Preliminary Map Products from an Ecological Characterization of Eastern Long Island Sound and Fishers Island Sound Regions: Long Island Sound Cable Fund Phase II Survey Area

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Long Island Sound Study
A Partnership to Restore and Protect the Sound

Connecticut Department of ENERGY & ENVIRONMENTAL PROTECTION

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1.0 INTRODUCTION

1.1 Preliminary Map Report

This document is a preliminary report of the results of the Ecological Characterization component of the Long Island Sound Mapping and Research Collaborative's (LISMaRC) contribution to the Long Island Sound Cable Fund Habitat Mapping Initiative: Phase II – Eastern Long Island Sound. This report provides a brief introduction to the Initiative, a summary of the methodologies utilized for the Ecological Characterization and a set of preliminary maps illustrating progress to date assessing the infauna and epifauna of the Phase II area. This report is prepared in response to a request for preliminary map products from Connecticut Department of Energy and Environment (CTDEEP) to inform discussions with the Equinor Corporation pursuant to its development of the Beacon Wind offshore wind project, specifically regarding routing options for the subsea cable to bring the power to shore. This response is, therefore, congruent to the framework for the LIS Cable Fund to provide the best available science to inform sound management decisions. Moreover, this report provides information that can be used by a broad suite of stakeholders interested in this and similar sustainable energy infrastructure projects in general.

1.2 Background

The Long Island Sound Cable Fund was established in 2004 following the settlement of a lawsuit based upon the incorrect installation of a power transmission line from New York to Connecticut running under Long Island Sound. The Long Island Sound Study Policy Committee signed a Memorandum of Understanding on administering the fund for research and restoration projects to enhance the waters and related natural resources of Long Island Sound. In 2006, the Long Island Sound Study Policy Committee signed a second Memorandum of Understanding formally establishing a framework for the fund's use. The Policy Committee agreed that the Fund be used to: "Emphasize benthic mapping as a priority need, essential to an improved scientific basis for management and mitigation decisions." A LIS Cable Fund Steering committee, comprised of representatives from the Connecticut Department of Energy & Environmental Protection, State of New York Department of Environmental Conservation, State of New York Department of State, U.S. Environmental Protection Agency Regions 1 and 2, Connecticut Sea Grant, and New York Sea Grant was convened to provide management and guidance for use of the fund.

Between 2004 and 2012, multiple workshops and meetings were held to help refine the vision for the benthic mapping effort. Additionally, a spatial planning exercise (Battista and O'Brien, 2015) was conducted to identify areas of LIS to focus data collection and analyses with the understanding that:

- Current funding was insufficient to have operations cover the entirety of LIS;
- By concentrating in areas where there were multiple interests from a range of stakeholders the utility of data collected and presented can be maximized.

The results identified three distinct geographic areas (Figure 1)

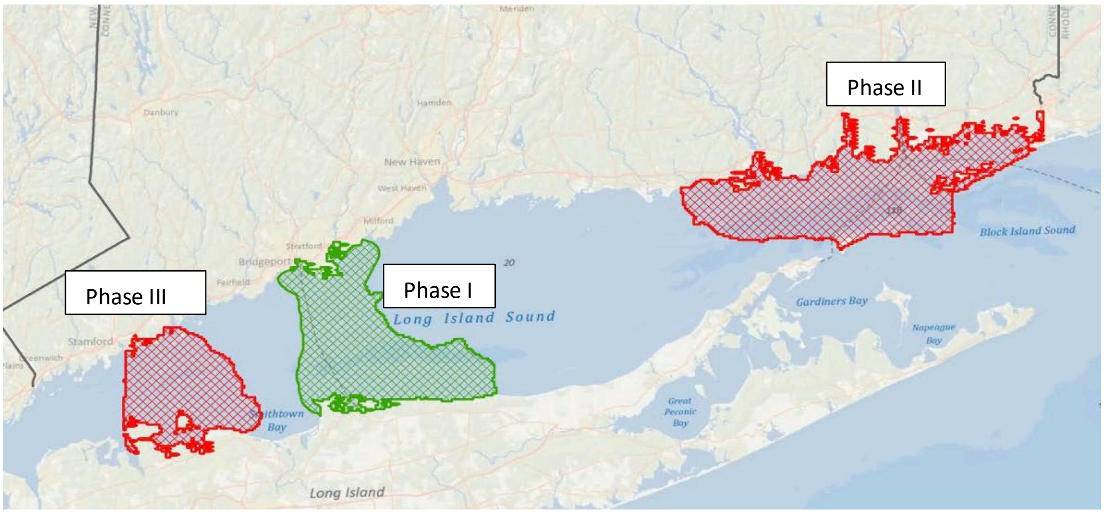


Figure 1. Map of LIS depicting the three priority areas identified for habitat mapping.

Workshops and other meetings also defined the complementary topical areas necessary for a comprehensive habitat mapping effort for Long Island Sound and include:

- Acoustic Intensity - Acoustic intensity products are able to depict valuable properties about the composition, roughness, and texture of the seafloor to provide meaningful information to managers about the distribution and composition of seafloor habitats.

- Seafloor Topography - Seafloor topography products showing bathymetry and terrain relief are able to depict important features and seafloor changes to better explain physical, geological, and ecological processes.

- Benthic Habitat and Ecological Processes - Maps depicting seafloor habitats and their ecological communities are critical for many environmental management, conservation, and research activities, and for the growing focus on coastal and marine spatial planning. Such maps depict either separately or in combination the spatial distribution and extent of benthic habitats classified based on physical, geological, geomorphological, and biological attributes and the benthic communities that reside in the mapped habitats. Additionally, maps can be produced that depict ecological process across the sea floor.

- Sediment Texture and Grain Size Distribution - Mud, sand, and gravel dominated areas provide very different habitats and the main grain size often determines many seafloor characteristics. Therefore, grain size composition and sediment texture of the seafloor are essential elements of any habitat classification and detailed knowledge of grain size distribution is the basis for many management decisions.

- Sedimentary Environments - Besides grain size the stability and suitability for different habitats for various species depend on the dominating sedimentary environment characterized by processes such as erosion, deposition, and transportation. Mapping and understanding these processes in detail is important for understanding habitats as well as their potential to change.

- Physical and Chemical Environments - Products that depict the distributions and variability of environmental characteristics like temperature, salinity, dissolved oxygen and bottom stress are central elements of habitat classification. They are also important to wise regulation and planning for dredging and other engineering activities in the coastal ocean.

Three research teams were selected to conduct the multifaceted mapping project:

- *Lamont-Doherty Earth Observatory (LDEO) of Columbia University Collaborative*: a partnership of LDEO, Stony Brook University, and Queens College – City University of New York
- *Long Island Sound Mapping and Research Collaborative (LISMARC):* a partnership between the University of Connecticut, the U.S. Geological Survey, the University of New Haven, and the University of Rhode Island; and
- *National Oceanic and Atmospheric Administration (NOAA) Ocean Services Collaborative:* a partnership between the National Center for Coastal and Ocean Science (NCCOS) Biogeography Branch and the Office of Coast Survey.

1.3 Phase I Pilot Project

From 2012-2014 the teams worked together to address all of the critical elements for habitat mapping identified above and produced a comprehensive report and numerous map products aligned with each element. The results of the Phase I effort are available online (Long Island Sound Cable Fund Steering Committee, eds. 2015) at:

Pilot Report: http://longislandsoundstudy.net/wp-content/uploads/2010/02/LISCF_PilotMappingProject_Report_Final_June2015-reduced-file-size.pdf
Appendices: http://longislandsoundstudy.net/wp-content/uploads/2010/02/LISCF_PilotMappingProject_Report_Final_Appendices_June2015-reduced-file-size.pdf

1.4 LISMaRC Phase II Statement of Work

The overarching goal of the Phase II workplan was to provide environmental data and information to help better understand and manage the benthic resources of Long Island Sound by continuing with and improving on the efforts conducted in the Phase I Pilot. These included: 1) acoustic mapping of some of the shallow water areas of the Phase II region, 2) ecological characterization, 3) physical oceanographic characterization and 4) database management and public access data portal development.

1.5 The Phase II Area of Interest

The Phase II area was defined by the process summarized above and illustrated in Figure 2 below. This area stretches from Duck Island west of the Connecticut River east to the Rhode Island border including Fishers Island Sound and areas to the south of Fishers Island, including the Race. This area comprises approximately 518 square kilometers.

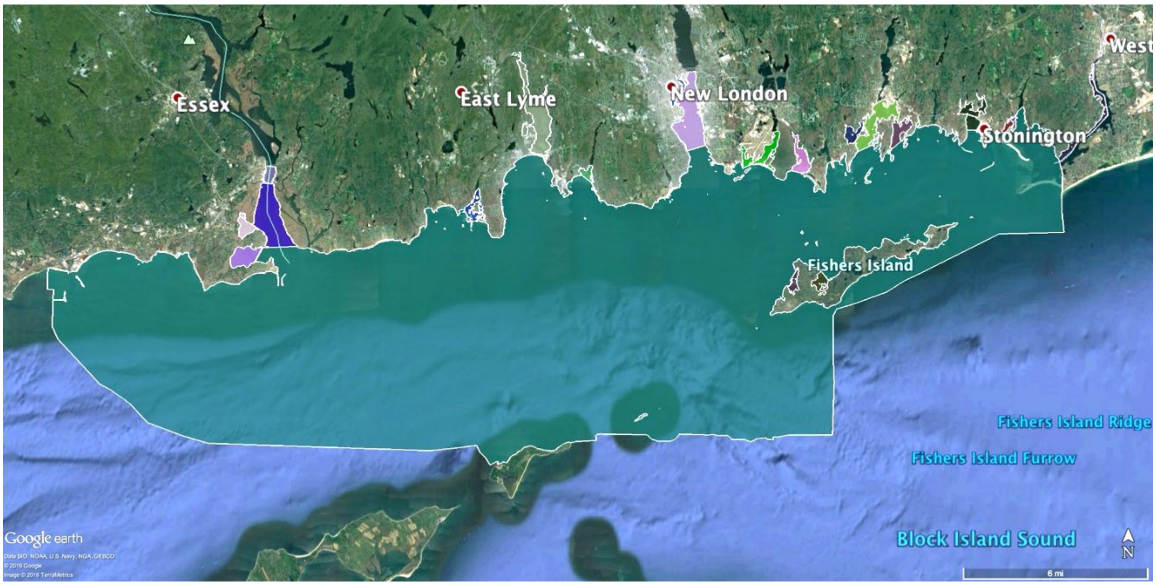


Figure 2. Map of the Phase II area (green polygon) in eastern Long Island Sound.

2.0 METHODS

2.1 Sample Site Selection and Sampling

2.1 Sample Site Selection and General Cruise Details

Sample locations were selected through a multi-step process. First, sampling effort was spread throughout the geographic extent of the study area across 90 sampling blocks (SB) or sites (NB) (Figure 3). The spatial distribution and locations of the SBs were selected with the overall objective to sample as many of the different seafloor habitats based on examination of existing seafloor bathymetry and backscatter data to be inclusive of depth and grain size gradients, the presence of transition zones between distinct seafloor features, and efforts to distribute sampling throughout the longitudinal range of the study area. The original plan for sampling effort was to implement three grab samples and three image transects in blocks and one each at sample sites.

The majority of the samples for ecological characterization were collected during two sampling periods, between November 28 and December 3, 2017 and May 8 and 15, 2018 using the United States Geological Survey's (USGS) Seabed Observation and Sampling System (SEABOSS; Valentine et al. 2000) for both infaunal grab and epifauna video/photographic samples. Additional sampling details for the SEABOSS cruises are provided in Ackerman et al. 2020. The Research Vessel Connecticut was used to support both of cruises.

Locations with high rugosity and complex topographies were sampled via still and video imagery with the Kraken2 ROV during one cruise conducted during May 2018, again using the RV Connecticut. Scuba was employed to collect quadrat camera still images and associated suction samples to assess and contrast patterns of diversity using visual versus direct sample approaches. This wet diving component of the project was conducted between August 2017 and August 2018. None of the results from the wet diving component are included in this preliminary report.

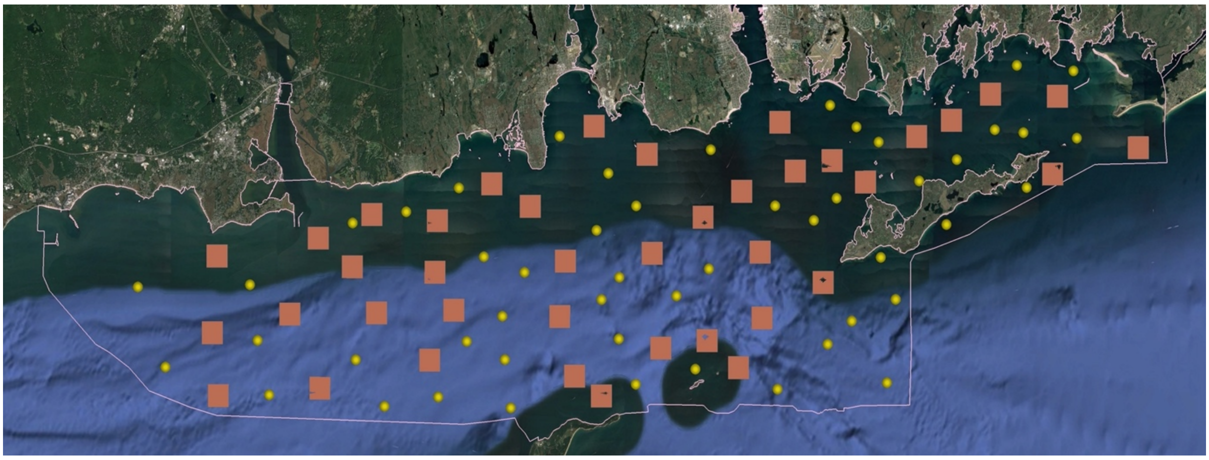


Figure 3. Map of the Phase II area, showing the sample blocks (orange squares) and sample sites (gold dots).

2.2 Infaunal Sample Design

Infaunal samples were collected with the 0.1 m^2 modified Van Veen grab on the SEABOSS system. The SEABOSS was lowered to just above the sea floor and then was allowed to drift for several minutes to collect video and still images (used for the epifaunal analyses, see Section 2.3), after which a grab sample was collected. Three samples were collected in in each SB and one sample at each NB site. Several SBs were not sampled completely, and several NB sites not samples at all, for infauna due to hazards for the sampling equipment. Of the 179 sediment samples taken, a total of 160 were collected and processed for infauna. After a small portion of surficial sediment, approximately 10 cm^2 by 2 cm deep, was removed for sediment analyses the entire contents of the grab sample obtained at each sampling site was then washed on a 1 mm sieve using filtered seawater. Several samples were sieved on a 500 µm to assess potential underestimates of abundance and diversity due to using a 1 mm sieve. The sieved samples were preserved with 70% ethanol and stained with Rose Bengal. In the lab, samples were sorted under a dissecting microscope and individuals were identified to the lowest possible taxon. There were no statistical differences in mean taxonomic richness, abundance and Shannon diversity among 500 µm and 1 mm sieved samples in the Phase II study area, and as such these were combined in subsequent analyses of the data. In this preliminary report / map set, we provide maps of the raw data for infaunal taxonomic richness, total abundance and Shannon diversity. Maps of the abundance across the sampling points for several numerically dominant taxa are also provided.

2.3 Epifaunal Sample Design

Epifaunal and emergent seafloor organisms and associated biogenic features were characterized using seafloor imagery. Images were collected during SEABOSS and ROV transects (n=602 SEABOSS images fall 2017, n=595 SEABOSS images spring 2018, n=110 ROV images spring 2018). Sampling efforts depended on seafloor characteristics: while most effort was concentrated in the SEABOSS cruises referenced above, select areas with precipitous topographies were sampled via still and video imagery with the ROV.

