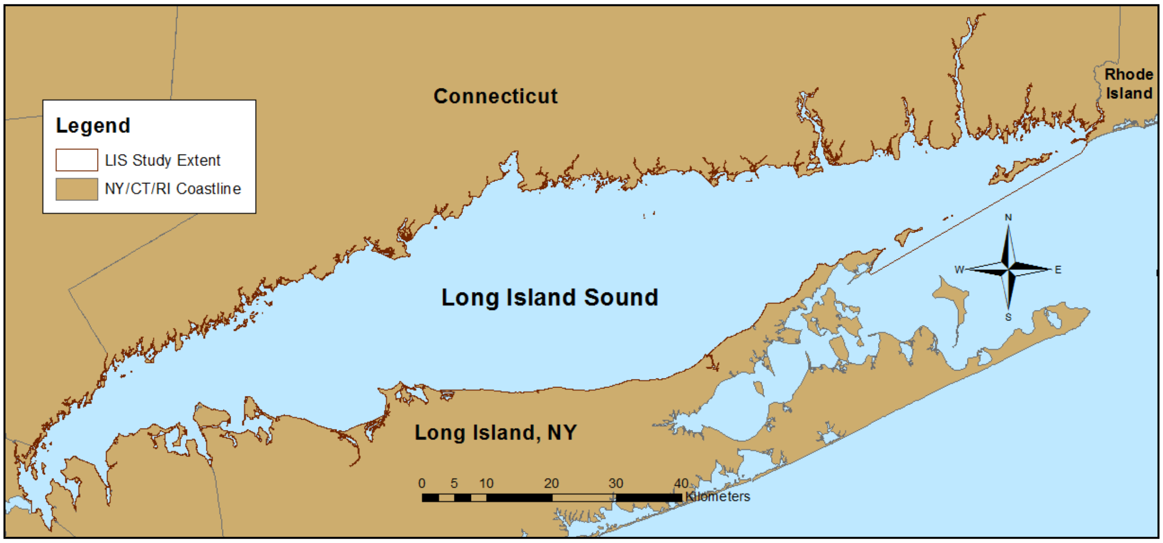


Figure 3: Study Extent for Long Island Sound - Data in the form of polygons was displayed from NYS and CT Area Hydrography and merged.

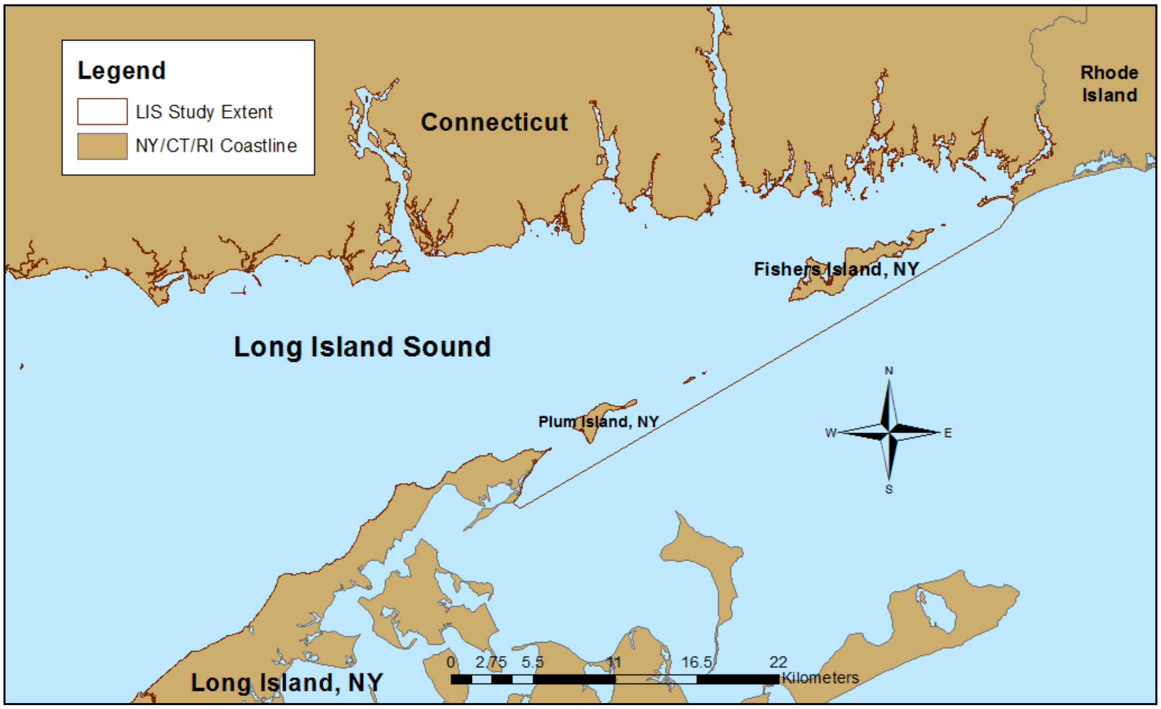


Figure 4: Mouth of LIS to the Atlantic Ocean - Study Extent is extended here to encompass all shorelines of the nearby islands including Fishers and Plum Islands.

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).

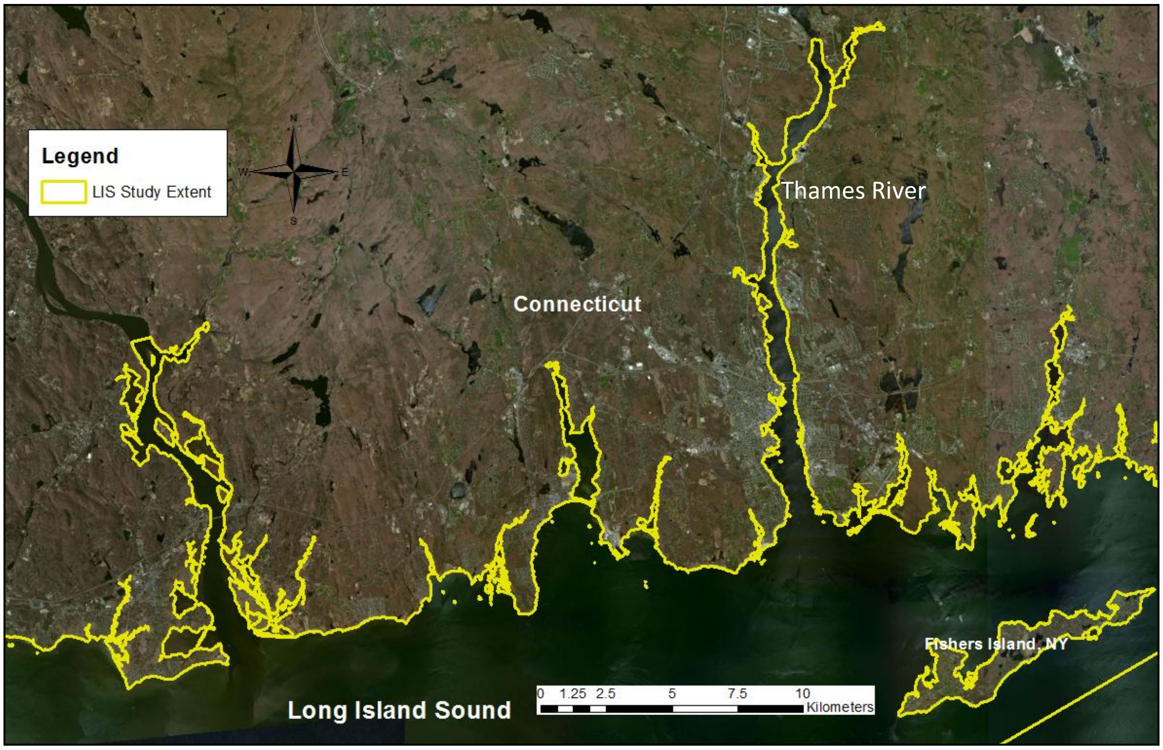


Figure 5: Study Extent and River Connections - The connecting rivers from Connecticut to Long Island Sound, Connecticut River and Thames River, were assessed and end points of the two waterways were identified and manually extended from the Sound.

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.

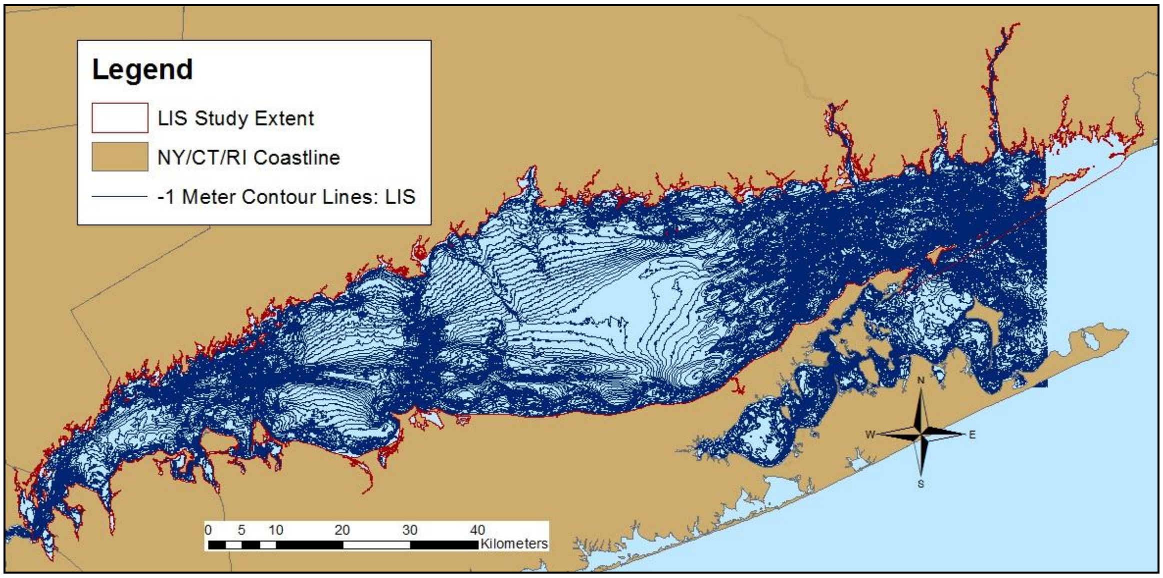


Figure 6: –1 m Contour Lines for Long Island Sound (LISRC, 2012) - The contour lines range from 0 to -98 meters depth and extend only as far as Fishers Island, though the study extent clearly extends further.

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).

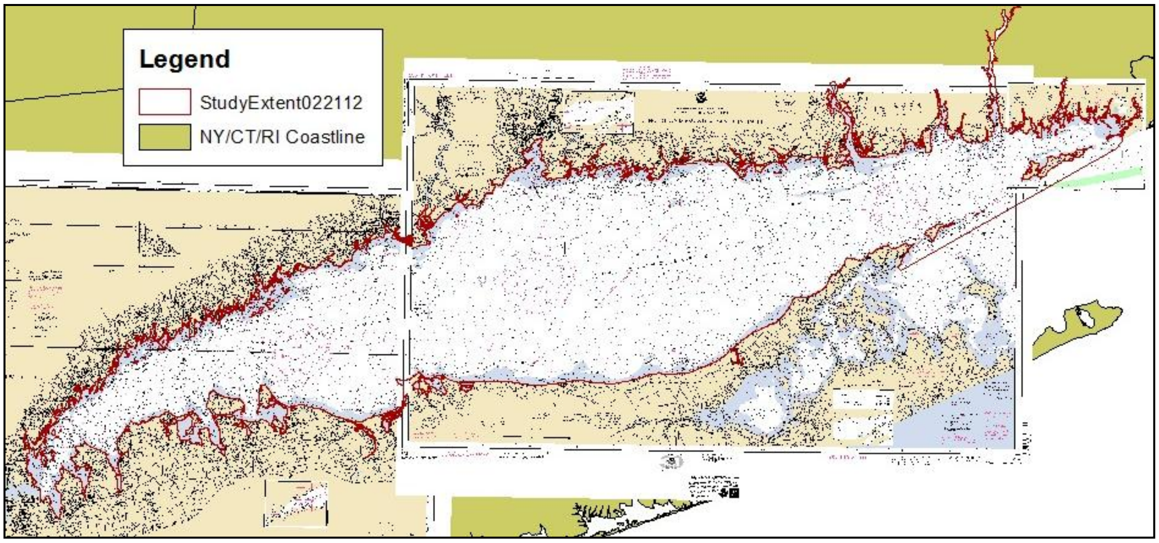


Figure 7: NOAA Raster Nautical Charts – Charts were downloaded and imported to GIS to fill depth values in areas that are exempt of depth data in the –1 m contour lines.