Within both sampling blocks and sites, sampling location selection differed based on the sampling method and platform. Trajectories for SEABOSS transects were selected algorithmically. Large numbers of potential transects (n=1000) with randomized start and end points were randomly generated for each sampling block and site. Transect locations were constrained by simple rules: transects could not be generated within 6.1m lateral distance (this is the beam of the RV Connecticut) and of depth contours ≤5m or identified obstructions. Bathymetry and backscatter profiles of each randomly generated transect were extracted from acoustic data sets. These profiles were ordered based on the variance and range of bathymetry and backscatter profile data such that transects with the greatest range and highest variance were highly ranked. This approach was taken since changes in bathymetry and backscatter are key indicators of transition zones (Zajac et al. 2003, 2020) and sampling transition zones was central to characterizing variation in communities. This algorithmic process was the principle means of efficiently sampling seafloor habitats within blocks and sites across the study region. This transect selection approach resulted in an overall reduction in the number of transects sampled per sample block (originally planned as n=3, reduced to n=1) and increased the number of sample blocks that were actually sampled during research cruises. Wet-diving locations were determined based on visual assessment of fine scale bathymetric data to target sites across depths. Trajectories for image and video sampling via ROV were selected using bathymetric data and navigation data from topographically challenging areas identified during SEABOSS transects.

SEABOSS sampling consisted of imaging, video, and sediment grab sampling. Still images were taken using a Nikon D300 camera and Photosea electronic flash set-up for orthogonal imagery (Figure 4). Video imagery was collected using a GoPro Hero4 for oblique forward-facing field-of-view and a SIMRAD SD video camera mounted for an orthogonal field-of-view. All bottom videos were acquired using a Kongsberg Simrad OE1365 video camera on the SEABOSS. A scientist monitored the real-time bottom video and acquired bottom photographs by remotely triggering the Nikon camera shutter. Bottom video was also recorded during the drift from the downward-looking Kongsberg video camera directly to hard drives using an Odyssey7 video recorder. Bottom videos were recorded in .MP4 format and a trackline shapefile of the location of the ship for the duration of the video collected during the fall 2017and spring 2018 field activities. Two hundred ten sites were occupied within the study area, and bottom videos were acquired at all 210 sites, resulting in 218 videos with a total duration of 48 hours 30 minutes and 218 video tracklines with a total length of 41.4 kilometers (Ackerman et al. 2020).

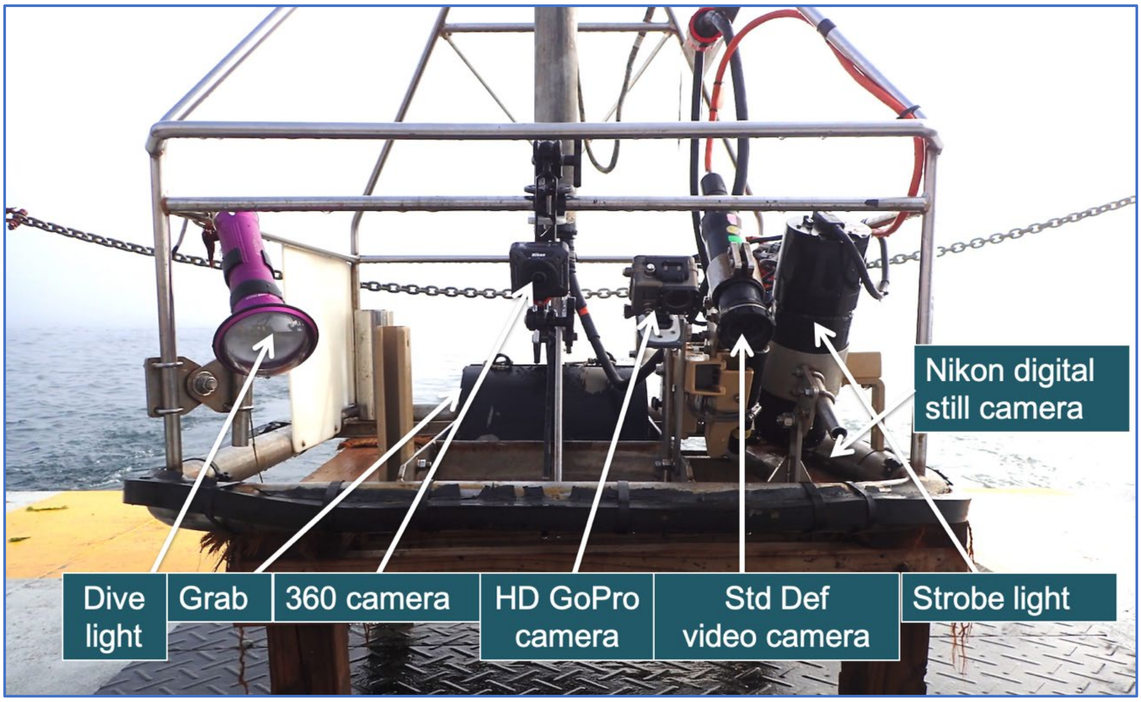


Figure 4. The USGS' SEABOSS illustrating the sampling and imaging equipment.

Wet-diving sampling, limited to depths <22 m, consisted of seafloor imaging and suction sampling. Images were taken using either a Sony NEX-5 or Sea & Sea DX-1200HD digital camera with two Sola Video lights mounted on a camera quadropod, set-up for orthogonal imagery (Figure 5a). Images captured 0.5m^2 square area of seafloor. Seafloor samples were collected via suction sampling (Figure 5b). Suction sampling consisted of collecting epifauna within a 0.5m^2 quadrat area using a compressed air suction sampler. Samples were collected in sealable 0.5mm mesh bags connected to the suction sampler then transferred to storage containers and preserved in 70% EtOH for later processing. Specific suction sample locations were imaged prior to and following suction samples.

Figure 5. Diver conducting quadrat photo transect (5a left) and suction sampling (5b right).

The Kraken2 ROV (Figure 6) was utilized to acquire imagery in topographically complex and spatially constrained habitats where maneuverability of the camera platform is required to collect adequate image samples. Such areas were difficult to access using SEABOSS. ROV sampling consisted of still and video imagery. Still images were recorded using a Nikon E995 digital camera and electronic flash set-up for orthogonal imagery. A Canon PowerShot G11 and electronic flash were also installed for mobile pan-tilt imagery.

All images were taken using artificial lighting (electronic flash or daylight color temperature lighting using HMI or LED sources) to enhance color saturation, edge sharpness, and depth of field. Paired parallel lasers were mounted adjacent to cameras and projected points into each image at 20 cm spacing to facilitate image calibration. All imagery was batch processed using the automated color correction routine in Irfanview software (version 4.35) in order to enhance color saturation and delineate color boundaries to facilitate identification of taxa.

Each image was subsequently examined for clarity and focus. Images with water turbidity that obscured the seafloor or that were out of focus such that identification of all organisms or biogenic features was impeded were rejected. Transects were divided into 50m segments and images subsampled randomly from each segment, ensuring epifauna along the entire length of each transect would be characterized. Images selected for analysis were ≥2m apart to preclude analyzing the same areas of the seafloor multiple times. This step produced a total of 1307 processed images for analysis.

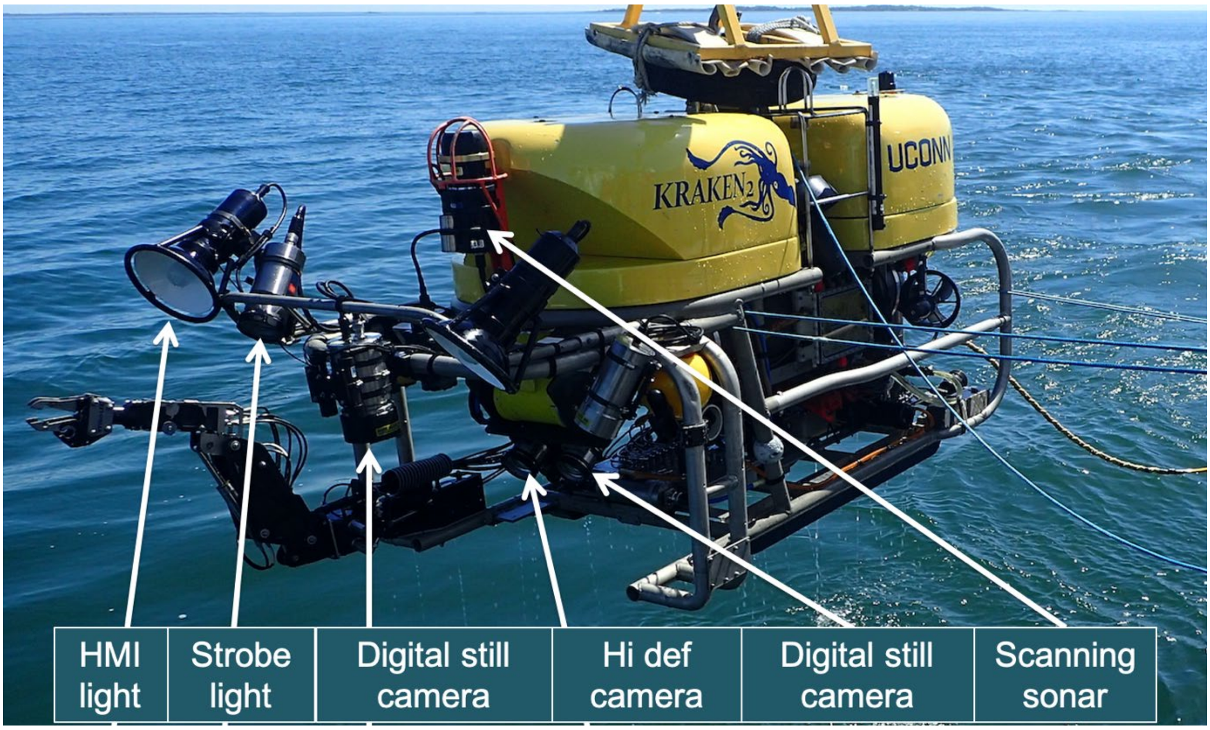


Figure 6. The Kraken2 ROV illustrating it's still and video imaging and sonar capabilities.

Each color corrected image was analyzed for percent cover of all living seafloor species (excluding fish) and biogenic features (e.g., shell, mud tubes, burrows) using ImageJ software (version 1.45s; Abramoff et al. 2004). Percent cover was quantified using a grid of square cells overlaid on each image. The grid featured 280 cells filling the entire image space, but the cells lining the image edge were ignored due to reduced lighting and potential optical distortion caused by the flat port and open aperture of the underwater camera, resulting in a usable grid of 216 cells (Figure 7).

Within each grid square, organisms and biogenic features were identified to lowest possible taxonomic level and marked using the "cell counter" tool in ImageJ. This function displays a mark on each object as selected in the image and, in a separate window, displays counts of each object type. ImageJ only classifies objectives and related numerical counts as a series of undefined "Types" (e.g., Type 1, Type 2, etc.) and does not have a custom naming feature. Therefore, workflow processing of images required a separate record of the identity of "types" for each image and subsequently rectifying counts with actual taxonomic and feature classifications post-processing.

Several counting conventions (i.e., decision rules) were required to address variability in the cover of organisms and biogenic habitat features on the seafloor. Some colonial organisms (e.g., coral, sponge) and biogenic features occupied multiple grid squares. In addition, some solitary organisms (e.g., mussel, crab, gastropod) also were present in multiple squares. Such individuals were counted in each square to account for the area of coverage in each image. Conversely, more than one organism or biogenic feature could be in a single square and were each counted in order to account for all biological elements within an image. Therefore, the total grid count could be greater than the total number of squares in the grid (but then normalized across images by calculating percent cover, as described below).

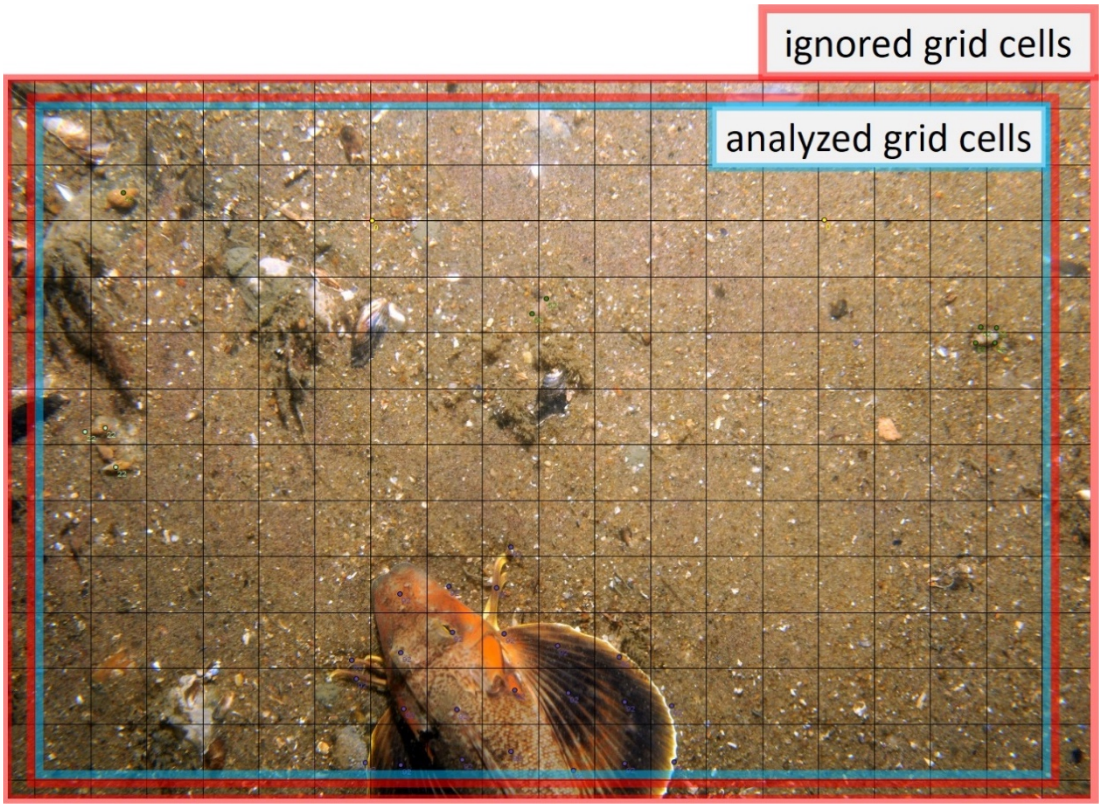


Figure 7. Screen capture of grid used for ImageJ analysis.

Total counts for each taxa or type of biogenic feature from each image were entered into a spreadsheet. All taxa, excluding fish fauna captured in images, and biogenic features were counted from imagery. Taxa and features from the full matrix were parsed for analyses as taxa (i.e., both sessile and mobile invertebrates), taxa and biogenic features (i.e., those structures produced by biota such shell, worm tubes, burrows). Counts were saved and archived as .ROI files (format that saves their position within the image for future analysis)). Using the scaling lasers in each image to calibrate length, the width and height of both the image and the grid was measured using the "measure" tool in ImageJ and area of coverage was calculated. Counts were converted to percent cover by dividing the count for each type of organism or feature by the total number of squares for the image. These data were subsequently used in analyses to address objectives regarding characterization of communities, variation in patterns of diversity, distribution of habitat features, and seasonality of patterns. Maps, shapefiles, and layer files were created for the % cover of taxa and biogenic features, as well as diversity measures in ArcMap (v10.5).

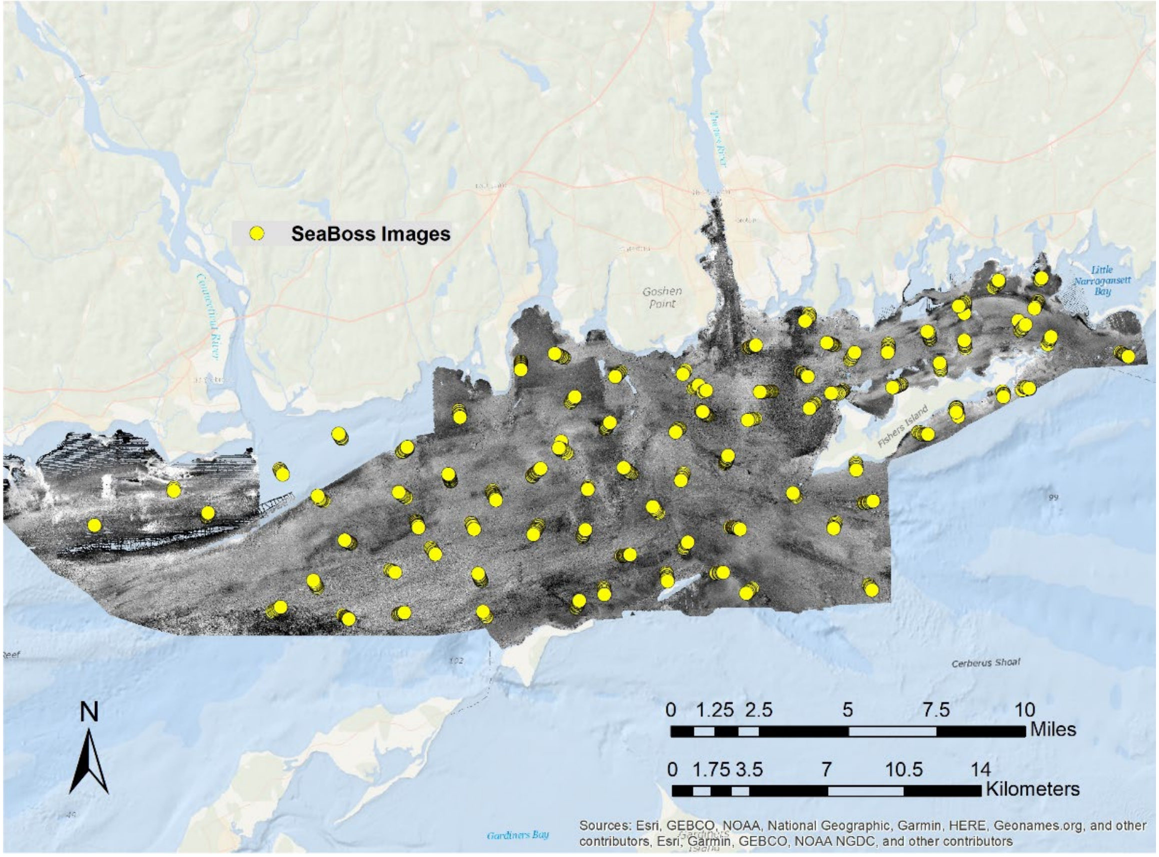


Figure 8. Map illustrating the locations of images acquired by the SEABOSS.

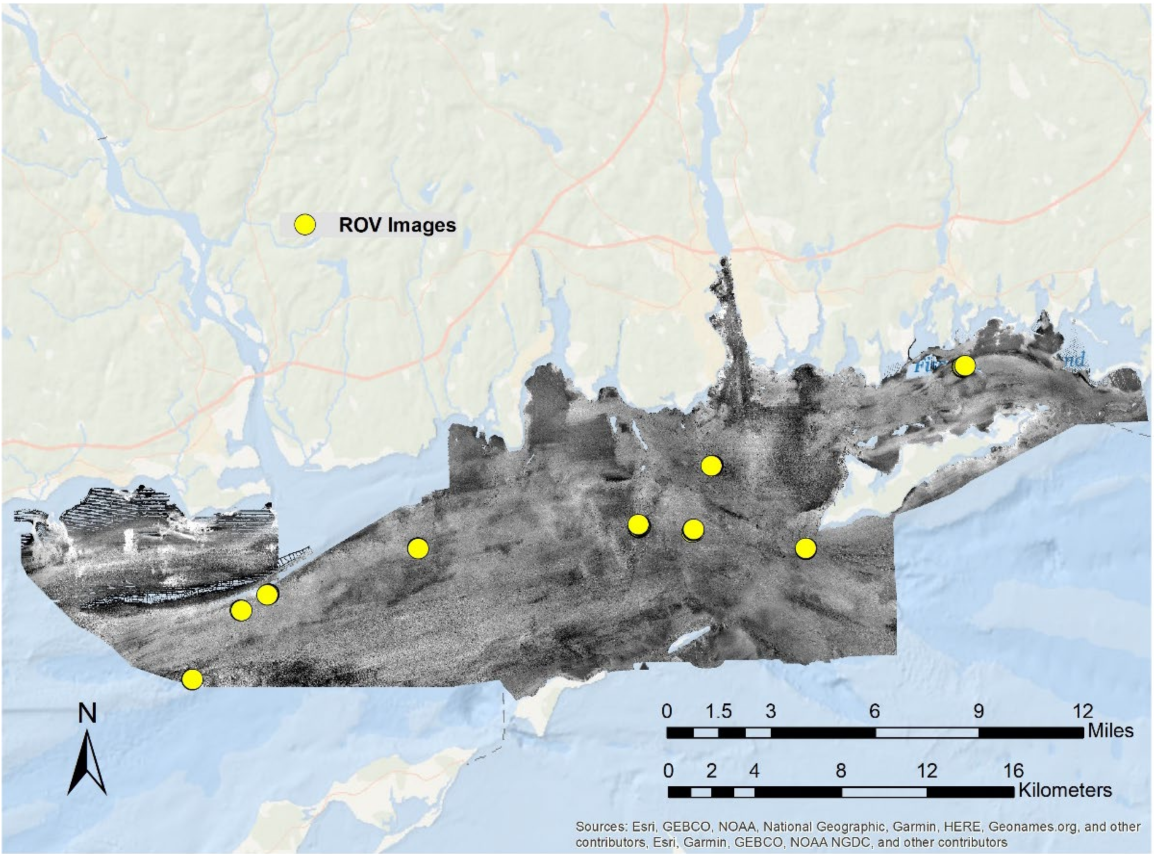


Figure 9. Map illustrating the locations of images acquired by the Kraken2 ROV.

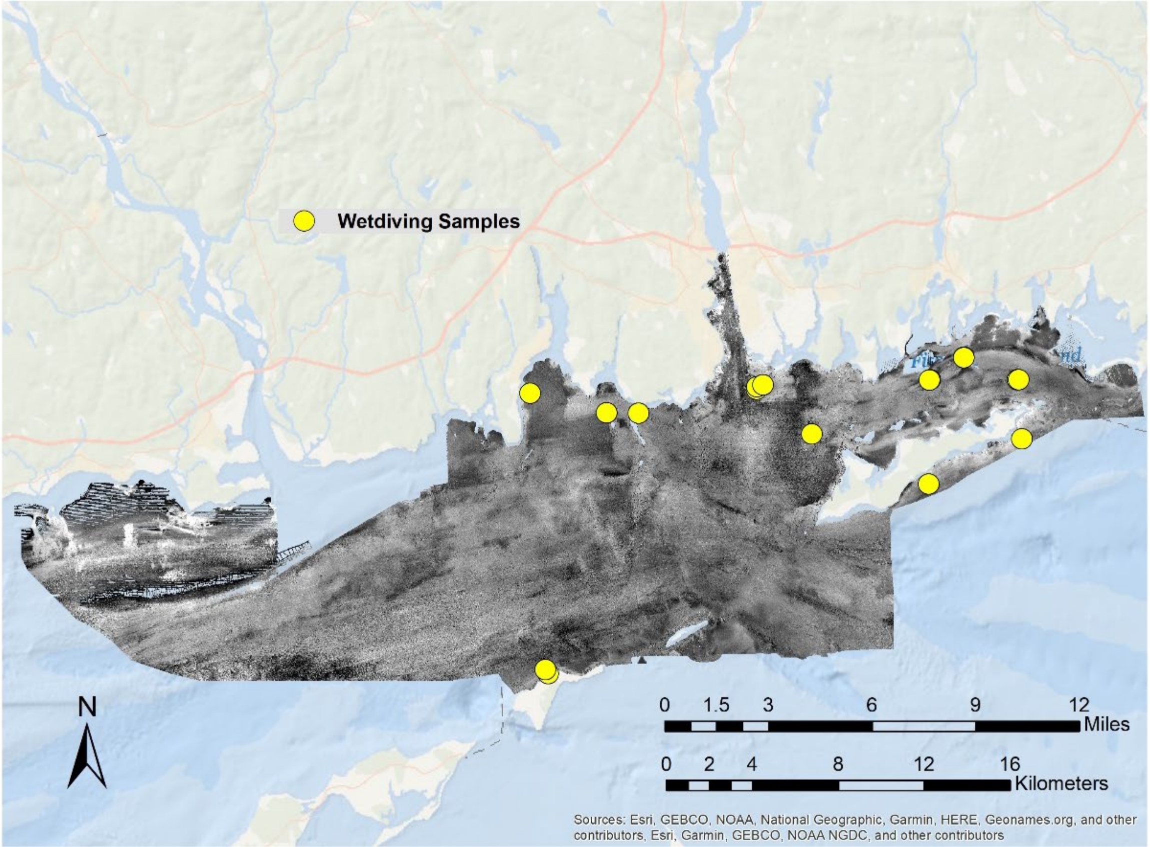


Figure 10. Map illustrating the locations of images and suction samples acquired by wet diving.

3.0 RESULTS

3.1 Sediment Grain Size

A subsample was taken from each sediment grab for grain-size analysis conducted at the sediment laboratory at the USGS Woods Hole Coastal and Marine Science Center. Sediment samples were only attempted in areas where collecting a sample would not damage the SEABOSS; therefore, no samples were collected in areas with a cobble, boulder, or rocky seabed, as identified in real time using the topside live video feed. Samples were also not attempted if the current was too strong, if the deployment was aborted due to the strobe malfunctioning, or if the grab sampler accidentally tripped earlier in the deployment. A total of 210 sites were occupied aboard the R/V Connecticut with the SEABOSS: 93 sites were occupied in fall 2017 during field activity 2017-056-FA, and 117 sites were occupied in spring 2018 during field activity 2018-018-FA. Sediment samples were collected at 179 of the 210 sites. Duplicate sediment samples were collected for collaborators (i.e., Tim Kenna, LDEO) as requested. Sediment grain size data is available in Ackerman et al, 2020.

3.2 Habitat Delineation

The integrated backscatter mosaic of the seafloor of the Phase II area was analyzed using eCognition Developer 64 (Trimble, 2013). This software segments the mosaic into meaningful objects (image-objects) of various sizes based on spectral and spatial characteristics (Lucieer, 2008) to perform a multi-segmentation classification to find regions with similar pixel values based on mean pixel brightness. Based on eCognition terminology, the mean brightness is equivalent to the mean intensity value of the backscatter pixels. The algorithm for multiresolution segmentation works by producing image objects based on pixel intensity to produce discrete objects that are homogeneous with respect to spectral characteristics (Drăguţ et al., 2010). The multiresolution segmentation was performed several times with varying scale parameter segmentations to produce image objects that best represented the backscatter tones. The multiresolution segmentation criteria for this study are modeled from previous studies on object-based seafloor image classification conducted by Lucieer (2008). An unsupervised classification was then performed using eCognition by comparing the image objects with the underlying boundaries of pixel tone across the image. This procedure grouped the objects into acoustic classes, or acoustic patch types, that were then used as the basis for habitat identification/classification that were assessed in conjunction with ecological data and analyses. The sediment type classifications for each of the acoustic patch types are based on the results univariate and multivariate statistical analyses of sediment data provided by the USGS relative to sample locations in each acoustic patch type (Figure 11).

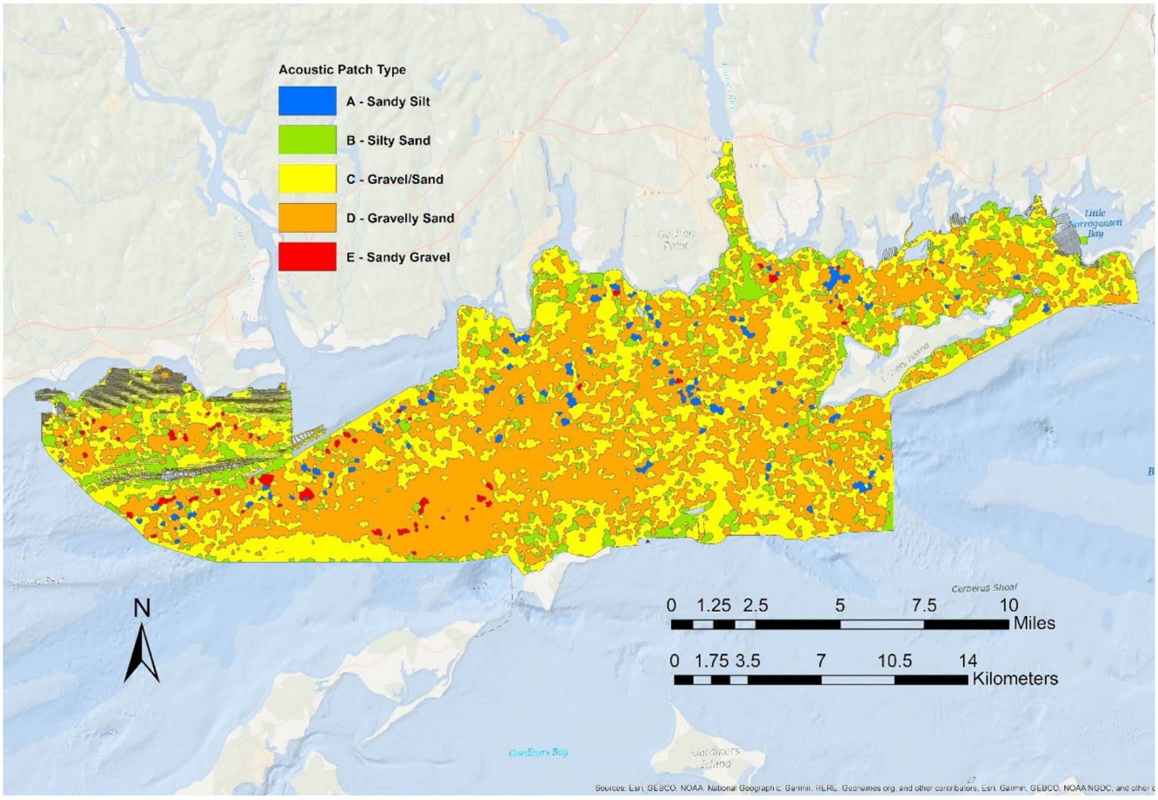


Figure 11. Spatial distribution of acoustic patch types (A- E) and their general sedimentary classifications.

The distribution of acoustic patch types across the Phase II study area is spatially complex, and as such the benthic habitats are extremely heterogenous. Most of the area is comprised of sands with varying mixtures of silt and gravel. In the western portion of the study area there is a complex mixture of patch types, transitioning to a relatively large area of Patch Type D (gravelly sand). The central portion of the study area is comprised of a heterogenous mix of patch types of varying types and sizes, extending east into Fishers Island Sound.

3.3 Infauna

3.3.1 Total Abundance

Infaunal total abundances ranged from 1 to 967 individuals 0.1 m^{-2} (Figure 12). Sample abundance exhibited large spatial variation across the study area. Relatively low abundances were found at most sample sites along the southern boundary of the Phase II study area, as well as in an area to the southeast of the mouth of the Connecticut River. Moderate to high abundances were found throughout the central portion of the study area and in portions of Fishers Island Sound. Sample sites with locally high abundances were scattered throughout the Phase II area.