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)

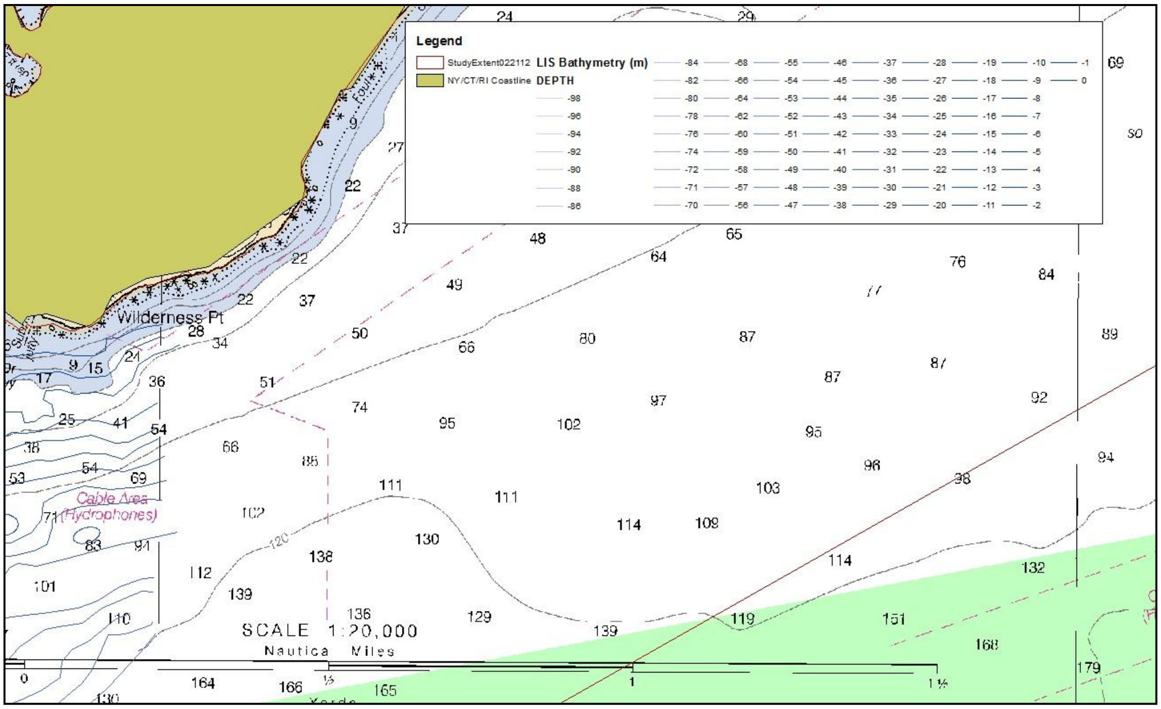


Figure 8: –1 m Contour Lines and Raster Nautical Chart - A zoomed in display of the contour lines extent just south of Fishers Island on the left and the RNC depth values (in feet) which were manually compiled as point data at each depth value location.

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).

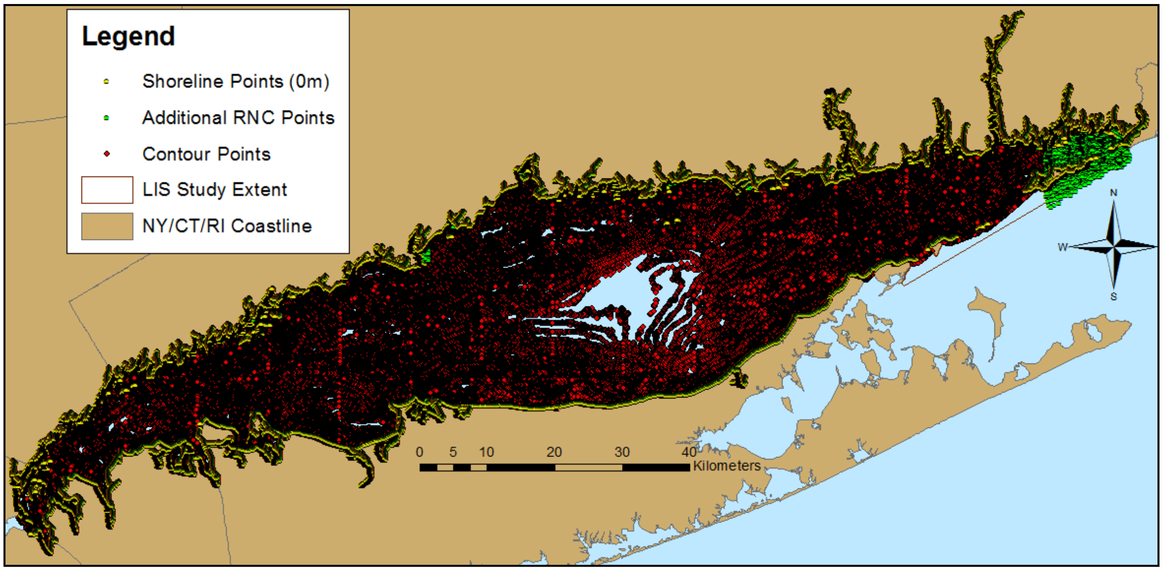


Figure 9: Bathymetry Point Datasets - Contour vertices, RNC digitized points, and shoreline vertices before interpolation with the IDW tool.

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).

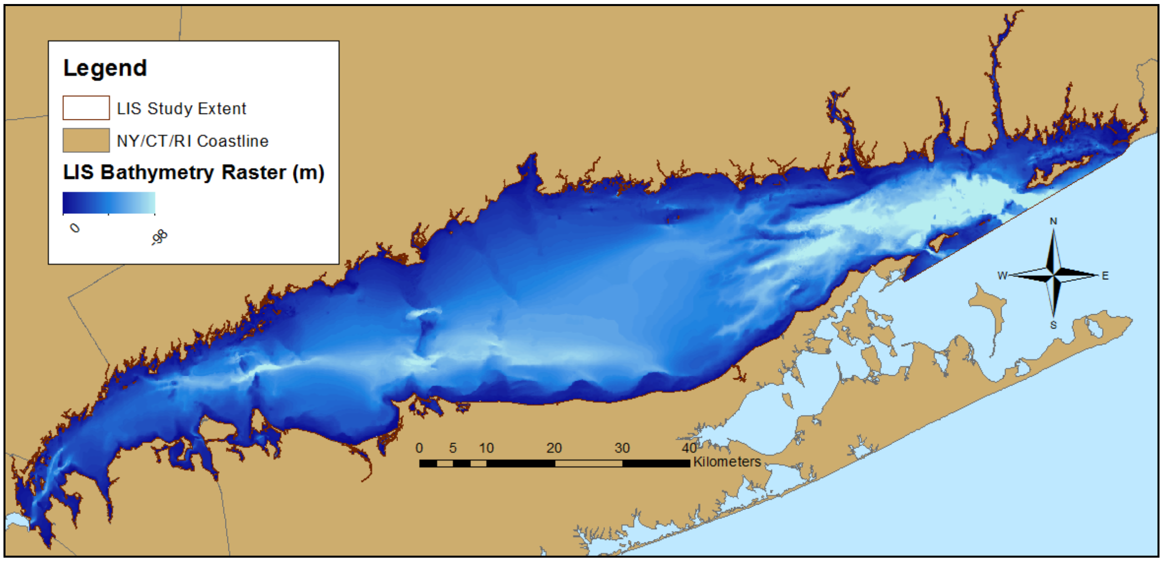


Figure 10: Long Island Sound Bathymetry Raster - The output bathymetry raster for the Long Island Sound study extent. The depth ranged from 0 to –98 meters.

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).

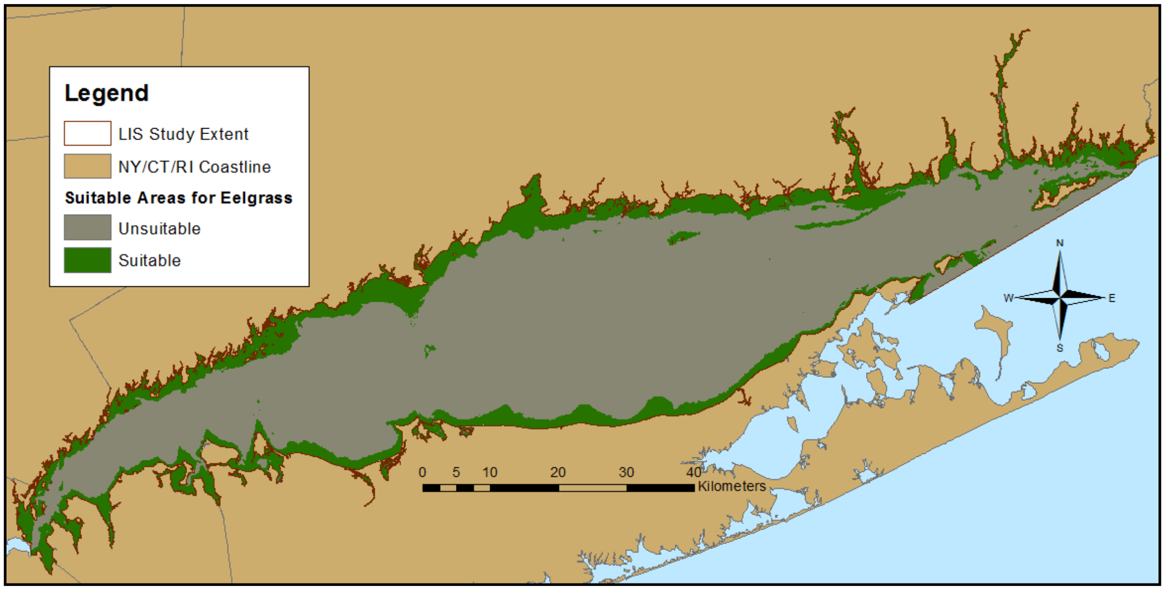


Figure 11: Suitable Band for Eelgrass by Depth - The division between areas where eelgrass can survive and areas that are too deep for eelgrass even if all environmental parameters are ideal

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).

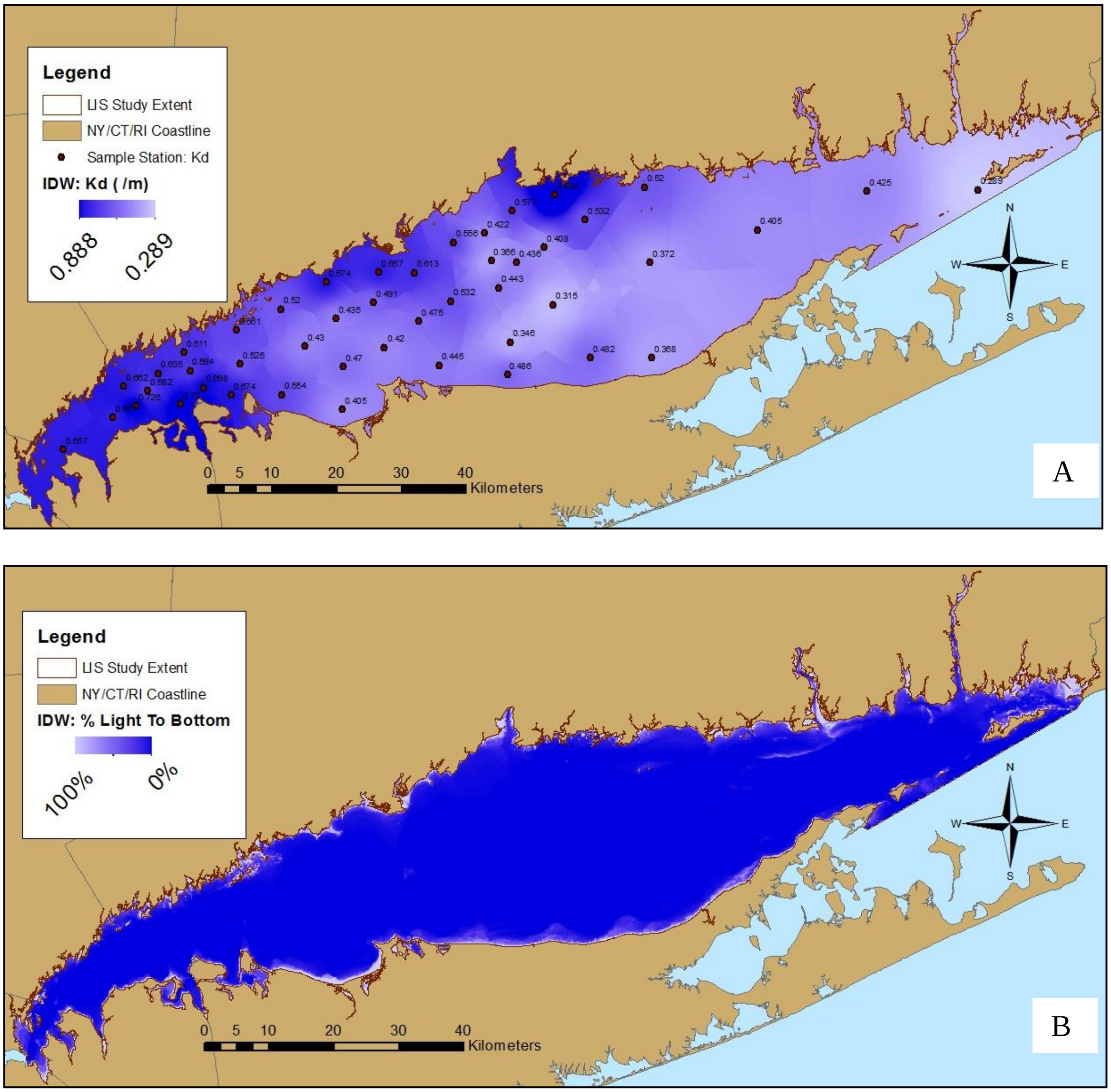


Figure 12: Interpolated Kd and Percent Light Reaching Bottom Raster - A. Kd values are estimated throughout LIS using the IDW tool and the average Kd value at each station during the growing season. B. Once processed, the Percent light reaching bottom was returned as a raster from a point feature class.