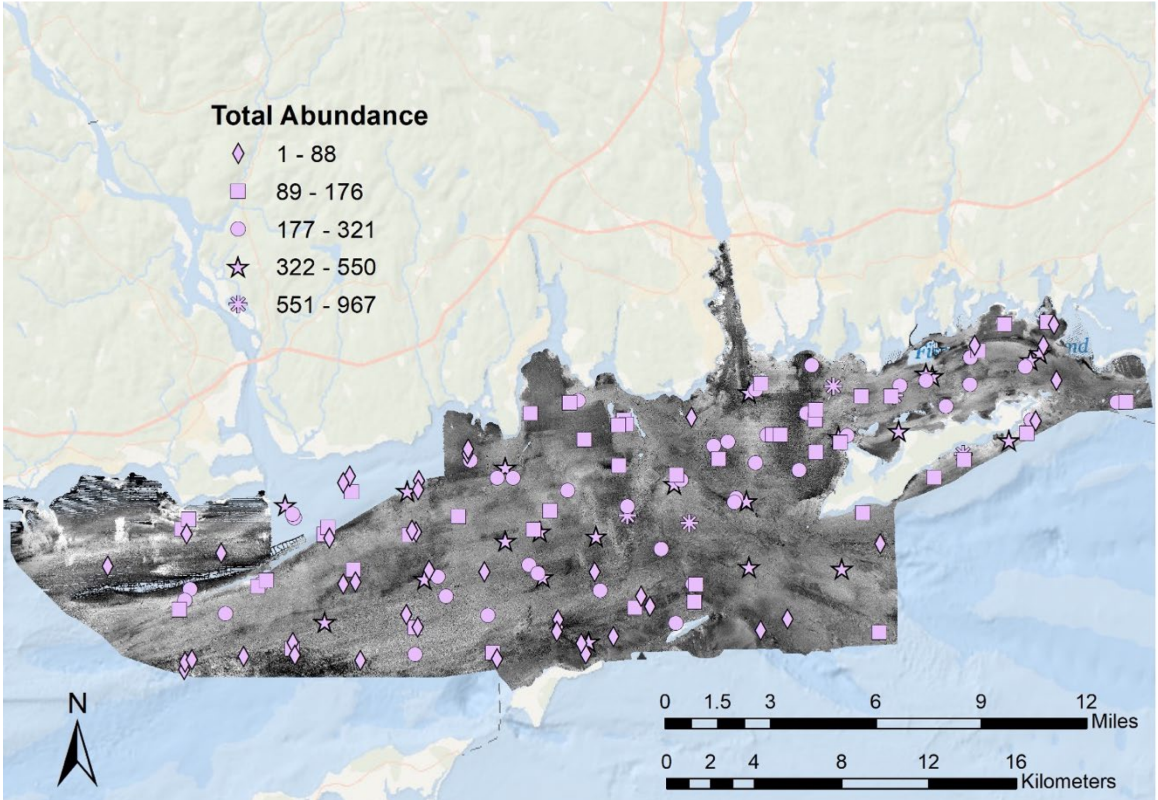


Figure 12. Total abundance of infauna 0.1 m^{-2} at each sample location in the PHASE II study area.

3.3.2 Taxonomic Richness

A total of 289 infaunal taxa were identified in all the samples collected in the LIS Phase II area. 85% of these were identified to the species level. Taxonomic richness ranged from 1 to 47 taxa 0.1m^{-2} (Figure 13). Similar to total sample abundance, taxonomic richness was relatively low at sites along the southern portion of the Phase II area. Higher richness was found at sites through the central portion of the area, and also at sites in Fishers Island Sound.

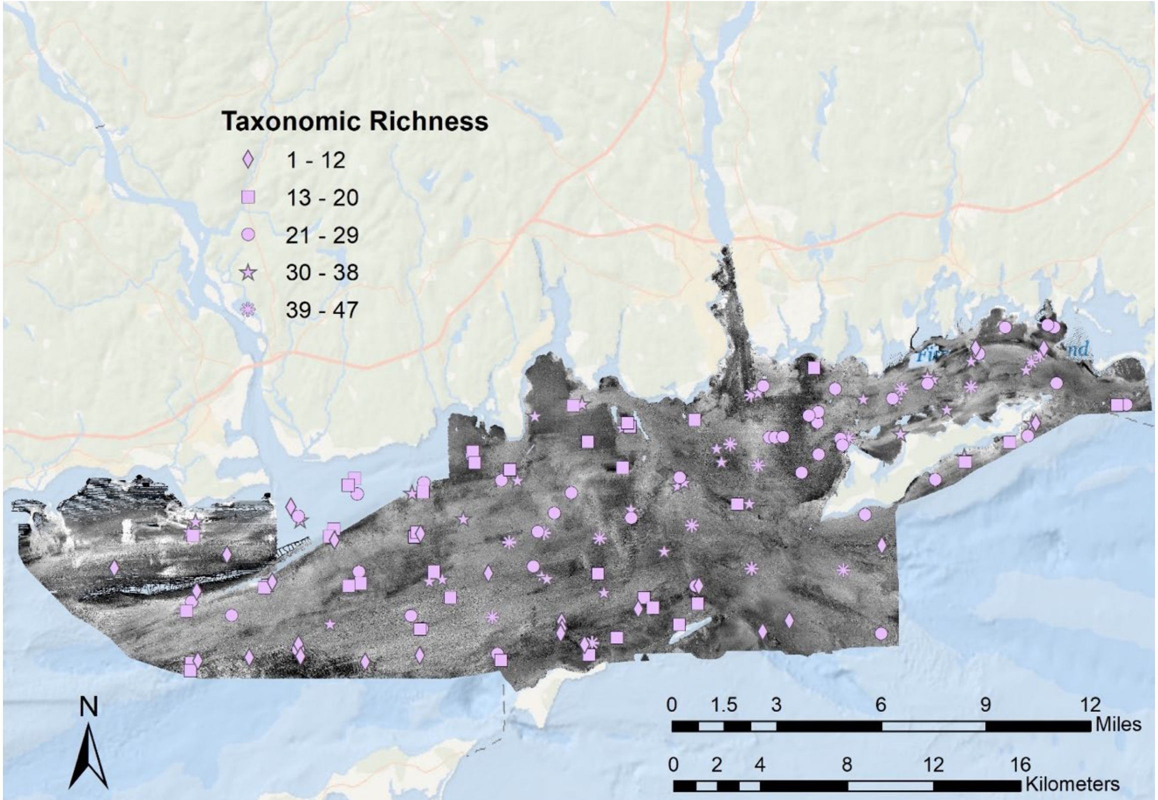


Figure 13. Total number of infaunal taxa (Taxonomic Richness) 0.1 m^{-2} at each sample location in the PHASE II study area.

3.3.3 Taxonomic Diversity

Taxonomic diversity, which takes into account both the number of taxa and their proportional abundance, was calculated using the Shannon diversity index H':

$$H' = -\sum_{=1}^{S}(pi \times log10pi)$$

where, S is the total number of species/taxa in the sample, pi is the proportion of individuals belonging to the ith species. Higher values of H' indicate greater species diversity. Shannon diversity ranged from approximately 0.18 to 1.4 (Figure 14). Shannon diversity exhibited a somewhat different spatial pattern than taxonomic richness, with more spatially constrained areas of high and low diversity. For example, there was relatively high diversity in the areas southeast of the mouth of the Connecticut River and also in the central portion of the Phase II area. There was a particularly large cluster of high infaunal diversity in samples taken south of the mouth of the Thames River, and into Fishers Island Sound.

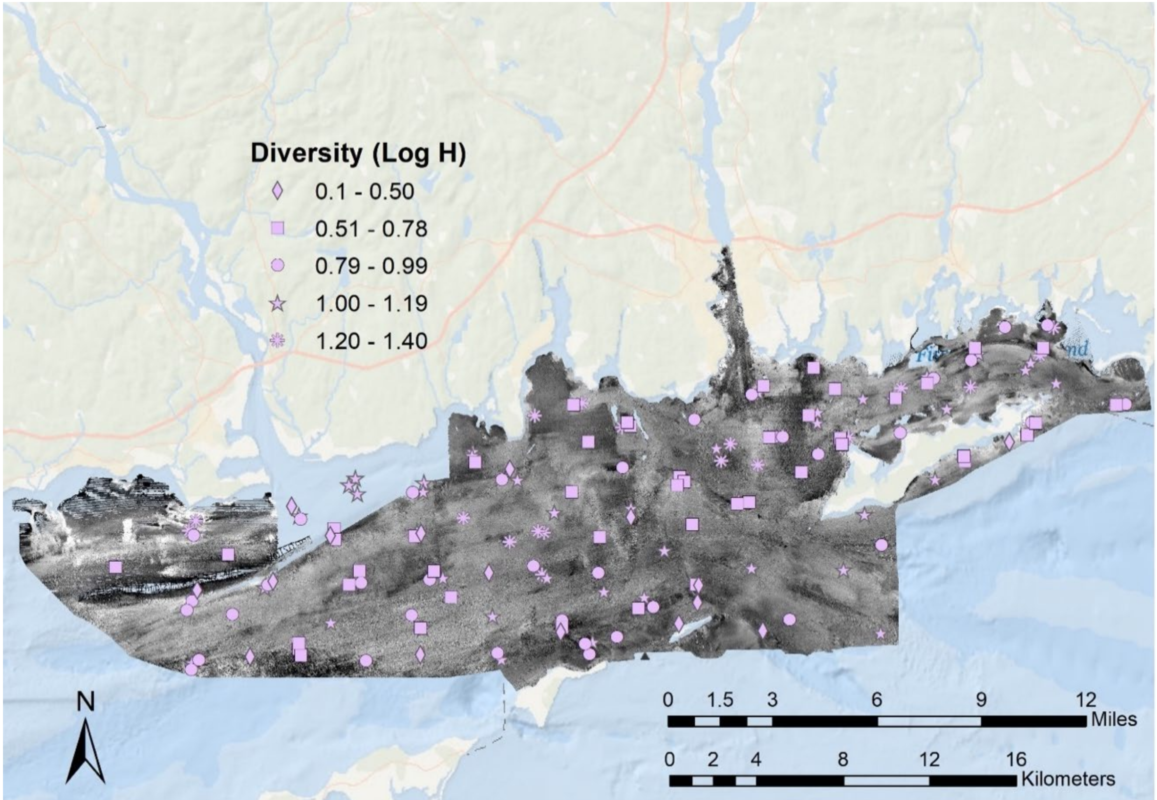


Figure 14. Taxonomic diversity H' 0.1 m^{-2} at each sample location in the PHASE II study area.

3.3.4 Numerically Dominant Taxa

The distributions of the most abundant taxa were also spatially variable. Three taxa, the amphipod *Ameplisca vadorum*, the maldanid polychaete *Praxiella praetermissa*, and the spionid polychaete *Marenzellaria viridis*, were most abundant along the northern sections of the Phase II area (Figure 15). *Ameplisca vadorum* and *Praxiella praetermissa* were also found in relatively high abundances in some of the deeper water sections of the central portion of the Phase II area. *Marenzellaria viridis* was most abundant southeast of the mouth of the CT River, and in Fishers Island Sound.

Five taxa were abundant throughout the deeper sections, as well as in some other locations, of the Phase II area (Figures 16 and 17). The capitellid polychaete *Mediomastis ambiseta* was most abundant through the center of the area, along the southern border northwest of Plum Island, and in Fishers Island Sound. Relatively high abundances were also found south of the mouth of the Connecticut River and Niantic Bay. *Spiophanes bombyx*, a small, tube building spioninid polychaete, was found in high abundances in the western half of the Phase II area, in a cluster south of the mouth of the Thames River, and in Fishers Island Sound. A small predatory polychaete, *Glycera capitata*, had a similar spatial distribution (Figure 16). A group of corophiid amphipods, *Corophium* spp. were distributed in high abundance through the central portion of the Phase II area, extending into the area of the Race southwest of Fishers Island, and also in Fishers Island Sound. A group of small bivalves within the genus *Astarte*, (designated as Astarte spp. as these may be juveniles of several other *Astarte* species that were found; alternatively, these may be *Astarte* *subaequilatera*) were found in very high abundances throughout the central portion of the Phase II area, and also in Fishers Island Sound, and south of Fishers Island (Figure 17).

Two of the dominant taxa found during the study had somewhat more limited spatial distributions. The slipper shell *Crepidula fornicata* was found in high abundance in the western portion of the Phase II area, and also in Fishers Island Sound, and south of Fishers Island (Figure 18). No individuals were found in deeper waters of the central portion of the area and southeast towards the Race. The terebellid polychaete *Polycirrus medusa* was found in high densities at several sites in the eastern most portion of the study area in deeper water, as well around the nearshore areas of Fishers Island (Figure 18).

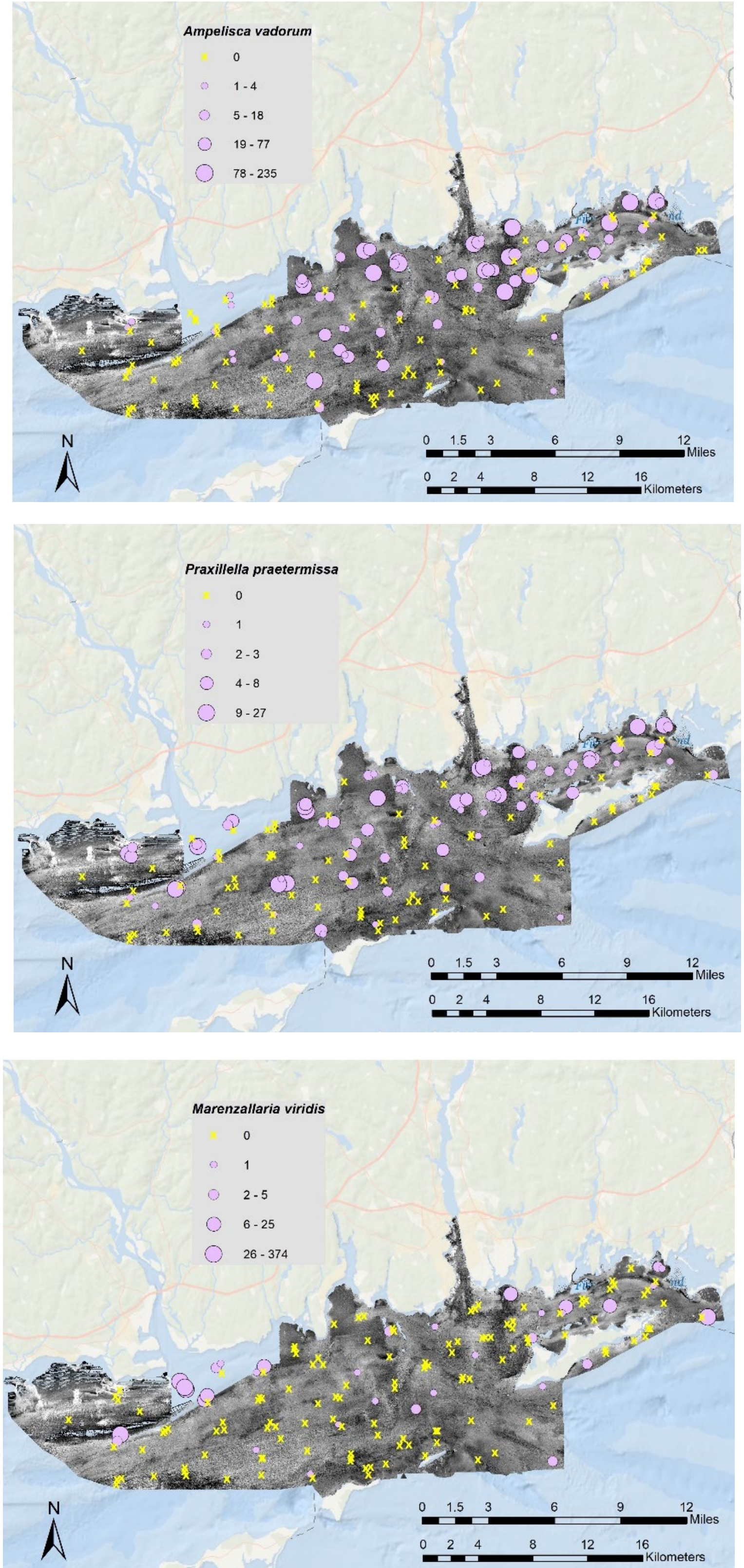


Figure 15. Spatial distribution of several dominant infaunal taxa that were primarily found in the northern portions of the Phase II study area.

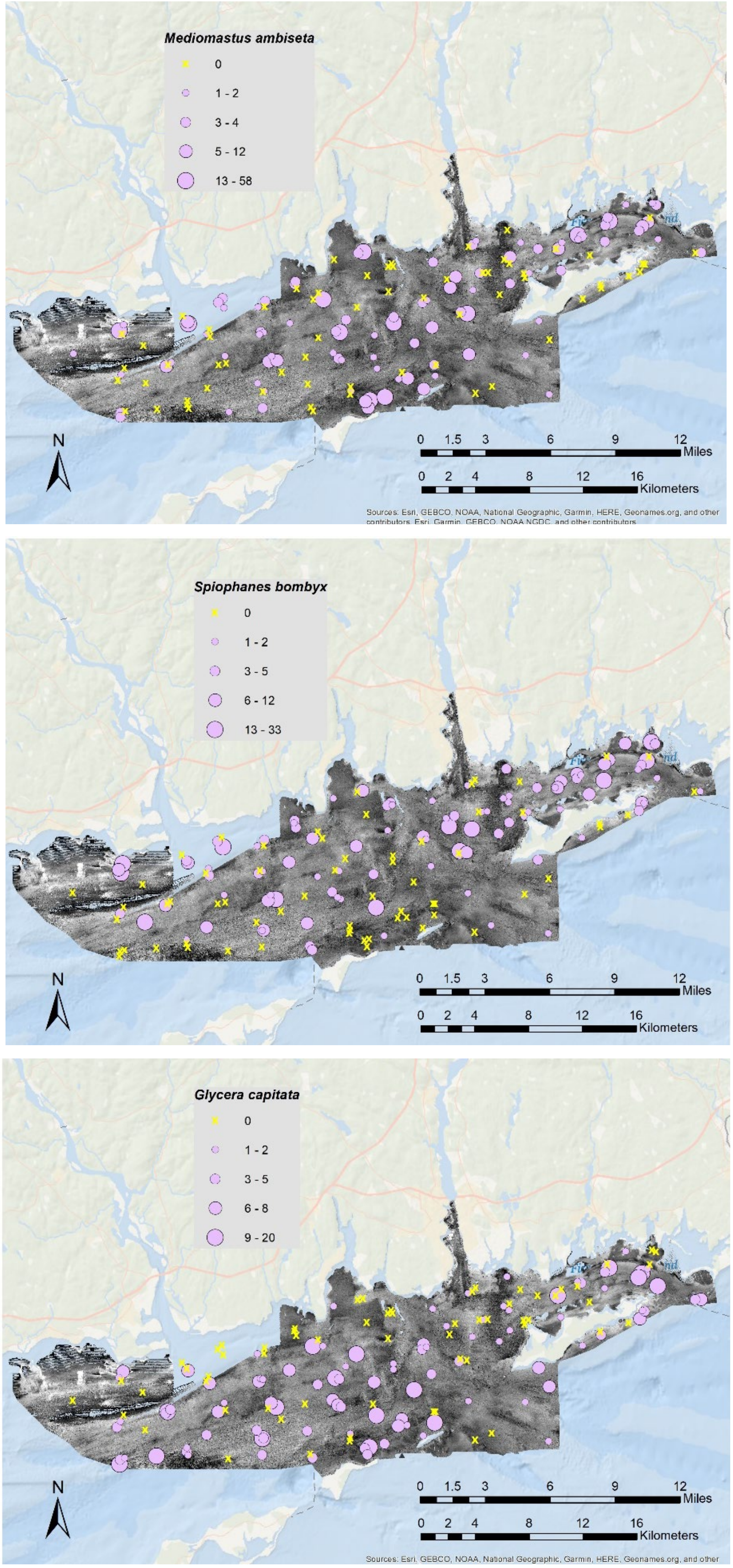


Figure 16. Spatial distribution of several dominant infaunal taxa that were found primarily in deeper waters in central portion of the Phase II study area, and in Fishers Island Sound.

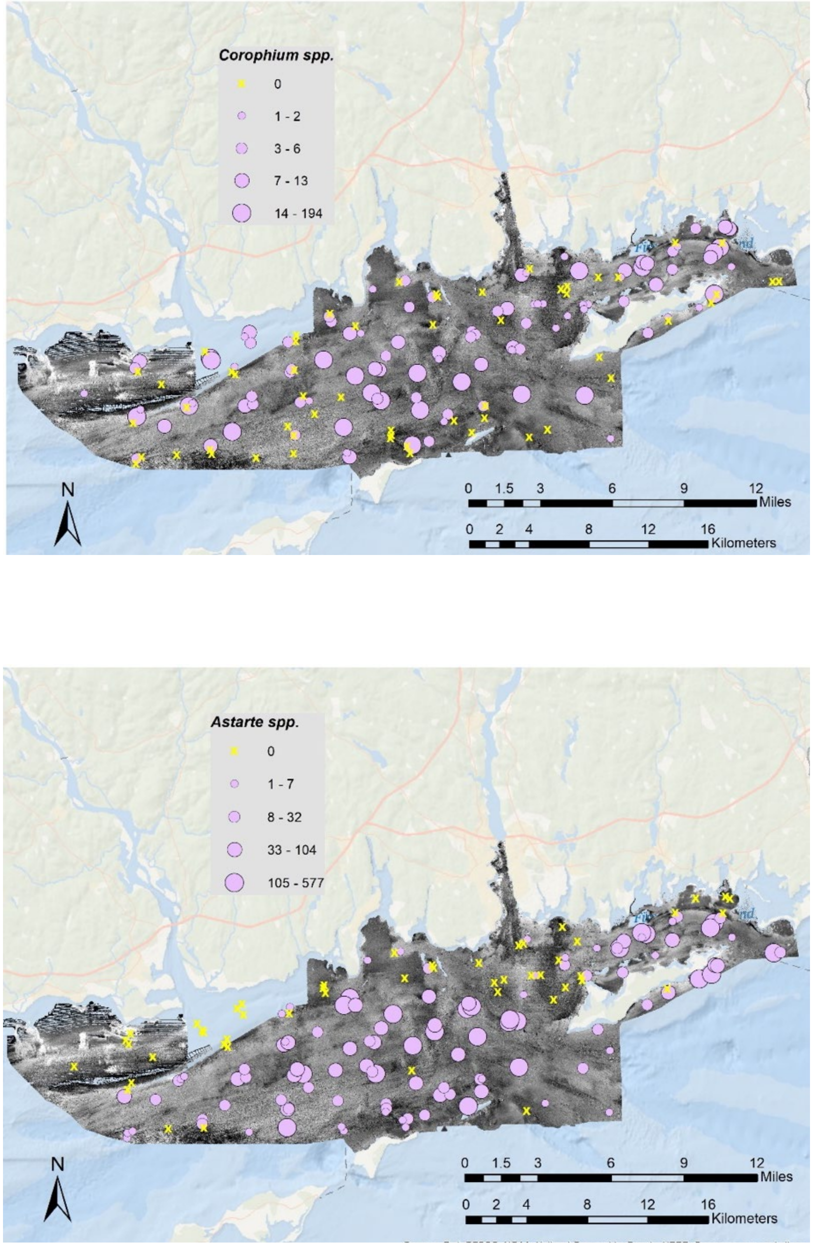
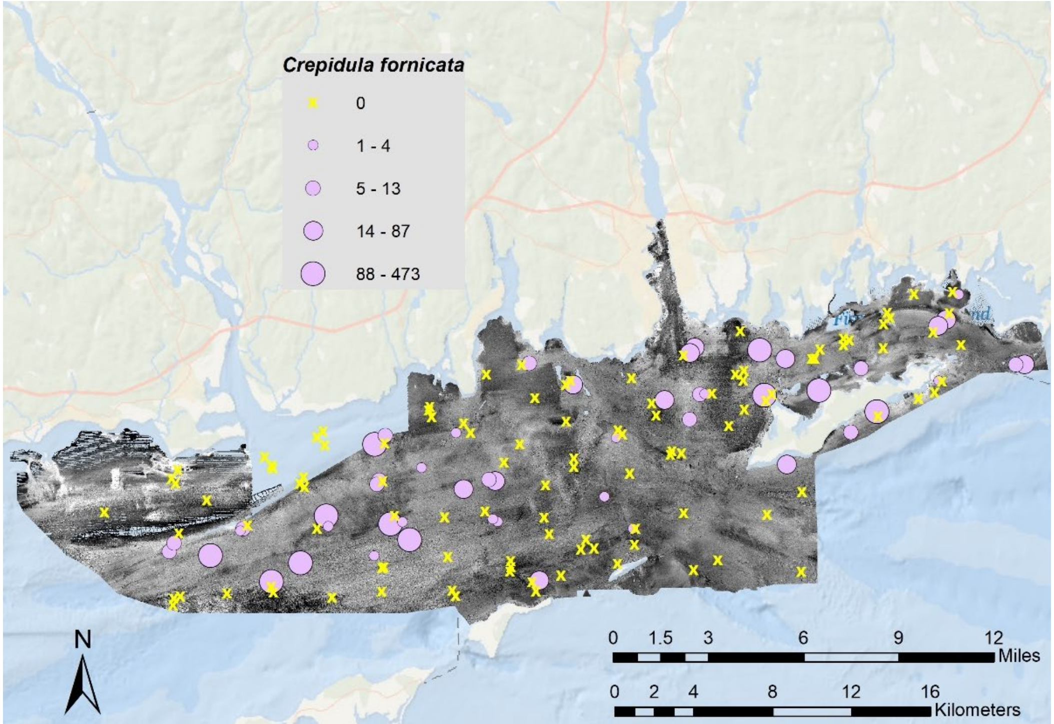


Figure 17. Spatial distribution of several dominant infaunal taxa that were found in deeper water in the central portion of the in the Phase II study area and around Fishers Island.



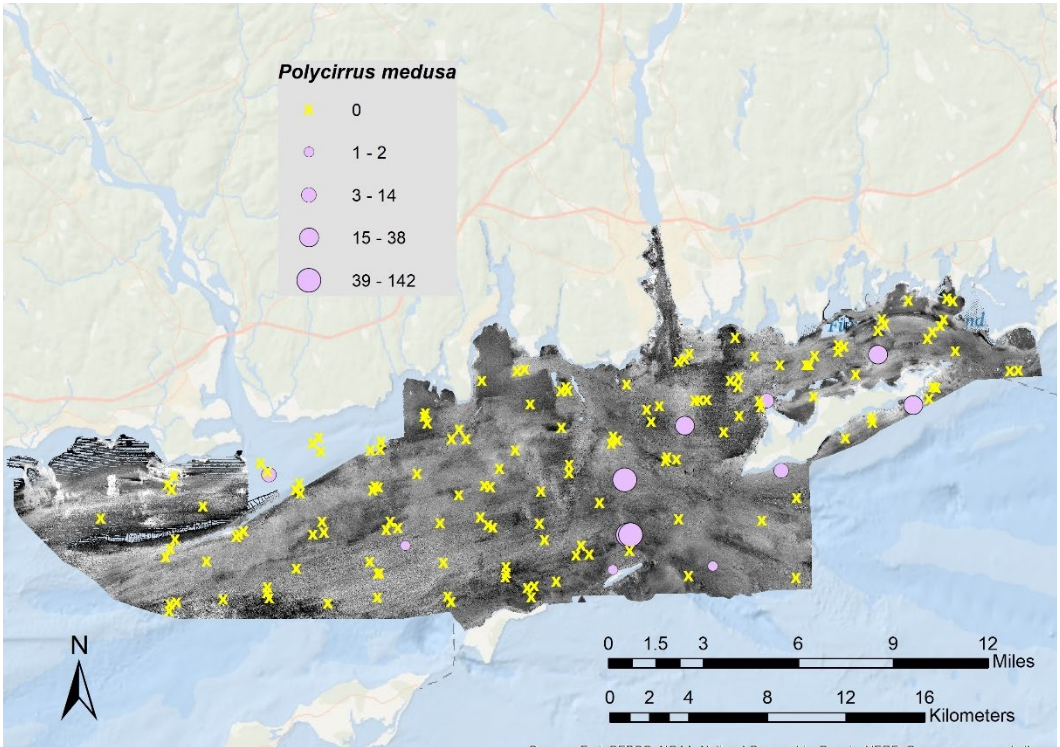


Figure. 18. Spatial distribution of several dominant infaunal taxa that had spatially variable distributions in the Phase II study area.

3.3.5 Infaunal Community Structure

Based on a series of multivariate analyses using the entire infaunal data set, 13 community types were designated (Figure 19). The levels of similarity among community types varied. Community types C, D, I, L and M had the most different communities from each other and the other community types; the other community types were fairly similar to each other. In general, infaunal community types showed a variety of spatial distributions across the Phase II area (Figure 19). The most prevalent community types C, J, K, L and M, were found primarily in specific areas of the Phase II area. Community type c was mostly distributed along the southern margins of the Phase II area, and also through the west central area. In relation to environmental conditions, these communities appear to be associated with higher sea floor rugosity, sand size-fractions in the range of ~ 1 to 0.25 mm (Φ 0 to1) and for some locations increasing depth. Community types J and K, which were relatively similar, were mostly distributed within the central portions of the Phase II area across the north to south breadth, with some J and K communities also found in Fishers Island Sound (Figure 19). These communities were found at greater depths within the Phase II area and had greater proportions of coarser sediment grain-sizes (~ 2 to 15 mm; Φ -1 to -4). Community type L was found primarily along the northern boundary of the Phase II area, in relatively shallower depths along the Connecticut shore, and was characterized by greater proportions of fine-grained sediments < 1 mm (Φ 3 to 8). Community type M was primarily found in the western portion of the Phase II area, south of the mouth of the Connecticut River, although there were a few sites with this community type in the eastern portions of the area. This community type was associated with high seafloor rugosity and mixed sediment grain sizes. Community type D was distributed through this area as well. The other community types were somewhat more scattered throughout the Phase II area.

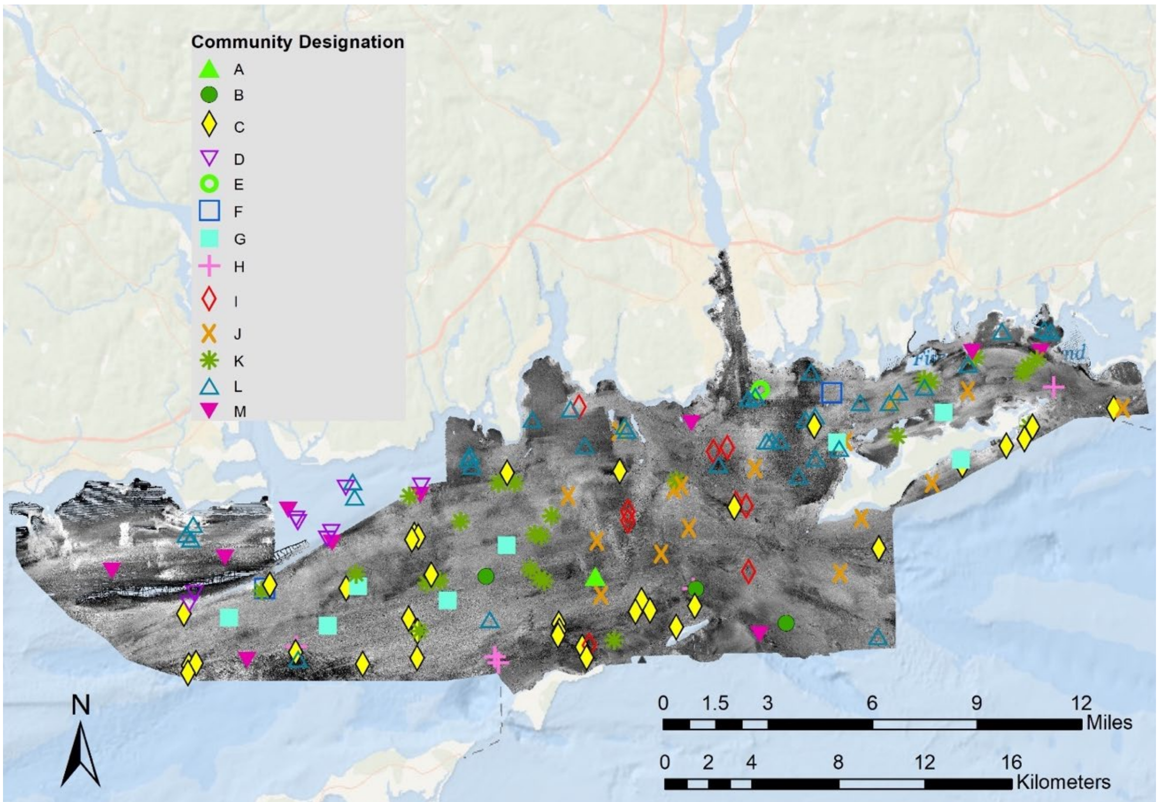


Figure 19. Spatial distribution of infaunal community types across the Phase II study area.