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).

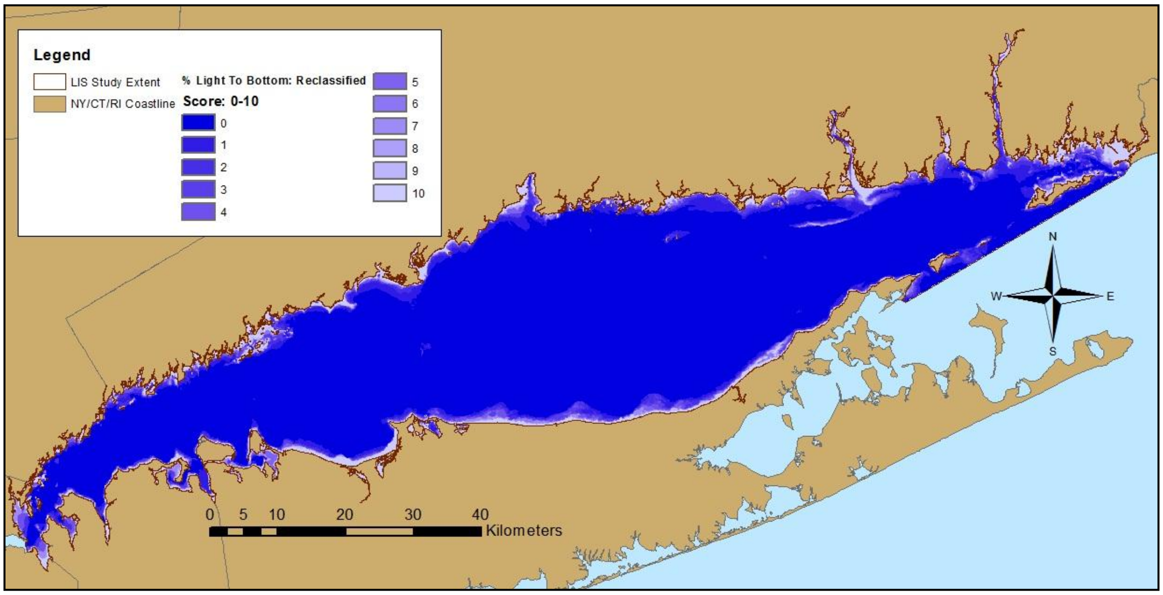


Figure 13: Percent Light Reaching Bottom Reclassified Raster - Percent light reaching the bottom is reclassified with a score from 0 to 10.

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).

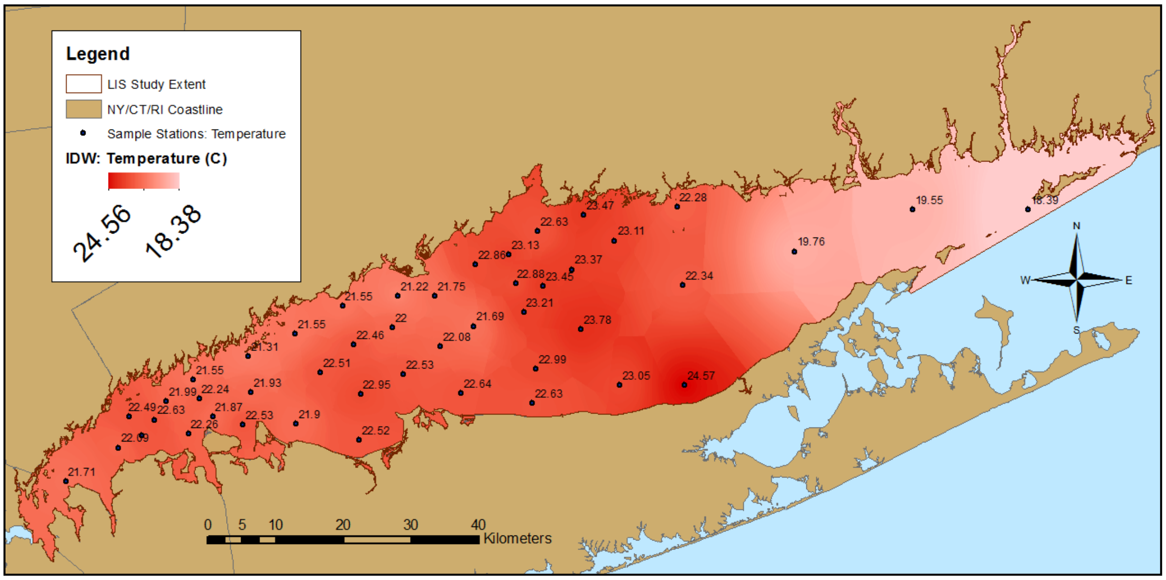


Figure 14: Interpolated Surface Temperature Raster - Surface temperature averaging the last meter of data in July and August, 2009 to 2011 and interpolated using the IDW tool.

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).

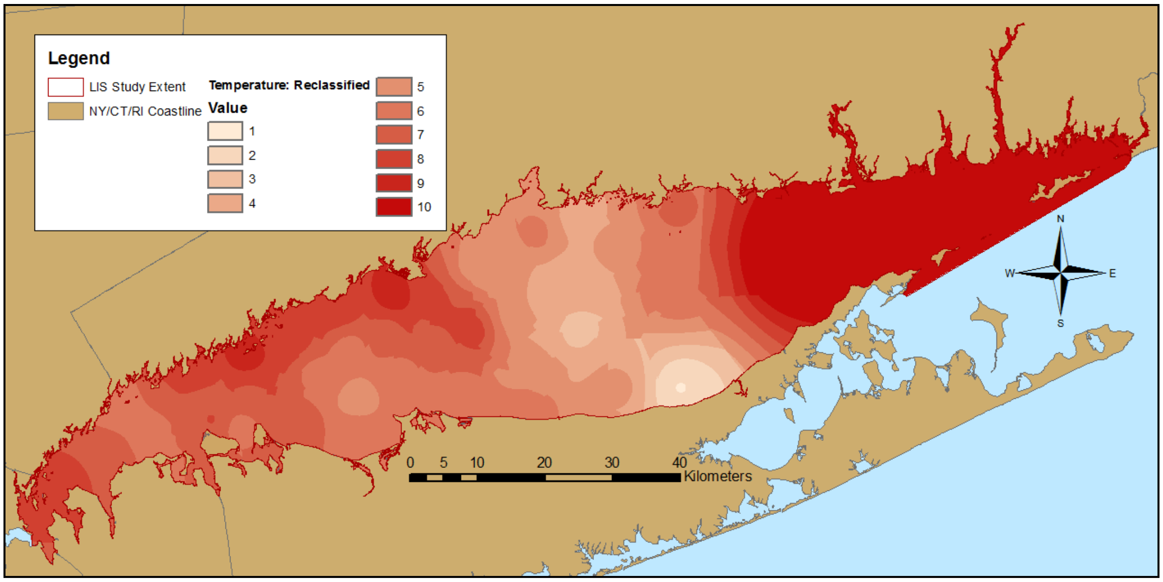


Figure 15: Surface Temperature Reclassified Raster - Surface temperature is reclassified with a score from 0 to 10.

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)

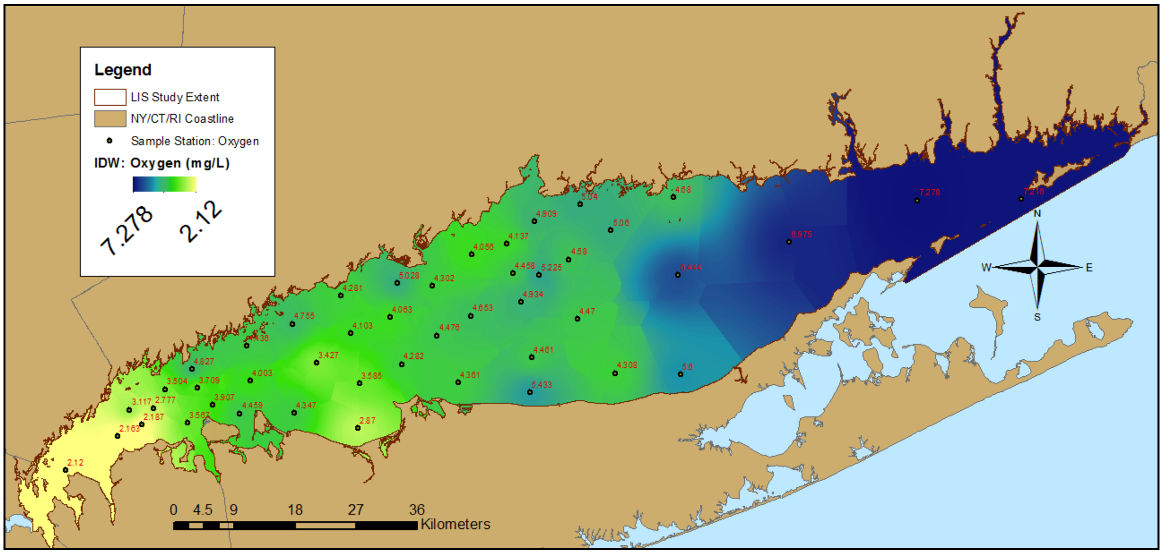


Figure 16: Low O_2 Interpolated Raster - Dissolved oxygen levels averaged at each mean center station for 2009 to 2011 and interpolated to estimate the values throughout LIS using the IDW interpolation tool. 46 stations were analyzed for dissolved oxygen.

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).

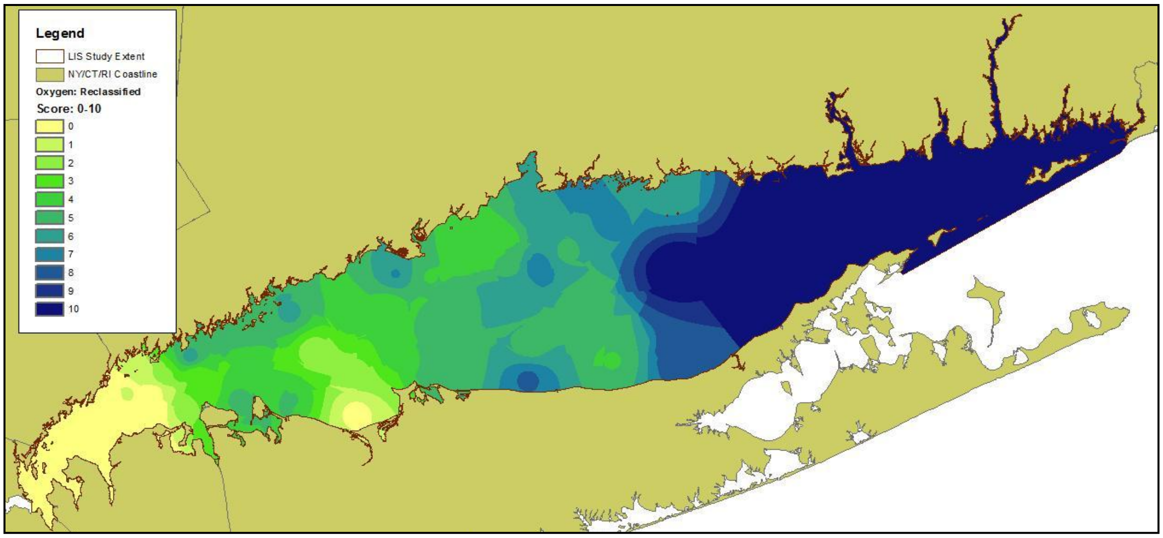


Figure 17: Low O2 Reclassified Raster - Low O2 is reclassified with the score from 0 to 10.