3.4 Epifauna

3.4.1 Epifaunal Diversity and Distribution of Communities

A total of 119 taxa were identified to the lowest possible taxonomic unit and additional 33 biogenic features, structures formed by organisms (e.g., shell, tubes, burrows) and used as habitat by vagile fauna were observed in the study region. The distribution and abundance of particular taxa (epi- and emergent- fauna) and biogenic features did not follow uniform geographic trends, reflecting the varied seafloor habitats characterized by grain size, seafloor roughness, seafloor stress (from current flows), depth (temperature and light), and west-to-east variation in conditions within the estuary. While multiple spatial patterns were identified that provide important insights, we identified multiple taxa and biogenic habitat features that represent larger gradients and general relationships between epifauna and physical characteristics of seafloor environments within the larger landscape. Noteworthy is that the most diverse sites are to the east in the study area and offshore, including eastern Fishers Island Sound, south of Fishers Island, and The Race (Figure 20).

Community composition also was differentially distributed (Figure 21). Image data were aggregated to block and site designations to identify large scale variation in community structure. Here we present the results of multivariate analyses with live taxa and biogenic features over both seasons. SIMPROF was used to identify similarities between sites at the 1% threshold level for hierarchical cluster analyses. These groupings were used as a factor for mMDS analysis, where 15 groups of sites were identified. Results of global ANOSIM were highly significant as were multiple paired comparisons. SIMPER identified the features and taxa that contributed most to dissimilarity between sites. However, these results, when visualized in a geospatial context provided little insight into general patterns of epifaunal and biogenic habitat distributions across the study area. We implemented a qualitative hierarchical approach for aggregating sites based on geographic proximity and similarity of ecological features. The most parsimonious was a set of four groupings representing general ecological settings - coastal, central LIS, Fishers Island Sound, and The Race (Figure 21). Note that there is a general west-east trend throughout. The coast region is quite variable. Coast sites are distributed principally along the coastal region in the western part of the study area while others found along the coast to the east are also distributed offshore (i.e., cluster groups B & C that make up the coast class are more similar to each other than they are to other cluster groups that include, but are not exclusive, to the nearshore area).

ANOSIM procedures demonstrated that post-hoc groupings were also highly significant. Results of SIMPER analyses demonstrated that the differential abundance of biogenic features composed of shell and terrestrial debris as well as structure forming taxa including hydrozoa/bryozoa, *Crepidula, Diadumene*, Rhodophyta, and Laminariaceae separated groups of sites at this large scale. Details of these analyses will be provided in the final report. Our objective here is to demonstrate that there are differences in community structure across the study region and all areas are not ecologically equivalent.

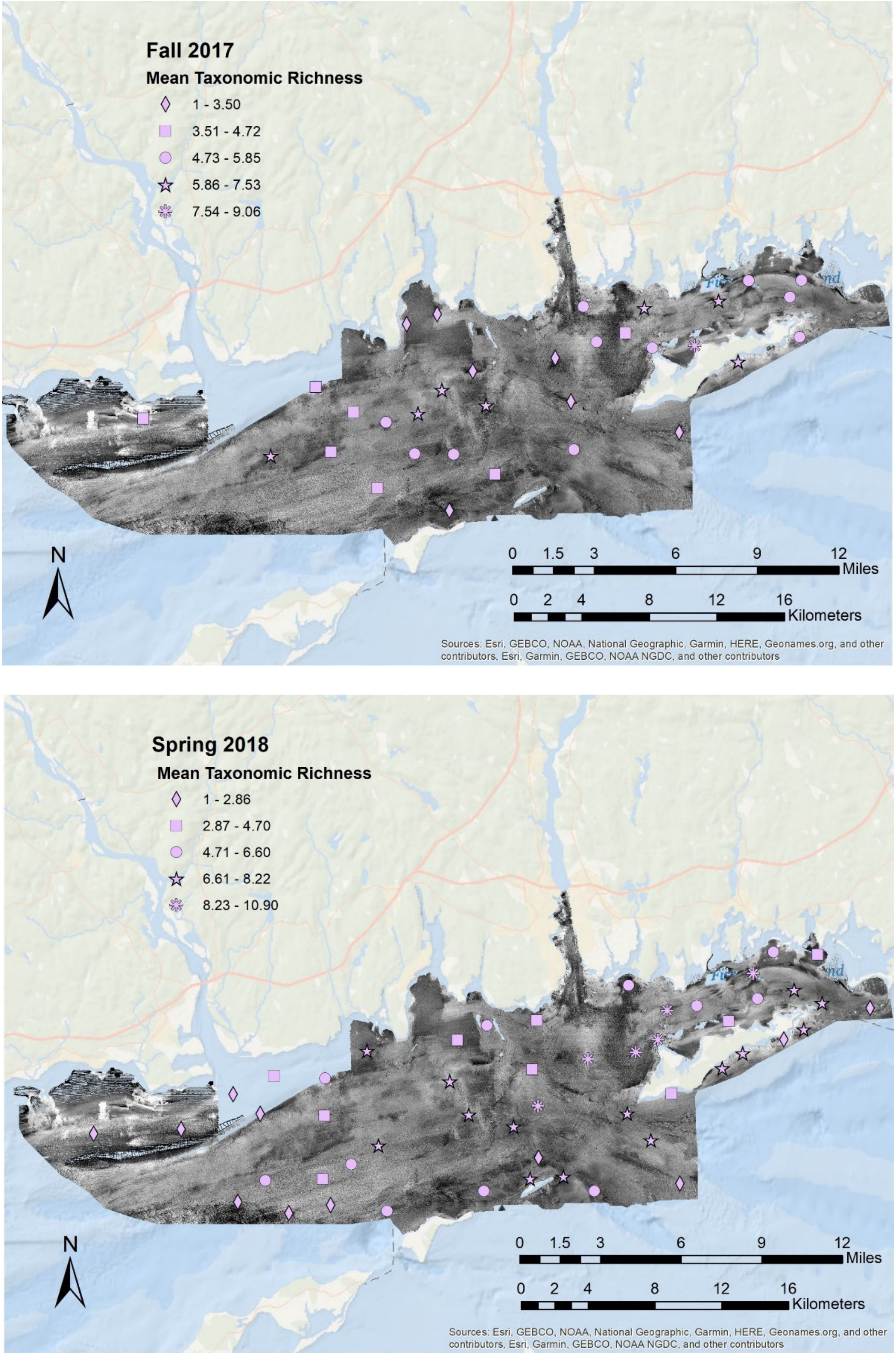


Figure 20. Mean epifaunal taxonomic richness for sites sampled in fall (top) and spring (bottom) at block-site level. Based on mean richness from image samples of variable size. Taxonomic richness parsed as quintiles.

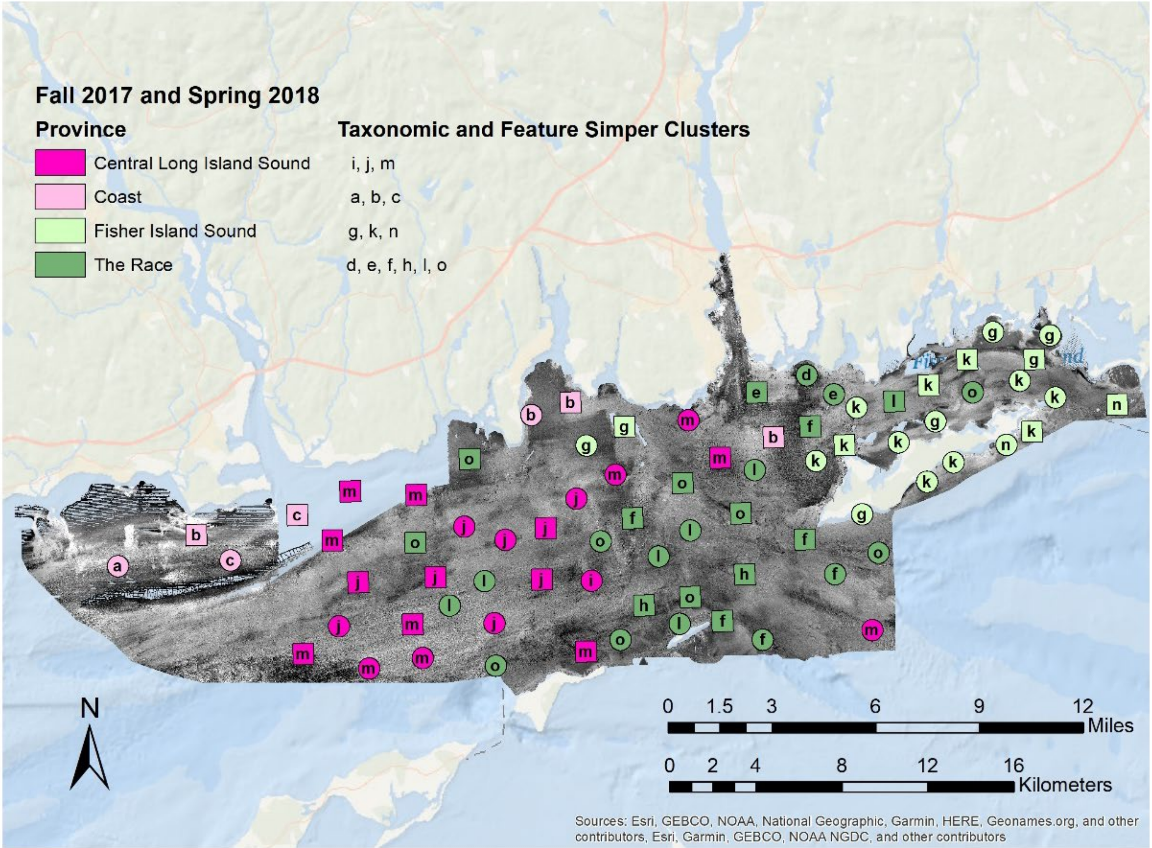


Figure 21. Distribution of community types based on block-site samples, identifying four major groupings and cluster members from multivariate analyses. See text for details of approach.

3.4.2 Taxon and Biogenic Features

Here we present a series of maps that show the distribution and abundance of sea floor biogenic features and epifaunal taxa with diverse life histories and fill important functional roles as seafloor habitat. Most of these taxa are structure forming, serving an “ecosystem engineering” role, while the biogenic features are themselves structure. These structures are utilized by vagile fauna for shelter from currents and predators (for physiological benefits and survivorship, respectively) as well as aggregating prey (e.g., amphipods, decapod shrimp) ad used as foci for feeding (Cau et al. 2020).

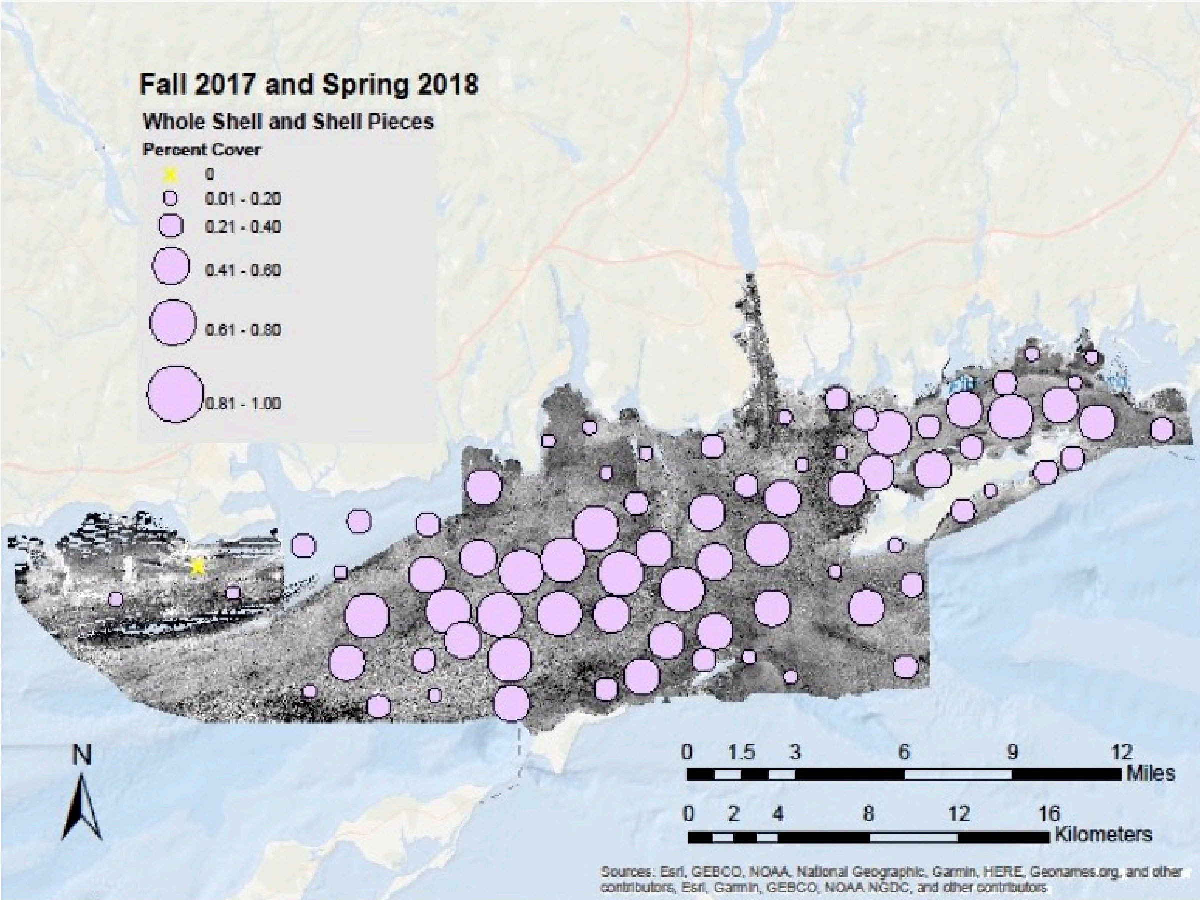


Figure 22. Shell as whole and partial valves, especially in dense aggregates, is an important habitat feature, used by mobile fauna (e.g., Auster et al. 1991, 1995; Langton et al. 1995; Zajac et al. 2020). Species of ecological and economic importance (decapod crustaceans that serve as prey, juveniles of fish such as black sea bass, scup, red hake) use shell surfaces and interstices as flow refuges and shelter from predators.

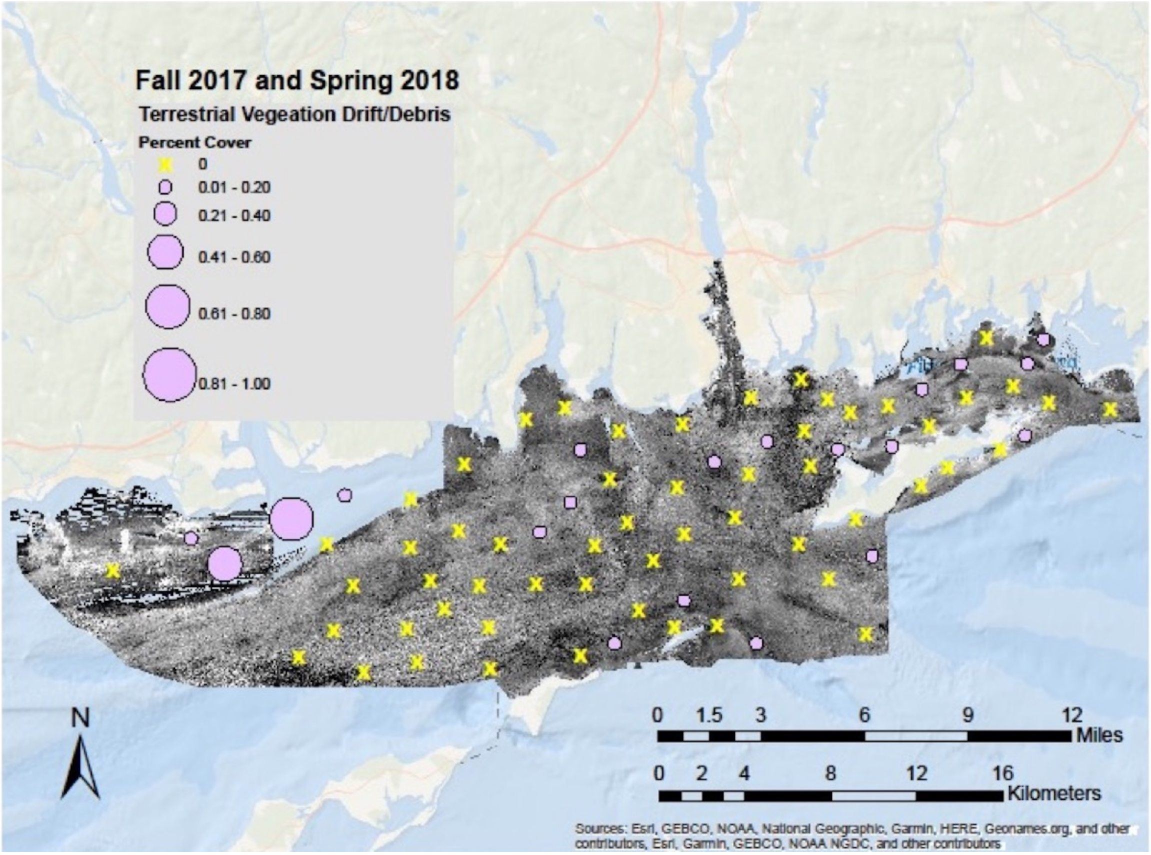


Figure 23. Seagrass, principally *Zostera marina* and terrestrial debris exhibit seasonal and storm related breakage and form mats/aggregates that drift over and lodge on the seafloor, moving to deep water. Such mats serve as habitat for mobile fauna, aggregating sources of prey (e.g., crustaceans) for larger predators, and provide shade resources and food for herbivores and detritivores, and transport carbon offshore to degrade and decompose.

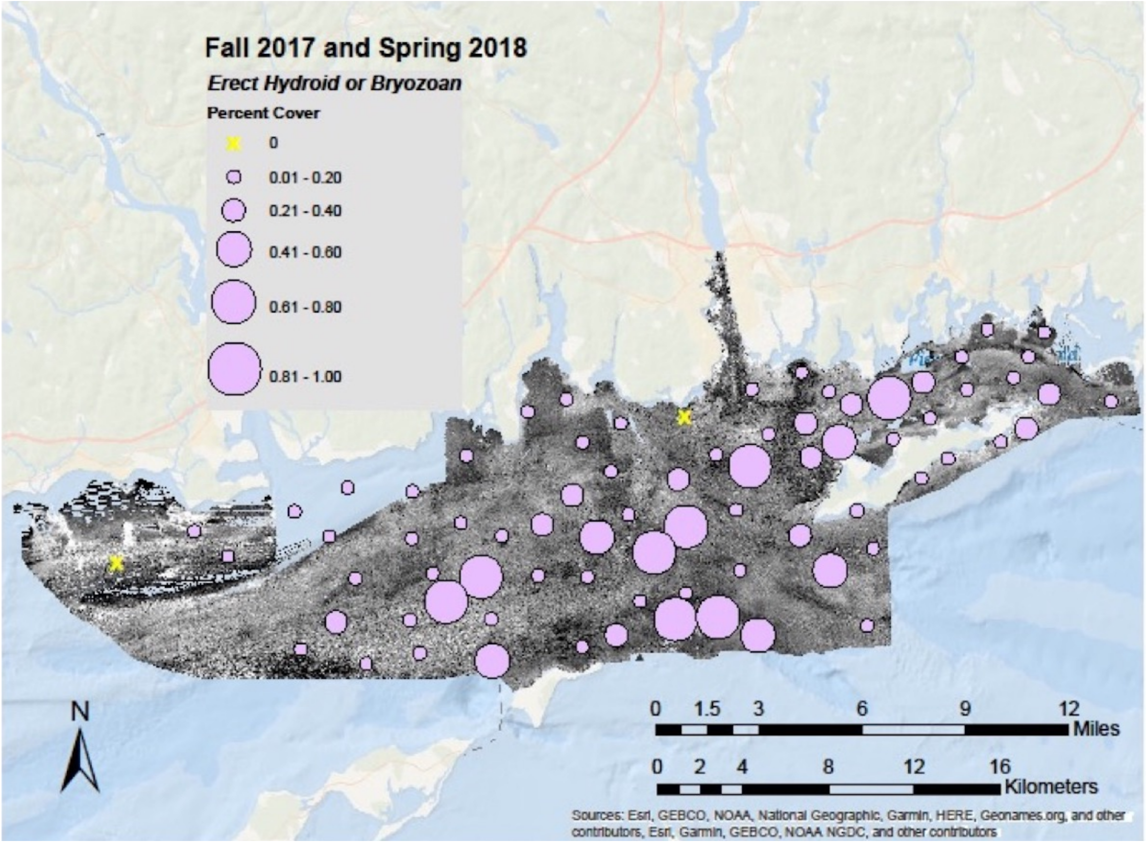


Figure 24. Hydrozoan and bryozoan turfs were very common throughout the Phase II study area, especially east of the Connecticut River towards the Race and in western Fishers Island Sound. Dense turfs were most common in highly structured habitats across available depths, covering available hard substrates. These dense aggregations serve as cover for small sizes of many mobile species. Hydroids exhibit seasonal recruitment due to short life-histories. These taxa also provide structure for small crustacea that are important prey items for vagile fauna like crustacean eating fishes (Cau et al 2020).

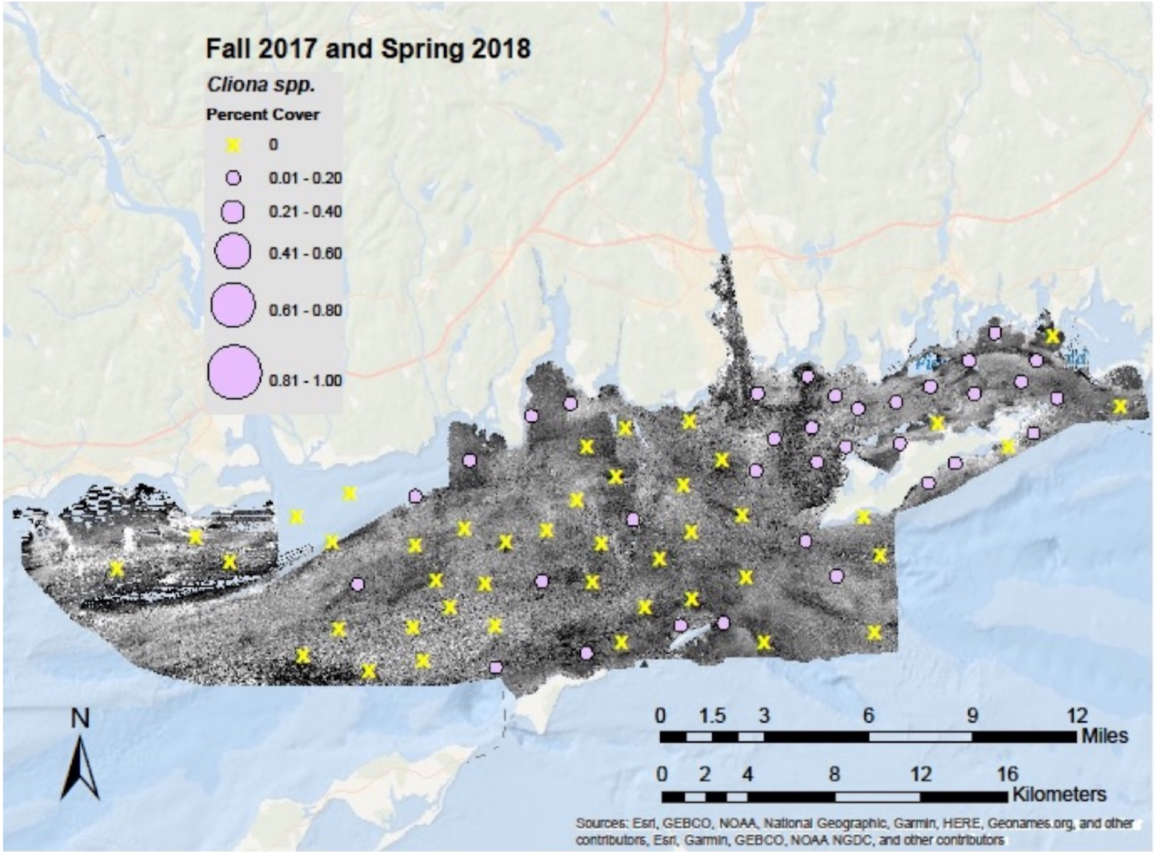


Figure 25. Boring sponge (Genus *Cliona*) colonies were scattered throughout the Phase II study area east of the Connecticut River. Clionaid sponges were especially common along the shore from Hatchett Point into Niantic Bay, in the Race, and throughout Fishers Island Sound. Boring sponges were especially common in shallow habitats featuring substantial spatial structure, but also were frequently found in deeper, less complex habitats. Clionaid sponges excavate into calcium carbonate substrates and are common marine and estuarine demosponges. Once established, colonies may grow to form large, encrusting colonies or even upright towers reaching 0.5m in height (Rosell and Uriz 2002). Such massive towers of Clionaid sponge provide substantial structure for mobile macrofauna, including fish, and can grow in fine sediment substrates with the presence of mollusk shell as an initial substrate for attachment.

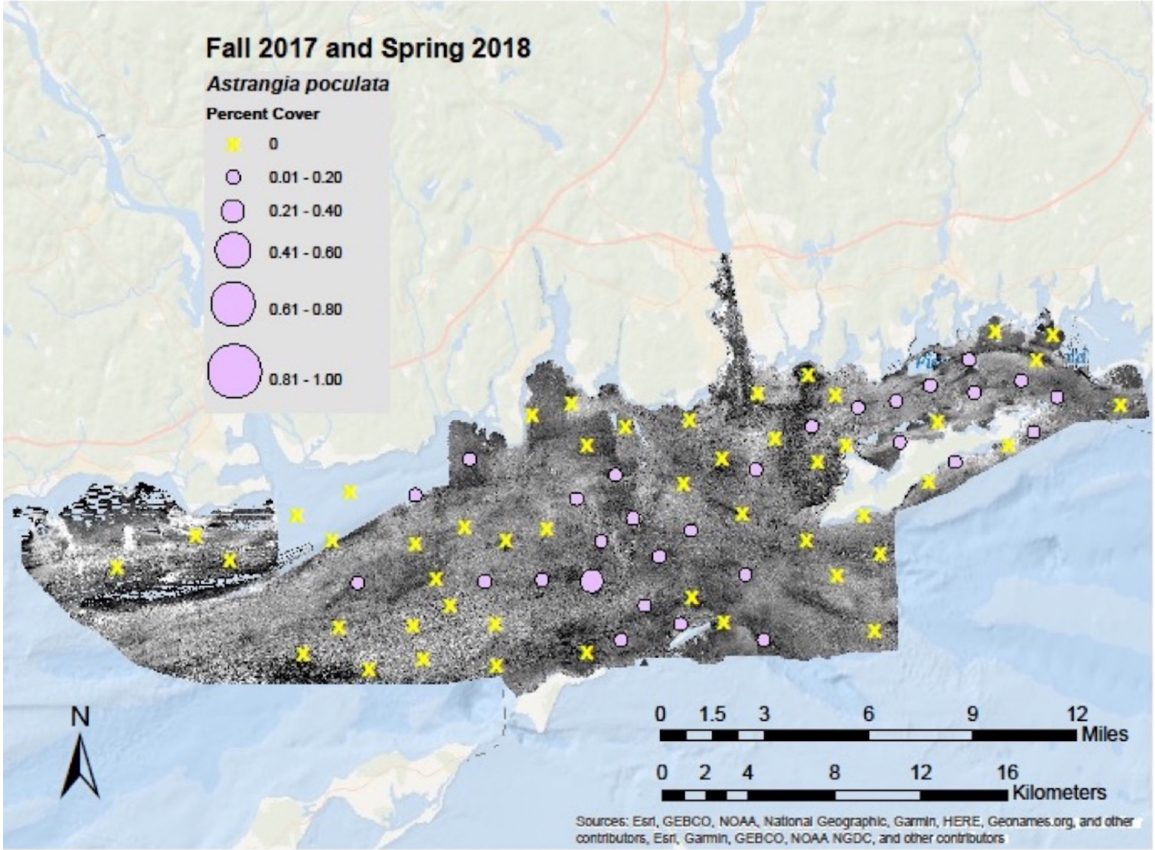


Figure 26. Northern star coral *Astrangia poculata* was common in 2 spatial clusters: central Fishers Island Sound, and at the western margin of the Race and around the deep scours adjacent to Valiant Rock. This coral is a temperate stony coral endemic to the North American continental shelf. While not reef-building, Northern star coral does increase the complexity of hard substrates due to its calcium carbonate “stony” skeleton. While capable of surviving as a heterotroph, coral growth is greatly enhanced by the autotrophy of symbiont photosynthetic dinoflagellates (Dimond and Carrington 2007). Despite this, few Northern star coral are found in the shallowest coastal habitats due to tidal current and wave disturbance and competition, especially macroalgae (Jacques et al. 1983; Grace 2004). For this reason, ideal Northern star coral habitats are limited. Although most common in areas that featured ample hard substrates, northern star coral was present at more than 5% of sample locations in areas characterized by silty sand. In these areas dominated by fine sediments, corals grew on isolated hard substrates such as scattered cobbles.

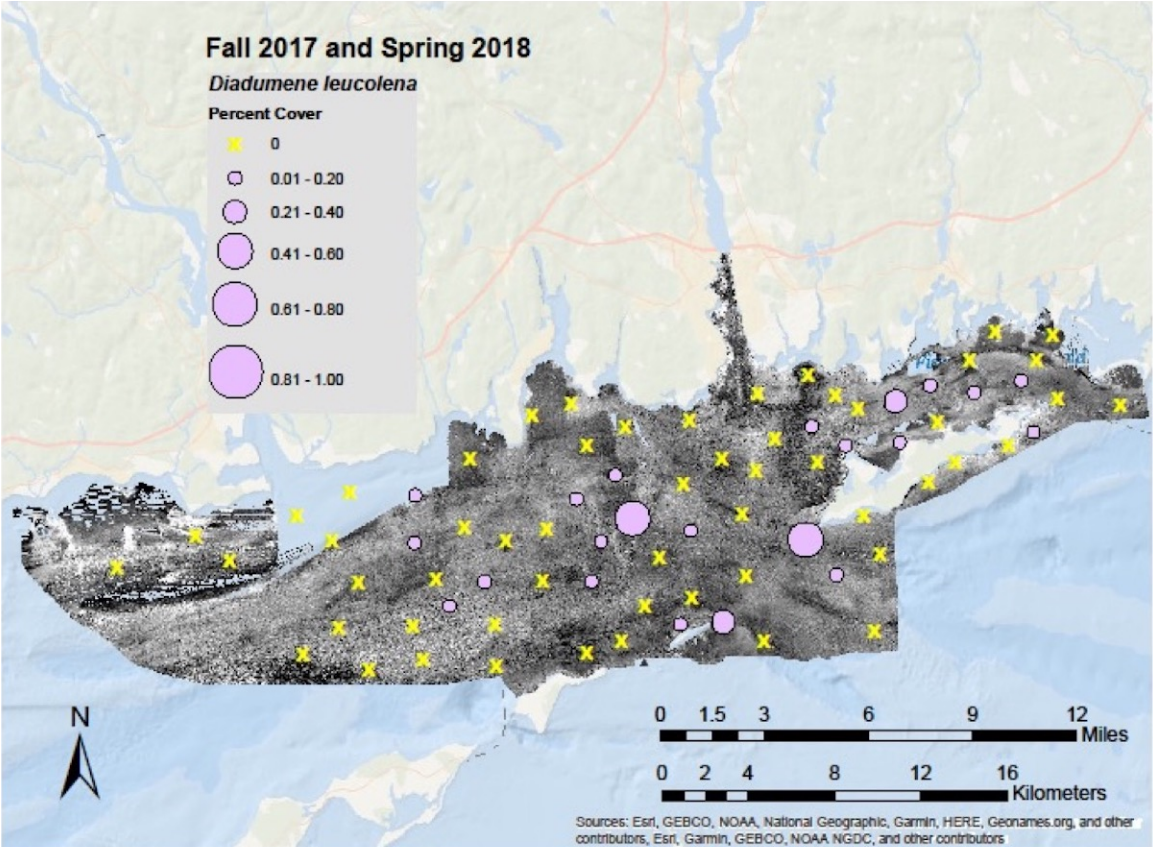


Figure 27. Ghost anemones *Diadumene leucolena* were scattered across the eastern 2/3 of the Phase II study area and were most densely concentrated at the Race and to the West of this feature. Largely limited to highly structured habitats in Long Island Sound, ghost anemones attach to hard substrates and are especially dense in areas that experience strong tidal currents. Despite the threat of their toxin-containing nematocysts, ghost anemones are preyed on by gastropods (*this is mostly documented in areas where it is invasive*). Ghost anemones increase the structural complexity of the hard substrates where they attach.