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).

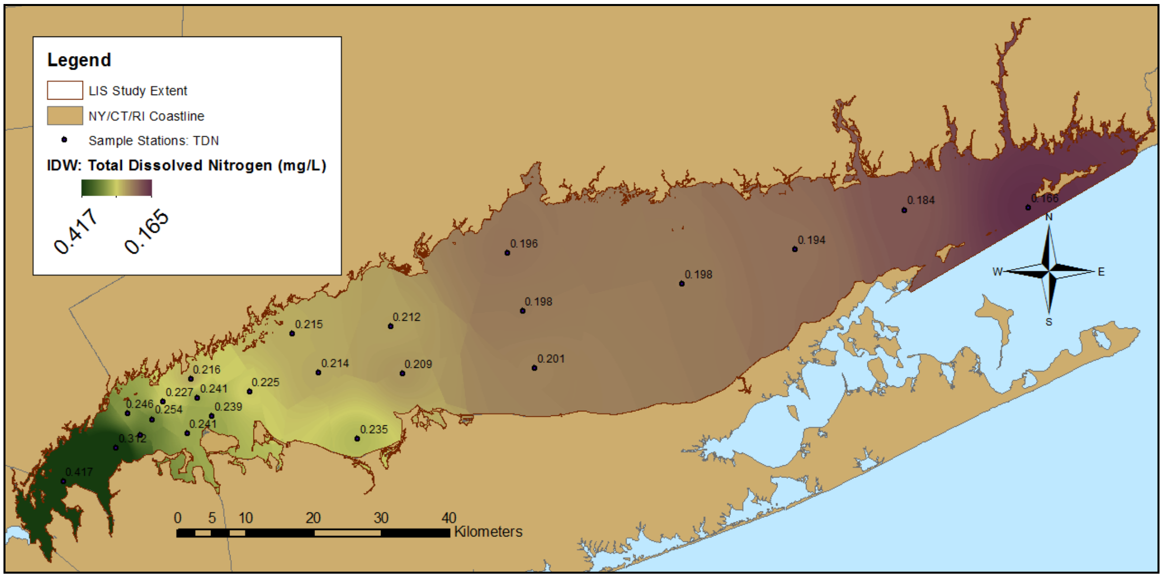


Figure 18: Total Dissolved Nitrogen Interpolated Raster - TDN averaged at each mean center station for 2009 to 2011 and interpolated to estimate the values throughout LIS using the IDW tool. 23 stations were analyzed for TDN.

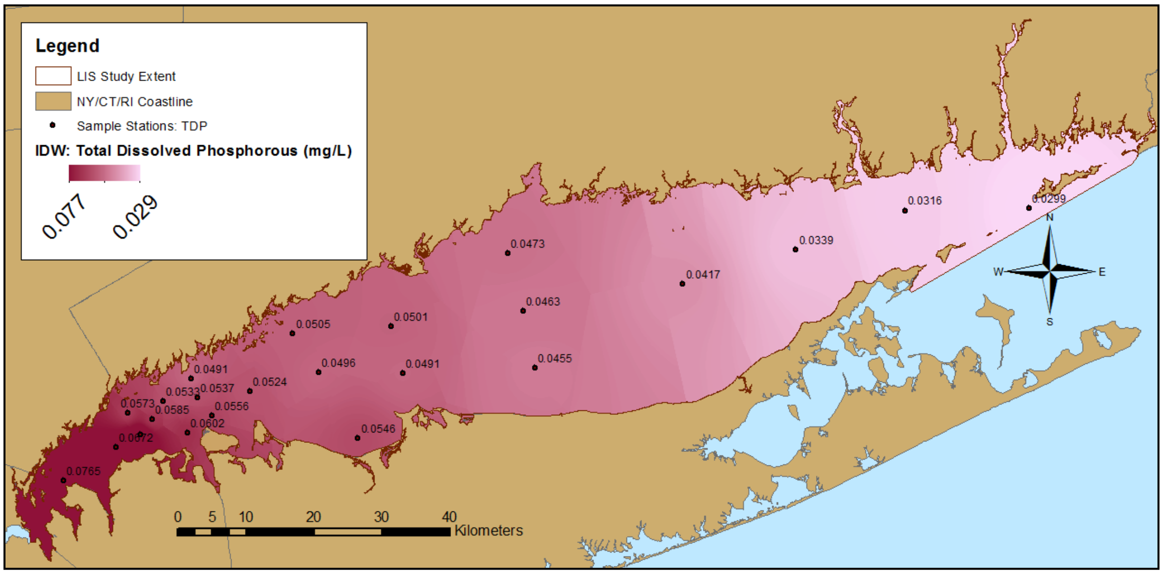


Figure 19: Total Dissolved Phosphorous Interpolated Raster - TDP averaged at each mean center station for 2009 to 2011 and interpolated to estimate the values throughout LIS using the IDW tool. 23 stations were analyzed for TDP.

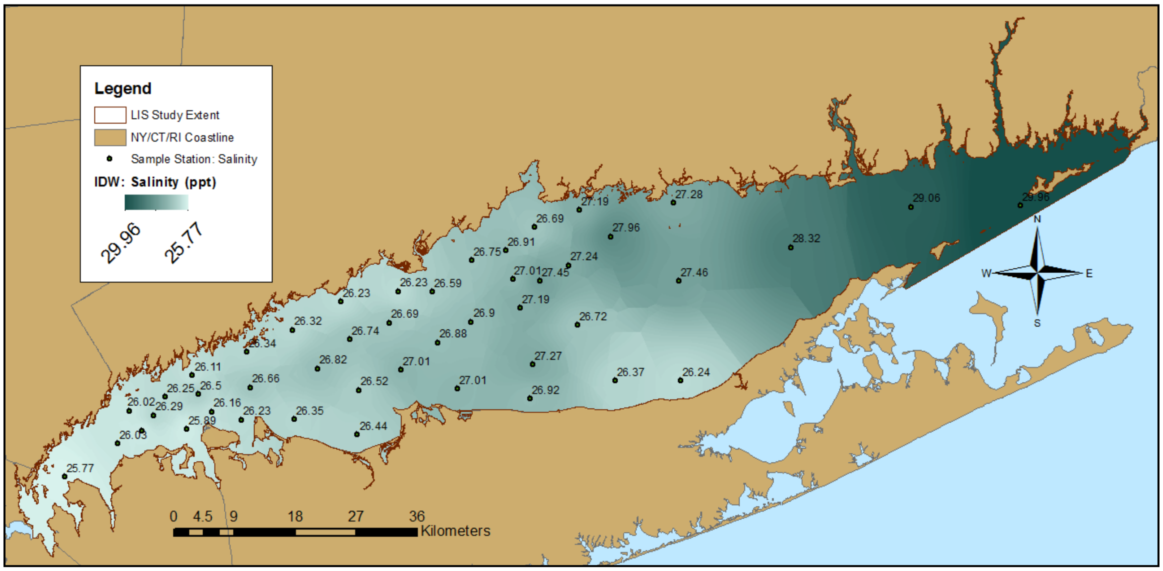


Figure 20: Salinity Interpolated Raster - Salinity average at mean center station from 2009 to 2011, year round and interpolated using the IDW tool. 46 Stations were analyzed for salinity.

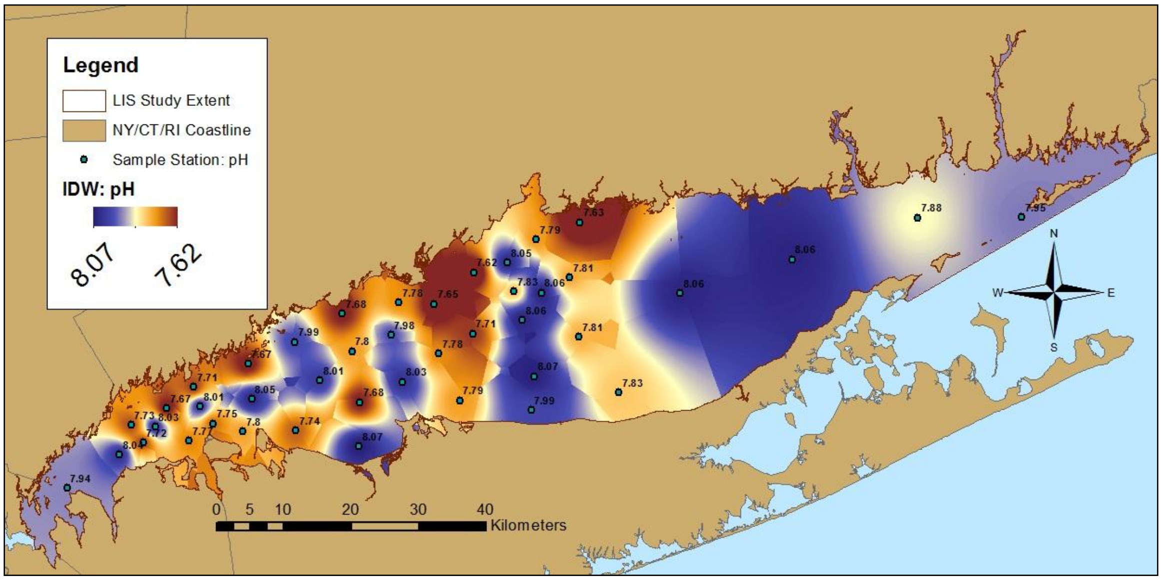


Figure 21: pH Interpolated Raster - pH averaged at each mean center station from the 2009 to 2011 year round data and interpolated using the IDW tool. 43 Stations were analyzed for pH.

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).

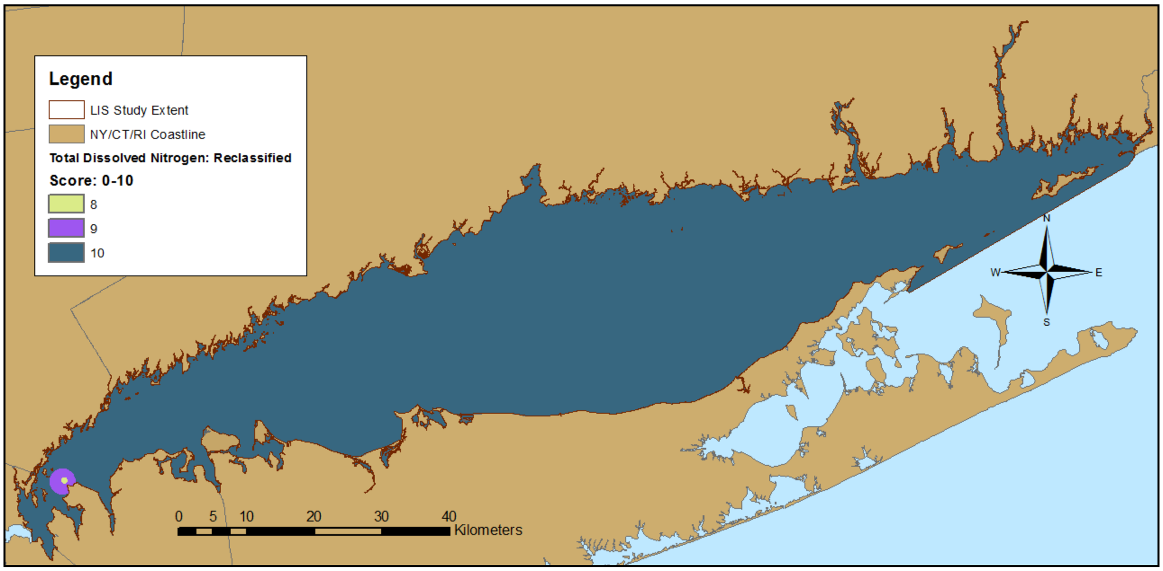


Figure 22: Total Dissolved Nitrogen Reclassified Raster - TDN is reclassified with the score from 0 to 10.

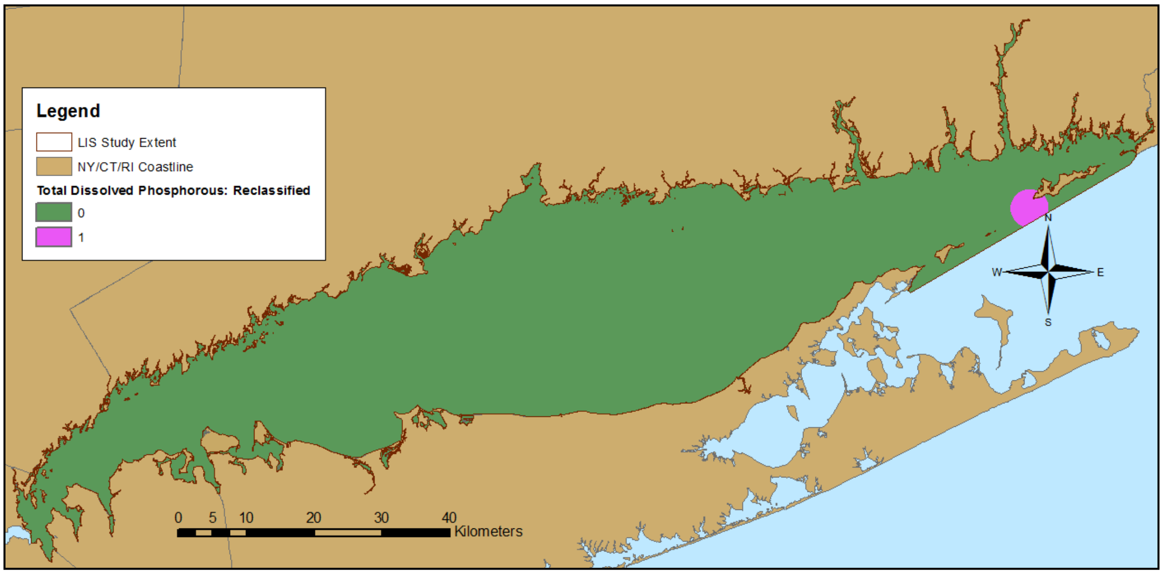


Figure 23: Total Dissolved Phosphorous Reclassified Raster - TDP is reclassified with the score from 0 to 10. TDP is included in the Chesapeake Bay based submerged aquatic vegetation parameter ranges to account for the freshwater and brackish water species. It does not really apply for LIS, which is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

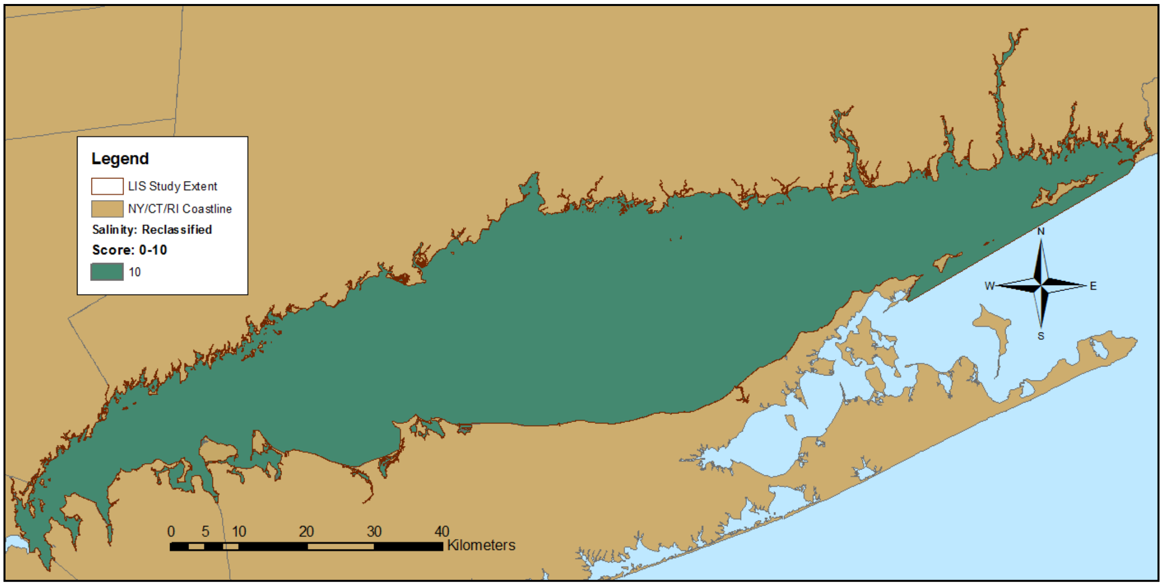


Figure 24: Salinity Reclassified Raster - Salinity is reclassified with the score from 0 to 10. Salinity range does not exceed the maximum threshold of 10ppt at any station in LIS.

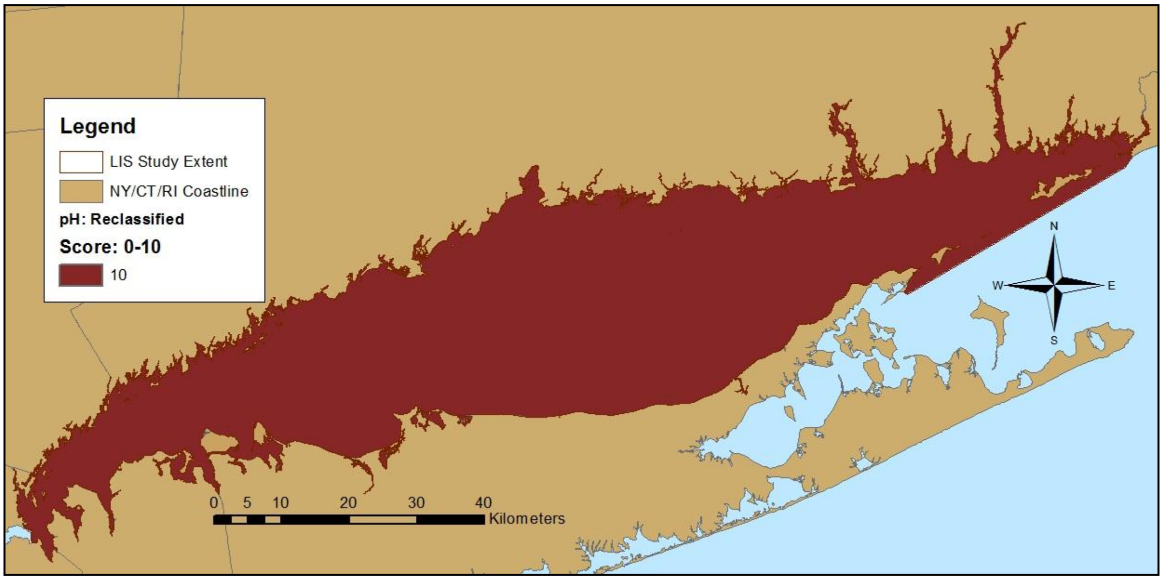


Figure 25: pH Reclassified Raster - pH is reclassified with the score from 0 to 10. pH does not exceed the maximum threshold of 8.8 at any station in LIS.

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).

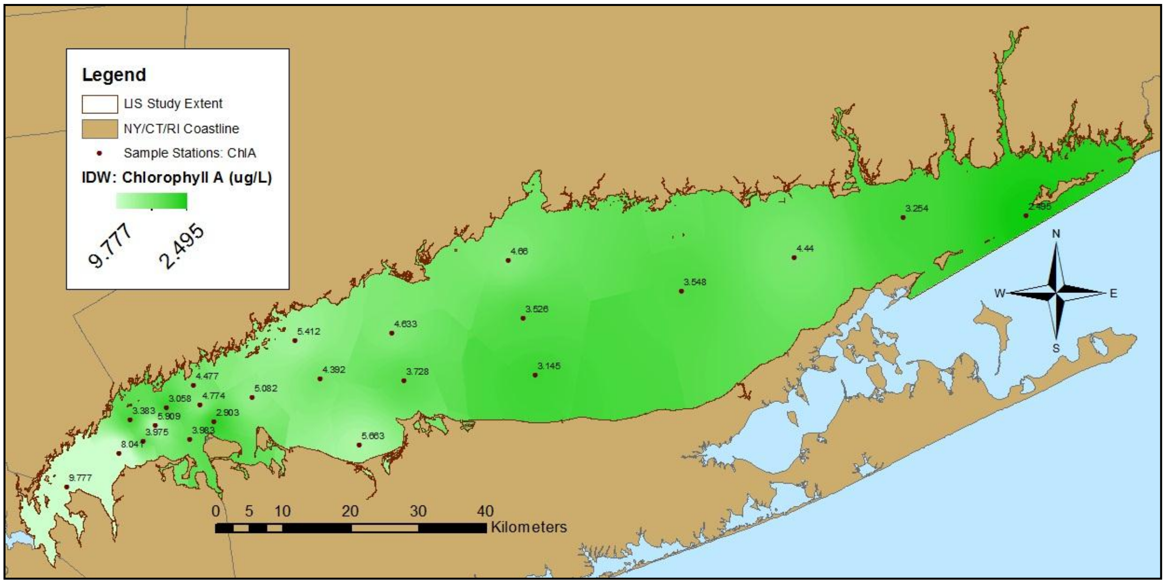


Figure 26: Chlorophyll *a* Interpolated Raster - Chlorophyll *a* values at 23 stations throughout LIS averaged data from 2009 to 2011 growing season and produced estimates using the IDW interpolation tool. 23 Stations were analyzed for Chlorophyll *a*.

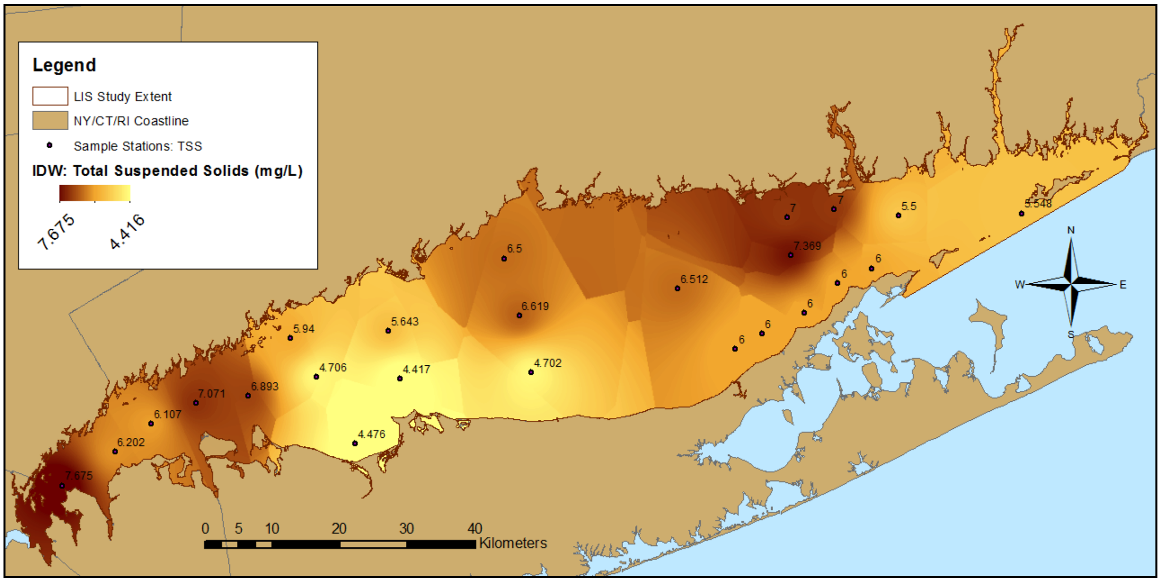


Figure 27: Total Suspended Solids Interpolated Raster - Total Suspended Solids averaged at 17 mean center stations during the growing season, 2009 to 2011. Data were interpolated using the IDW tool. 24 Stations were analyzed for Total Suspended Solids.

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).

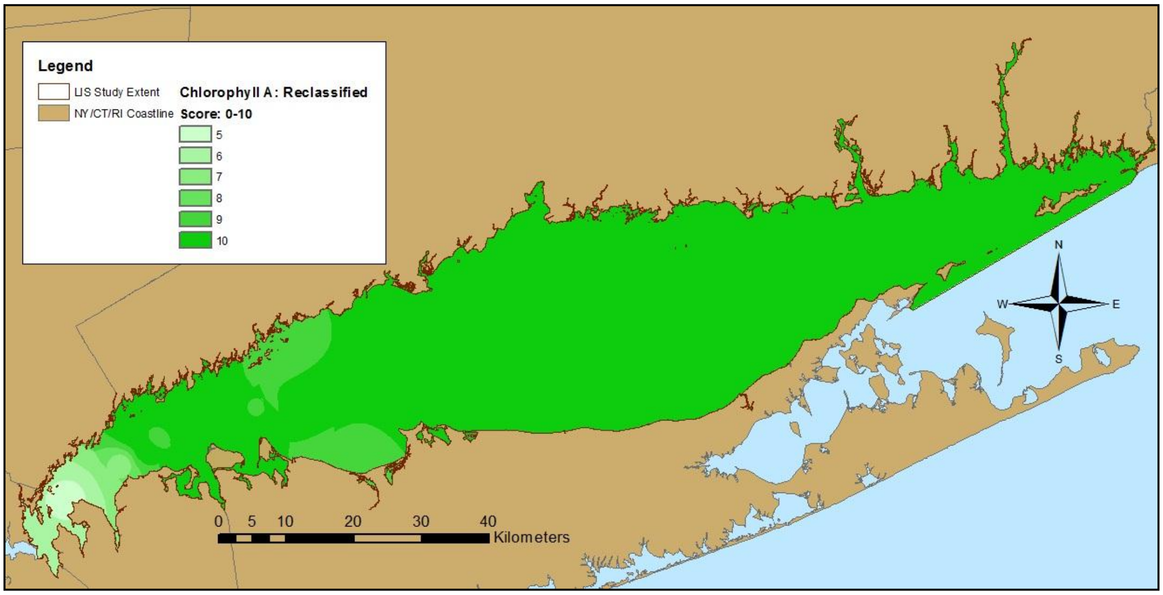


Figure 28: Chlorophyll *a* Reclassified Raster - Chlorophyll *a* reclassified raster with a ranked score from 0 to 10.

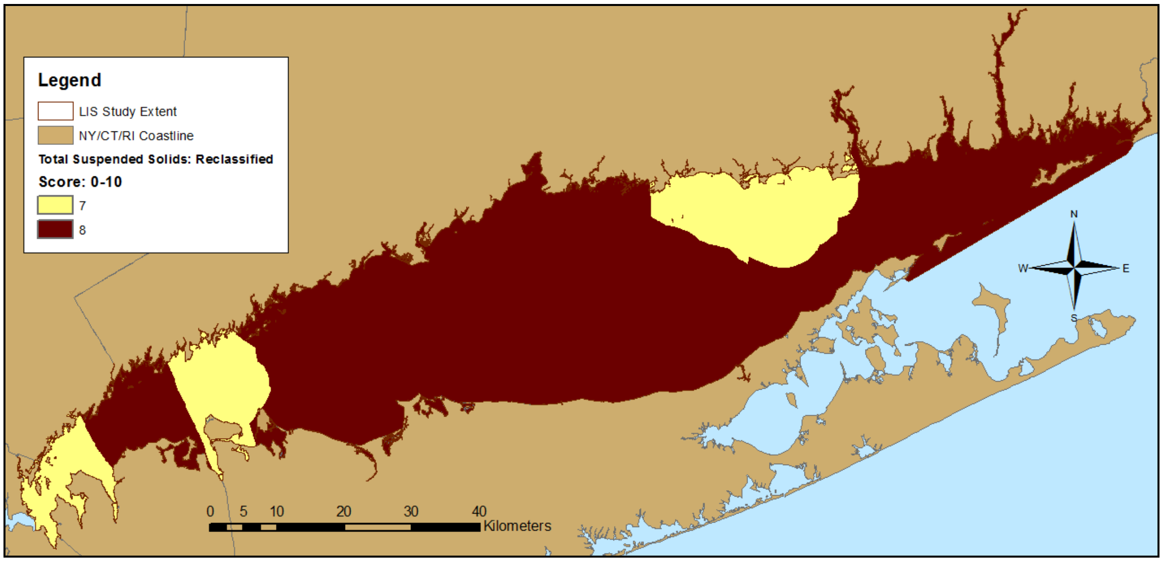


Figure 29: Total Suspended Solids Reclassified Raster - Total suspended solids is reclassified with a ranked score from 0 to 10.

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).

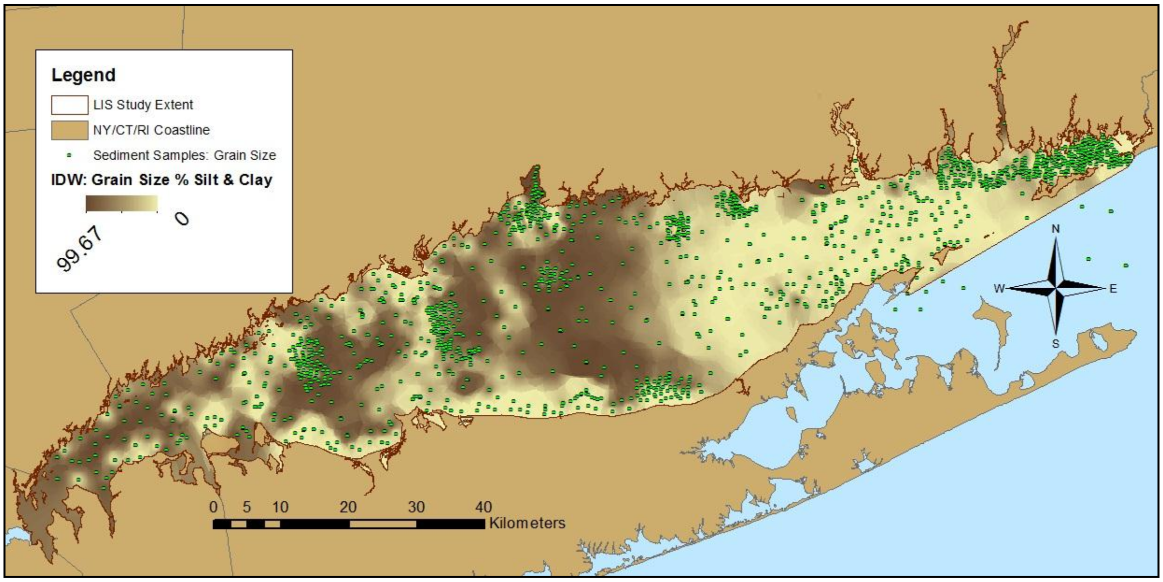


Figure 30: Percent Silt and Clay Interpolated Raster - Grain size analysis with data collected by WHOI for LIS and interpolated using the IDW tool. 2214 Samples were analyzed for Percent Silt and Clay.

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).

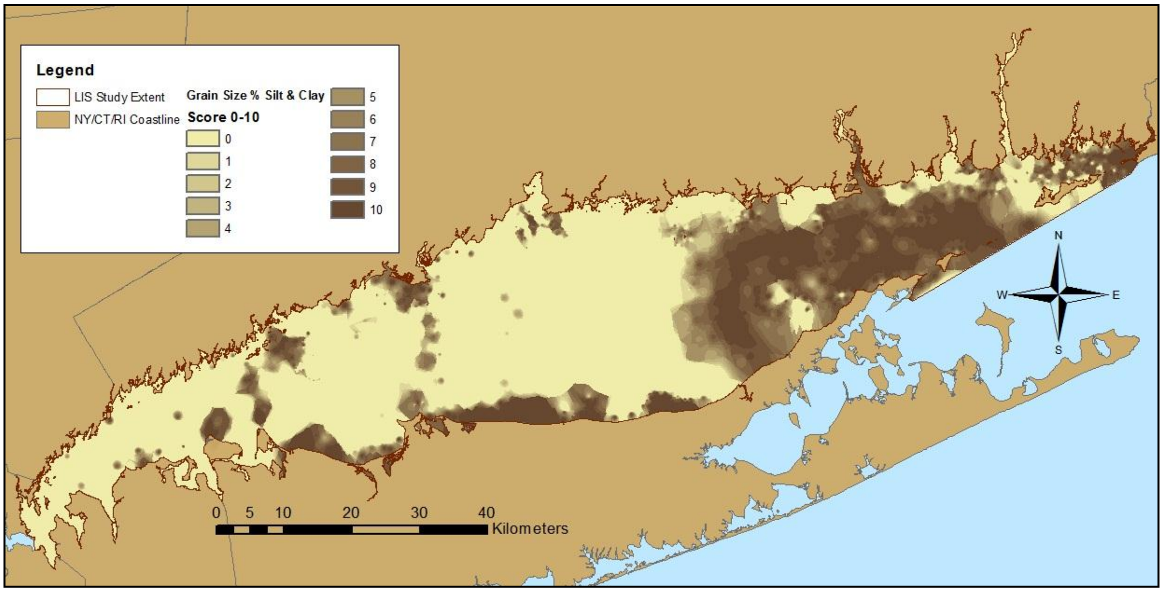


Figure 31: Percent Silt and Clay Reclassified Raster - Percent silt and clay reclassified to account for sandy and rocky bottoms where new eelgrass seed can develop a strong root structure.

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).

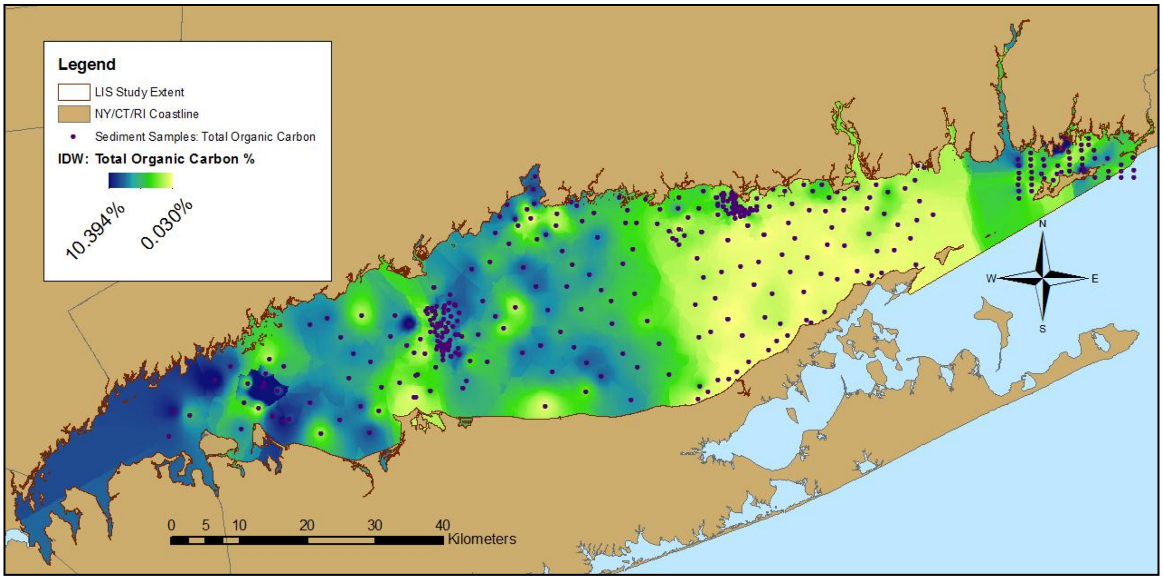


Figure 32: Sediment Total Organic Carbon Interpolated Raster - For Sediment Percent Organics, TOC value uncorrected for salt at each location throughout LIS was interpolated using the IDW tool. 406 Samples were analyzed for TOC.

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).

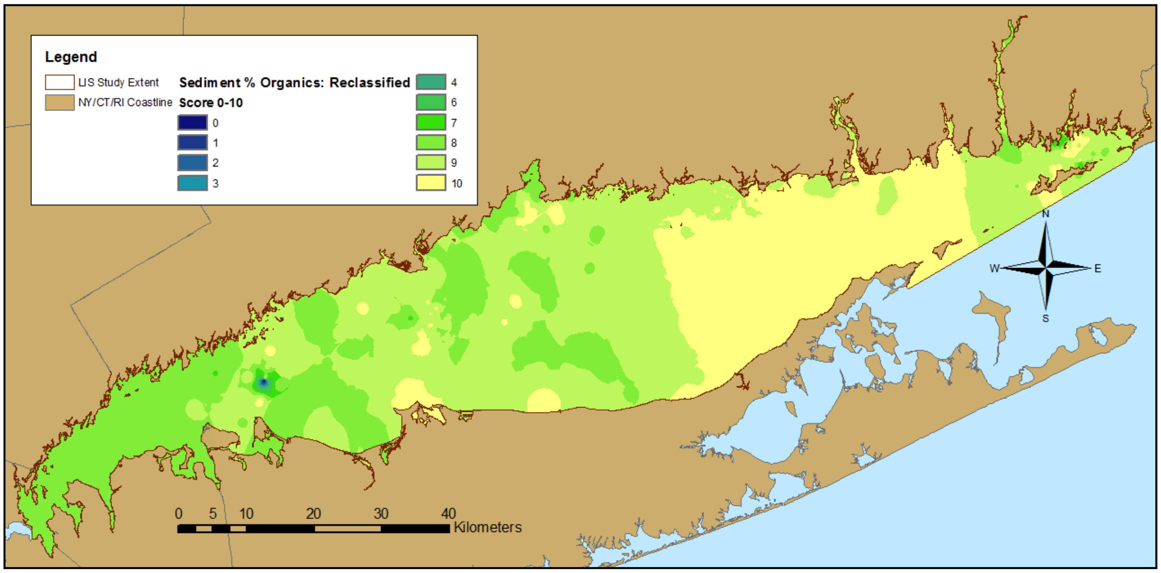


Figure 33: Sediment Total Organic Carbon Reclassified Raster - Sediment Percent Organic is reclassified with the score from 0 to 10.

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).

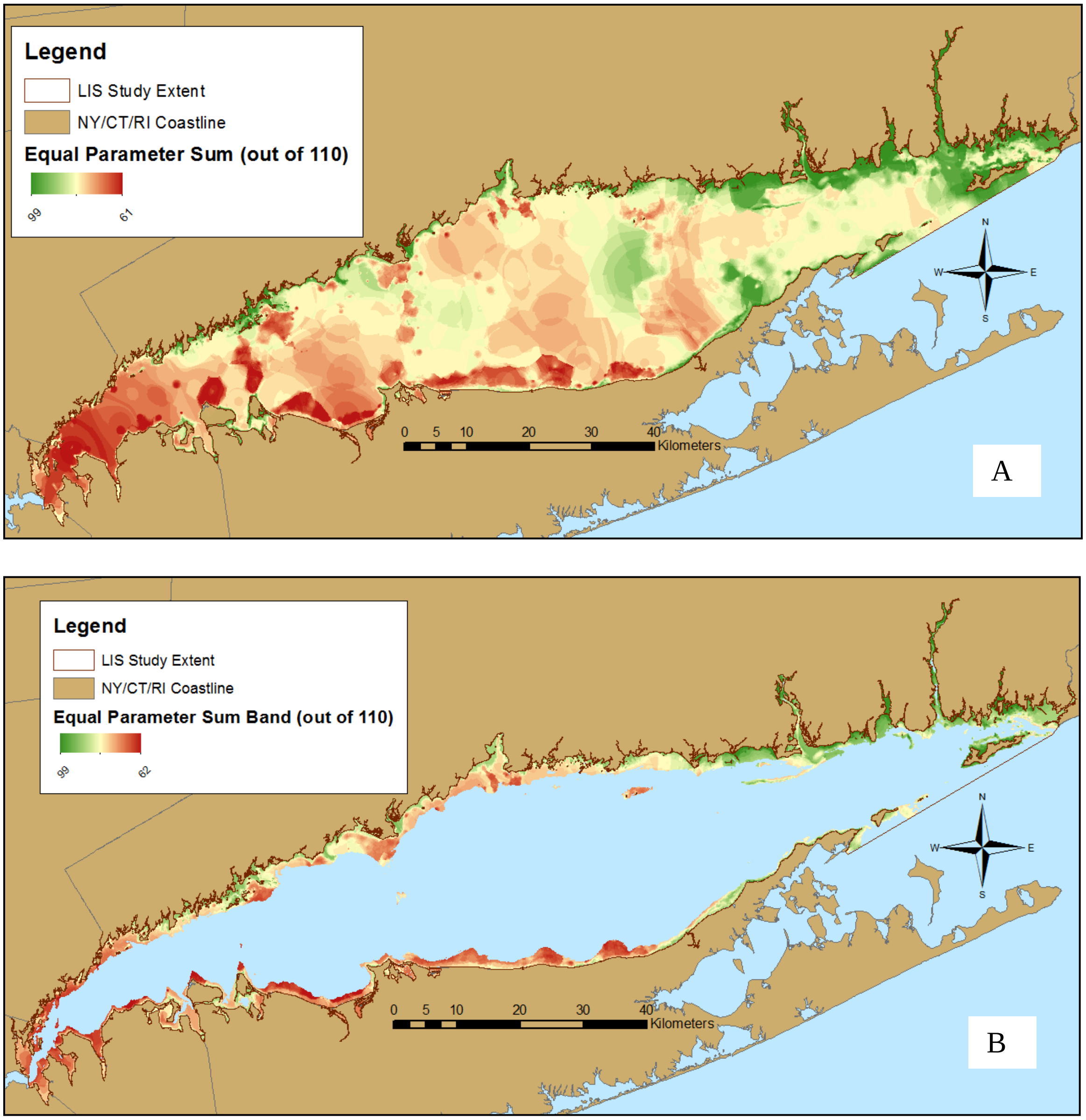


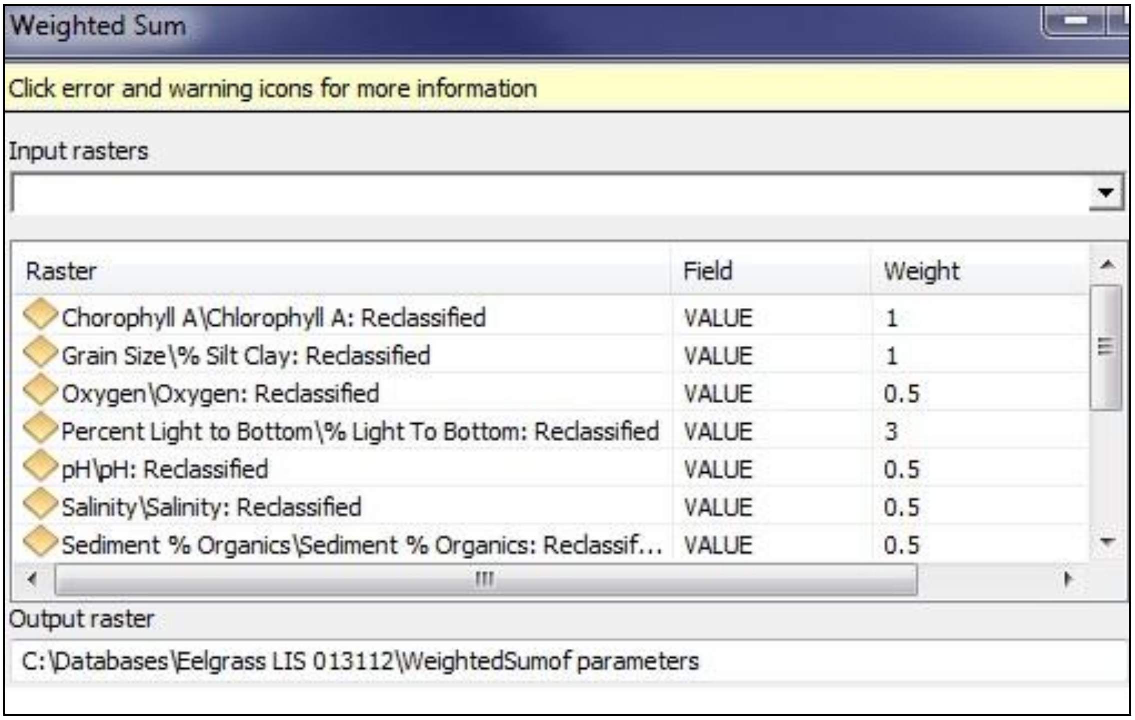
Figure 34: Equal Sum Parameters and Equal Sum Band – the reclassified parameters were A. summed using the Raster Calculator and B. then clipped within the suitable band.

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



Raster	Field	Weight
Chorophyll A\Chlorophyll A: Reclassified	VALUE	1
Grain Size\% Silt Clay: Reclassified	VALUE	1
Oxygen\Oxygen: Reclassified	VALUE	0.5
Percent Light to Bottom\% Light To Bottom: Reclassified	VALUE	3
pH\pH: Reclassified	VALUE	0.5
Salinity\Salinity: Reclassified	VALUE	0.5
Sediment % Organics\Sediment % Organics: Reclassif...	VALUE	0.5

Output raster

C:\Databases\Eelgrass LIS 013112\WeightedSumof parameters

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).

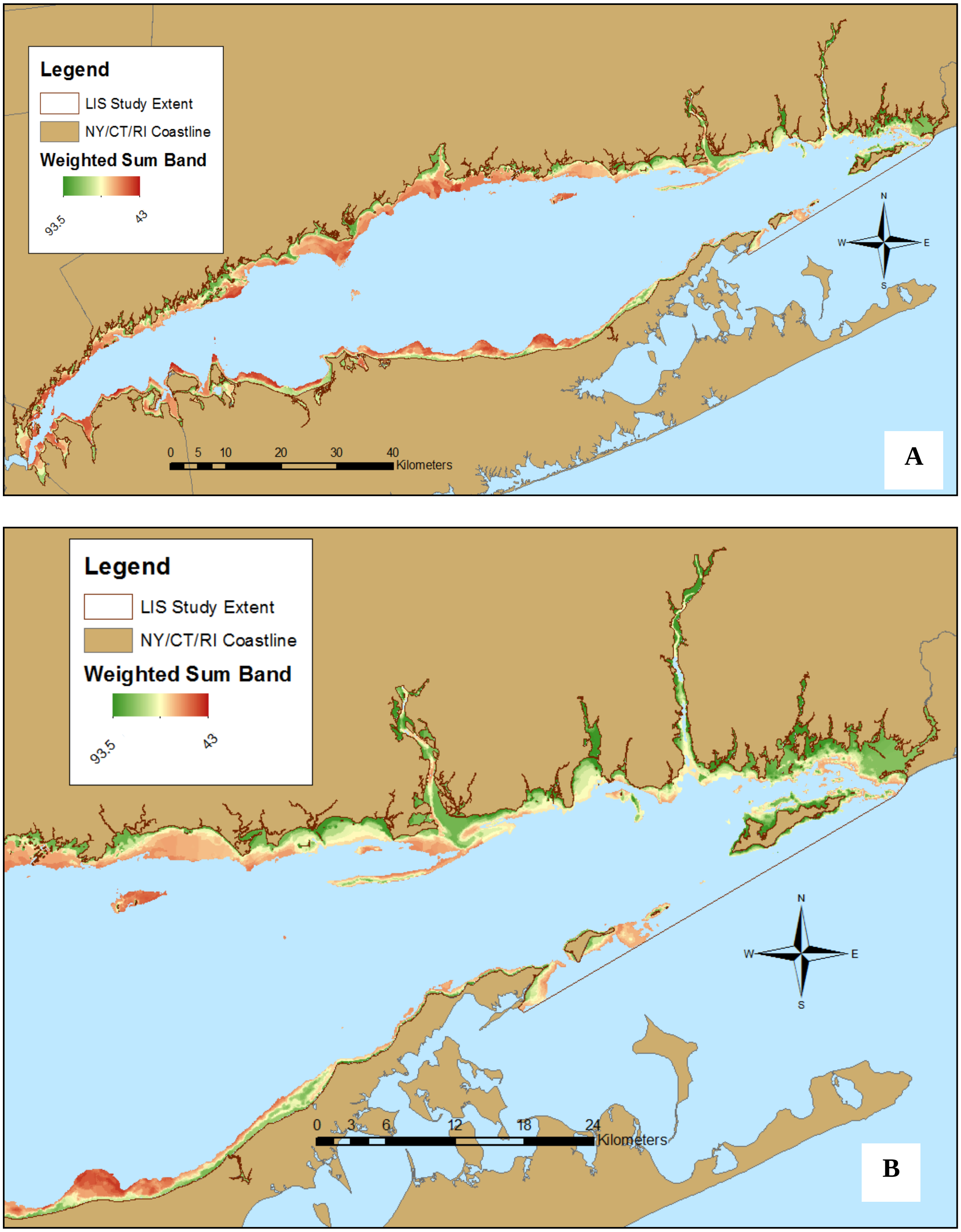


Figure 36: see caption on next page

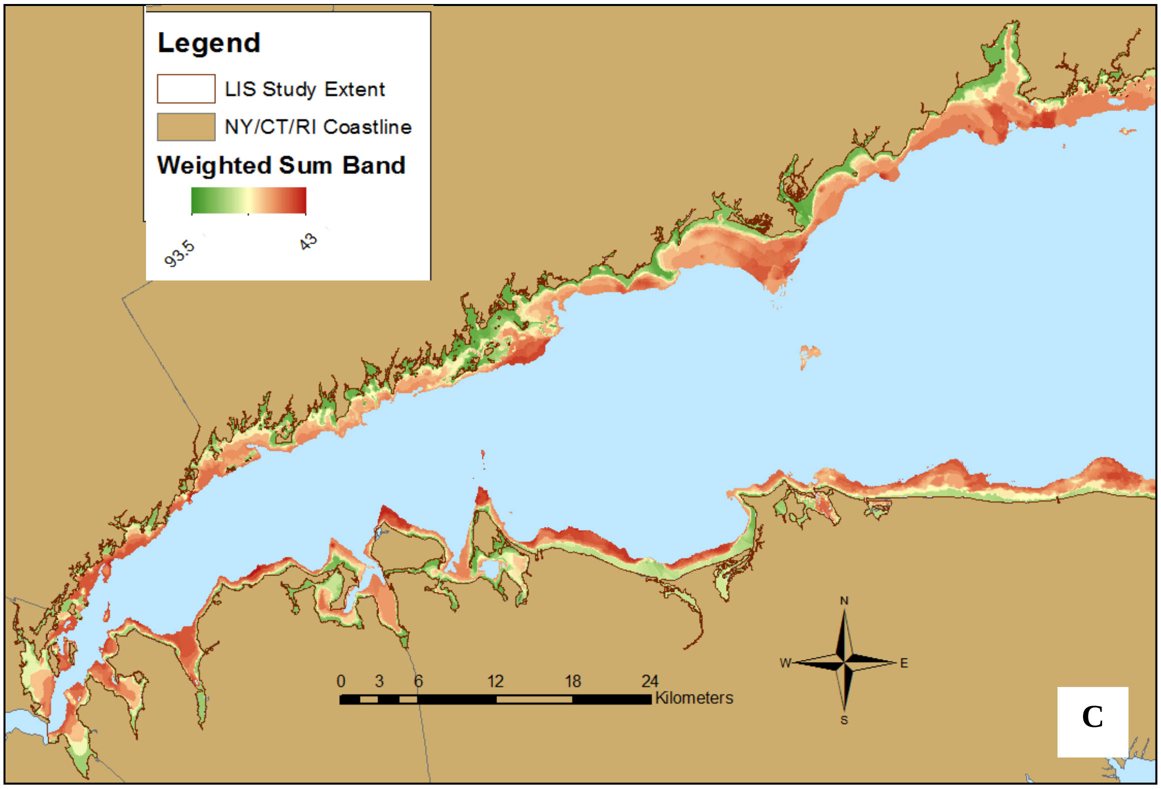


Figure 36: Weighted Sum Parameters Band - Weighted sum of ranked parameters within the Suitable Band has scores ranging from 43 to 93.5. A. Full study extent; B. Eastern LIS; C. Western LIS.

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.

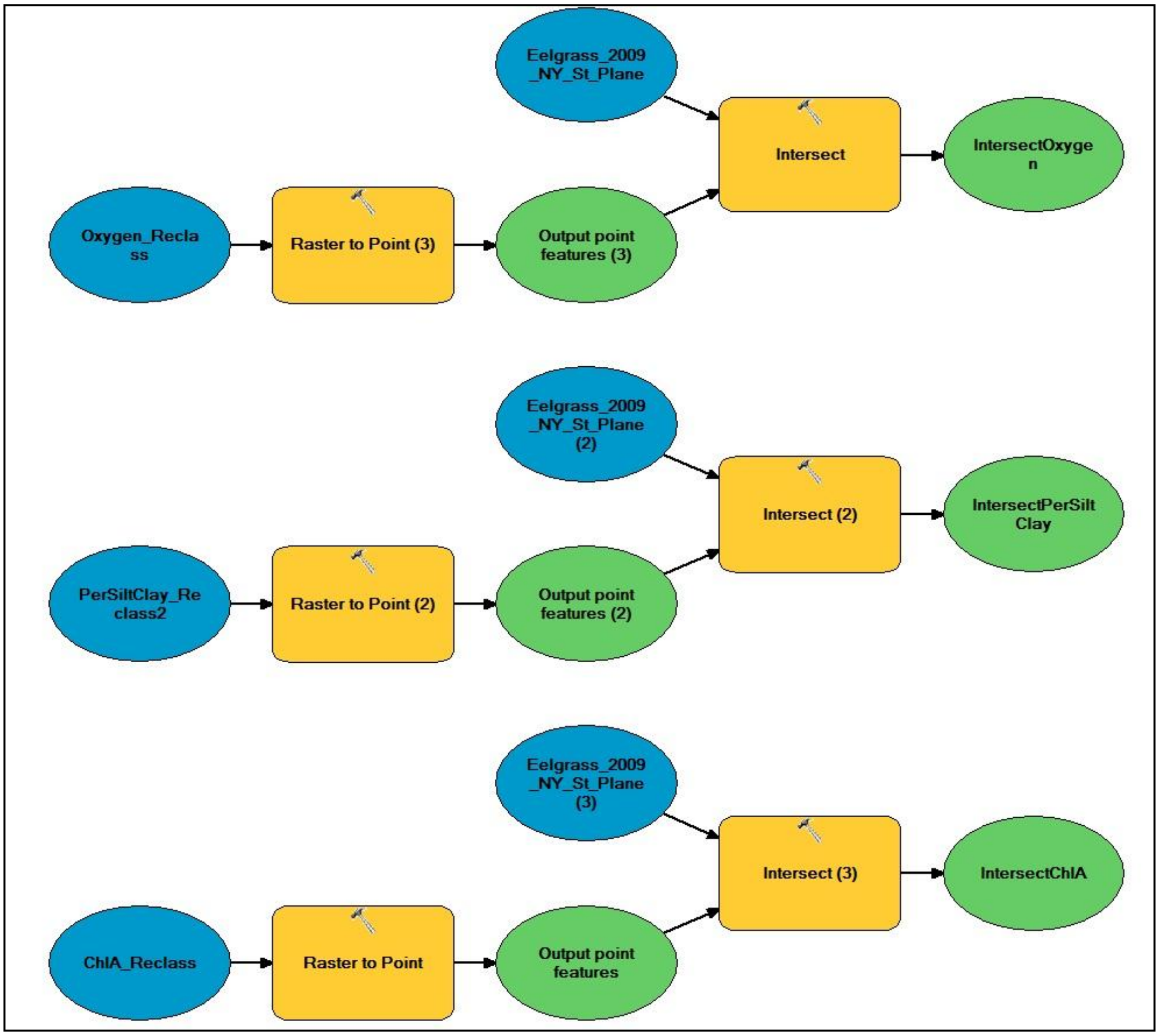


Figure 37: Intersect Model with 2009 Existing Eelgrass – The model inputs the reclassified parameter rasters, converts the raster to points, and intersects the points with 2009 Existing Eelgrass Bed data polygons. The result is a number of points from the original parameter that are overlain with the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

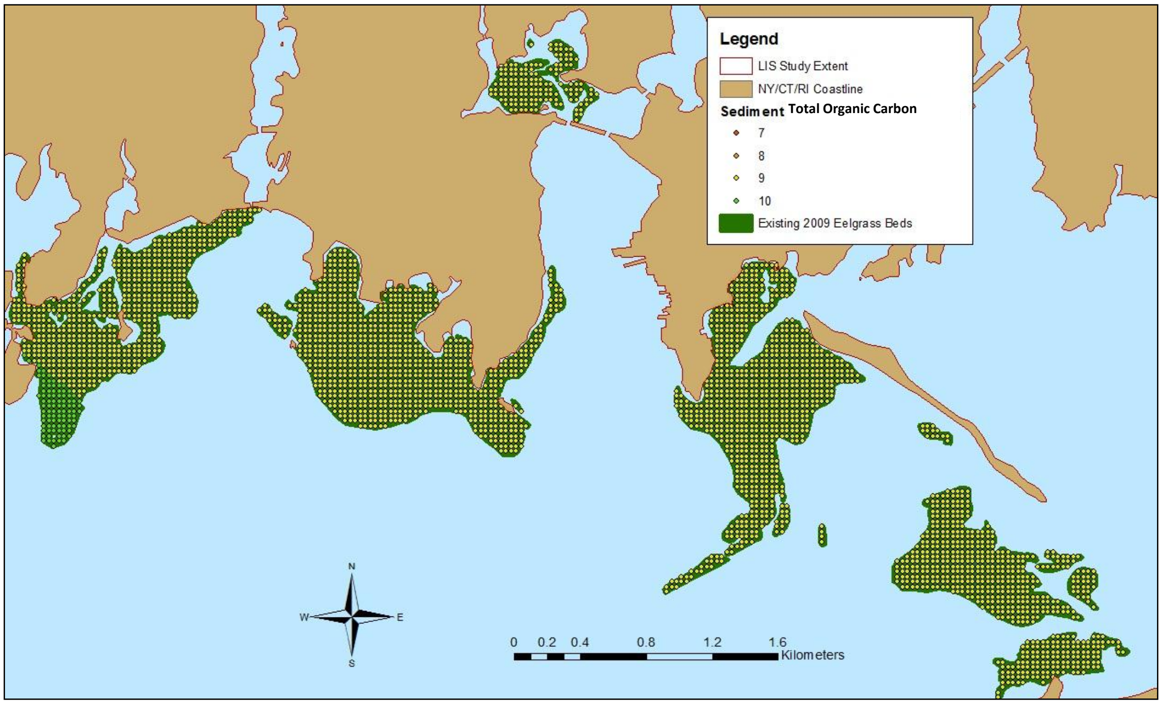
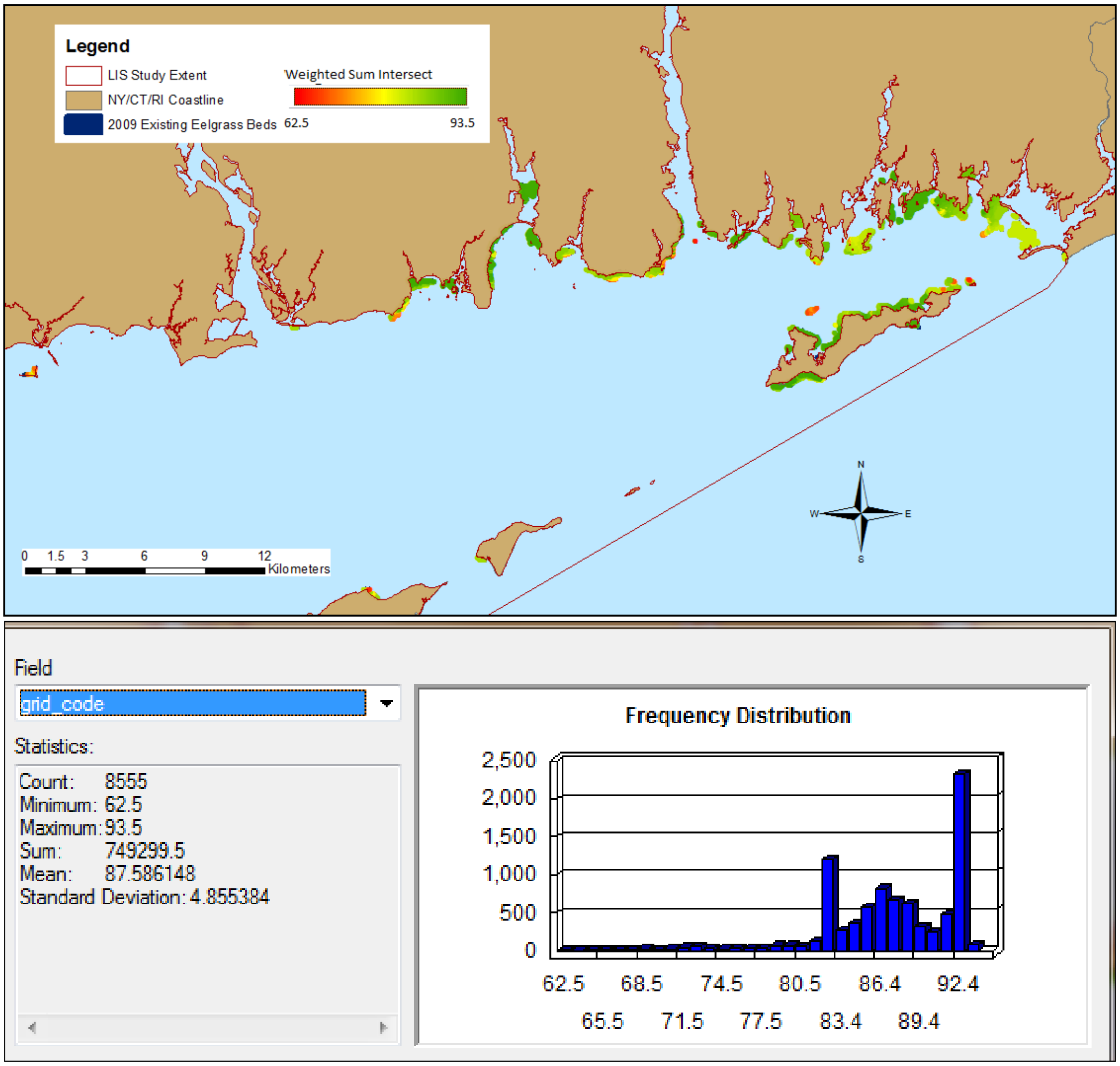


Figure 38: Sediment Total Organic Carbon Intersect with 2009 Existing Eelgrass - A view of the intersect of the total organic carbon scores with the 2009 existing eelgrass bed data (CT DEEP). The scores intersecting the existing eelgrass beds here are Yellow for 9 and Green for 10.

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.



grid_code

Statistics:

Count: 8555
Minimum: 62.5
Maximum: 93.5
Sum: 749299.5
Mean: 87.586148
Standard Deviation: 4.855384

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