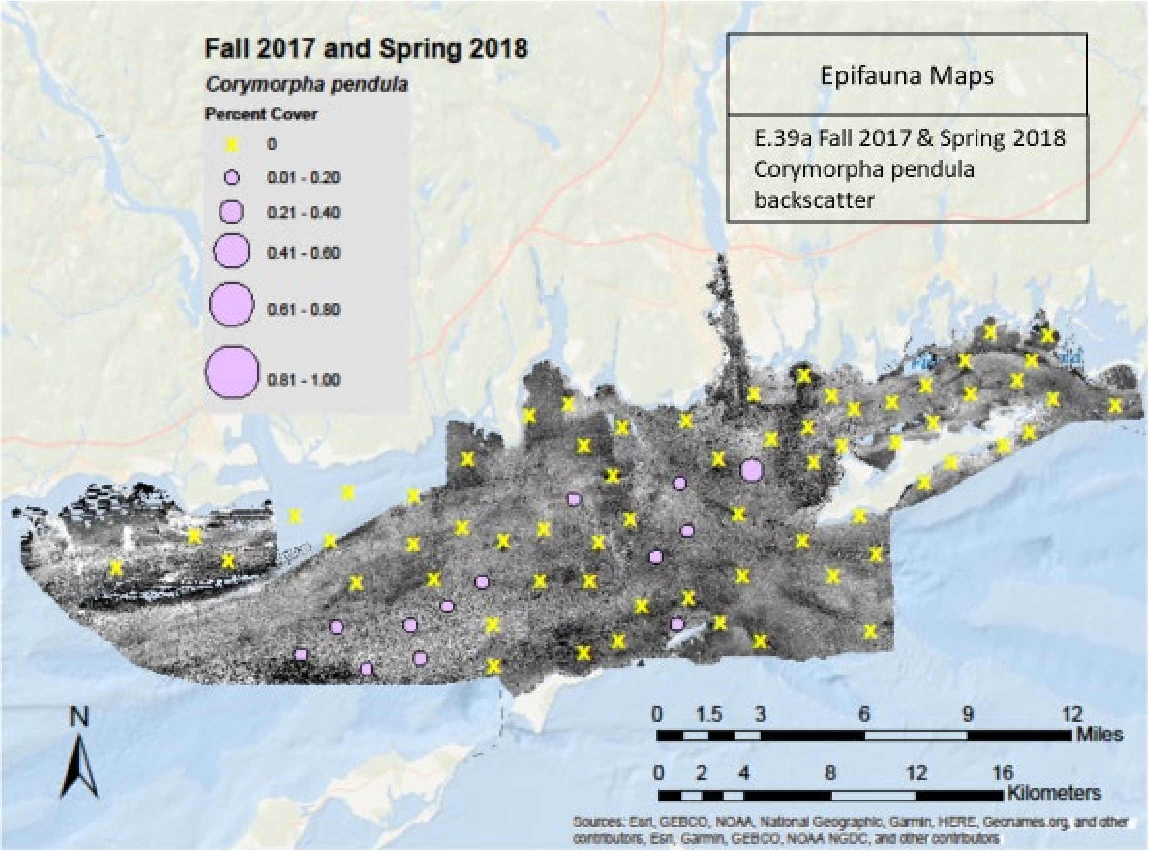


Figure 28. *Corymorpha pendula*, an ephemeral, emergent hydroid found in fine sediment seafloor habitats, was most common at the southwestern extent of the Phase II sampling effort and was most consistently abundant in a patch midway between the Thames River and the Race. These areas were characterized by flat, unstructured seafloor. When densely aggregated these hydroids form important habitats for other sessile as well as mobile organisms (Cau et al. 2020; Byer and Grabowski 2014). *C. pendula* can be found late winter through spring, although spatial distributions may change year-to-year and are absent in summer and fall.

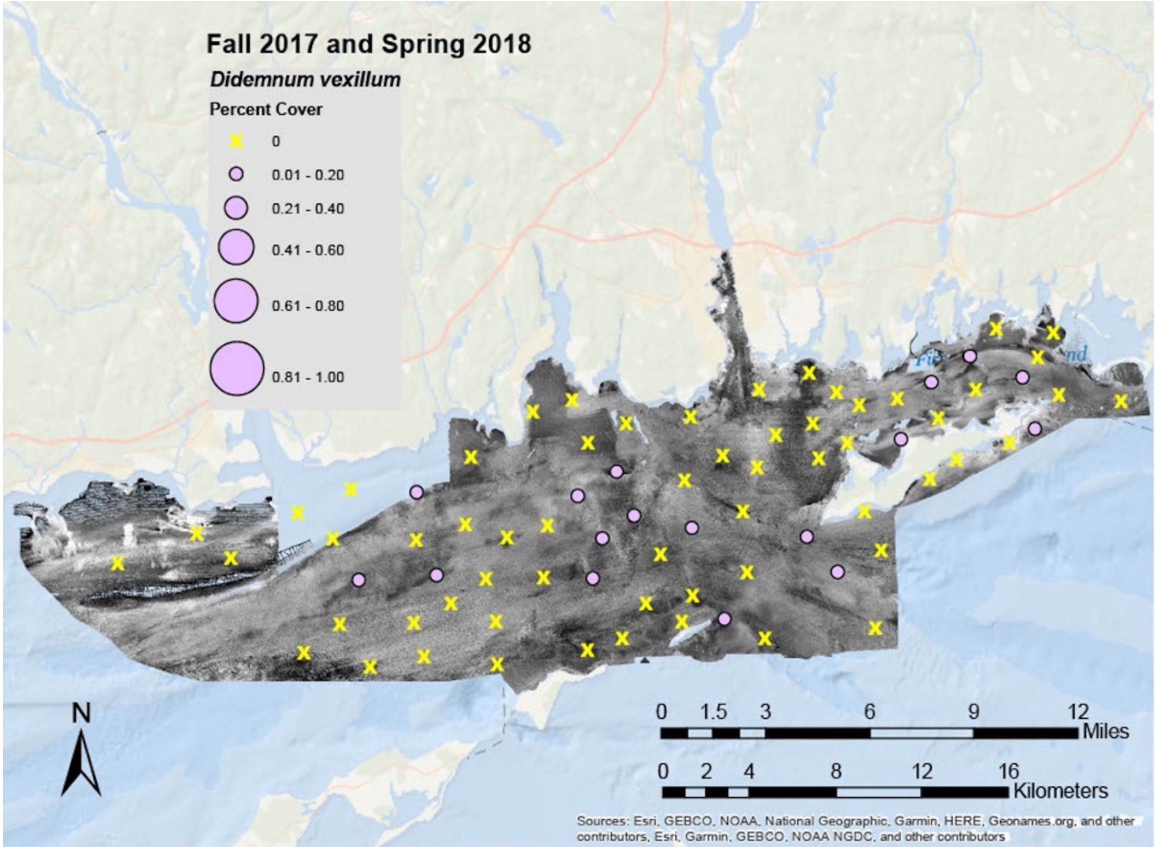


Figure 29. The carpet tunicate, *Didemnum vexillum*, is an invasive colonial tunicate that has been introduced worldwide. Endemic to shallow Northern Pacific shelf substrates, carpet tunicate has been introduced worldwide over the past 20 years, with instances of major impacts on endemic seafloor communities (Mercer et al. 2009). This species is generally dominant in Long Island Sound in comparison to the native *Didemnum candidum*.

Colonial tunicates in the Genus *Didemnum* are widely distributed throughout temperate to tropical waters worldwide. Within the study area, *Didemnum* colonies were widely scattered, but were especially common in Fishers Island Sound and west of the Race. In this latter area was also where the largest colonies were observed. *Didemnum* mostly found attached to hard substrates in deeper complex habitats characterized by strong bottom currents. Colonies can form sheets on hard substrates that may envelope other attached organisms, but also can enhance structural complexity and form refuges for small mobile organisms. Representatives of this Genus in Long Island Sound include the native *D. candidum* and the global invasive *D. vexillum*.

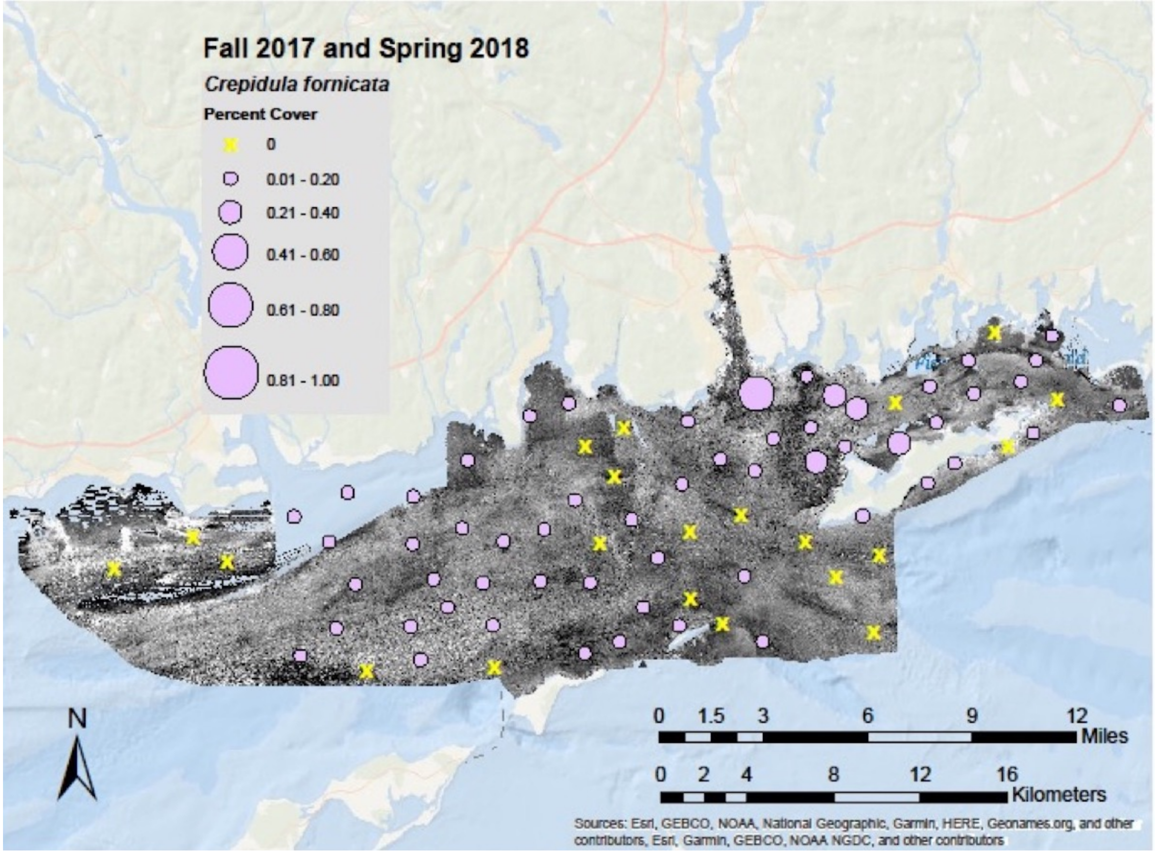


Figure 30. Atlantic slipper shell, *Crepidula fornicata*, is a filter-feeding gastropod that attaches to hard substrates. Despite this, slipper shells can form dense aggregations on fine sediments by attaching to shell, usually conspecifics (Foster et al. 2016). These "stacks" of slipper shells also provide opportunities for reproduction. Slipper shells were a common, and often abundant presence throughout the study area. At the mouth of the Thames River and the western edge of Fishers Island Sound, large continuous slipper shell aggregations dominated large patches of seafloor. These aggregations provide hard substrates for other organisms to attach to and are often colonized by diverse communities of epifauna and flora, including Rhodophyta, Clionaid sponges, hydrozoans, encrusting bryozoans, and bivalves. As density increases, these aggregations may form elevated reef structures (Ackerman et al. 2015).

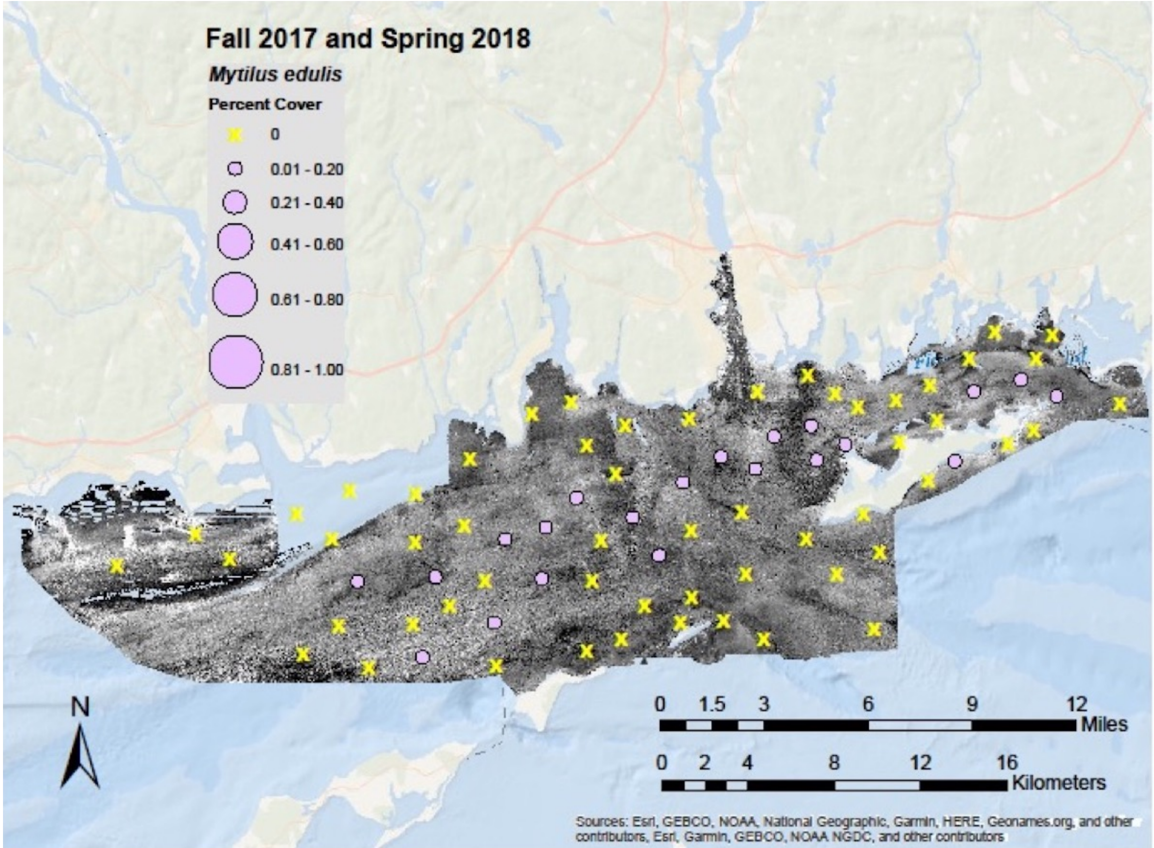


Figure 31. Blue mussels *Mytilus edulis* are filter feeding bivalves that attach to hard substrates using byssal thread. Mussel aggregations can form complex, dense 3-dimensional structures that provide refuge for many mobile invertebrates. This is especially important on fine sediments, as mussel mats bound by byssal threads can provide the only hard substrates for epifauna to colonize. Blue mussel aggregations are associated with more diverse and productive seafloor communities (zu Ermgassen et al. 2020). Once a dominant species in eastern Long Island Sound (Pellegrino and Hubbard 1983), it appears that its abundance and distribution may have declined relative to previous reports and observations. Dense aggregations are largely limited to Fishers Island Sound. Distribution was scattered and abundance low in other parts of the study area.

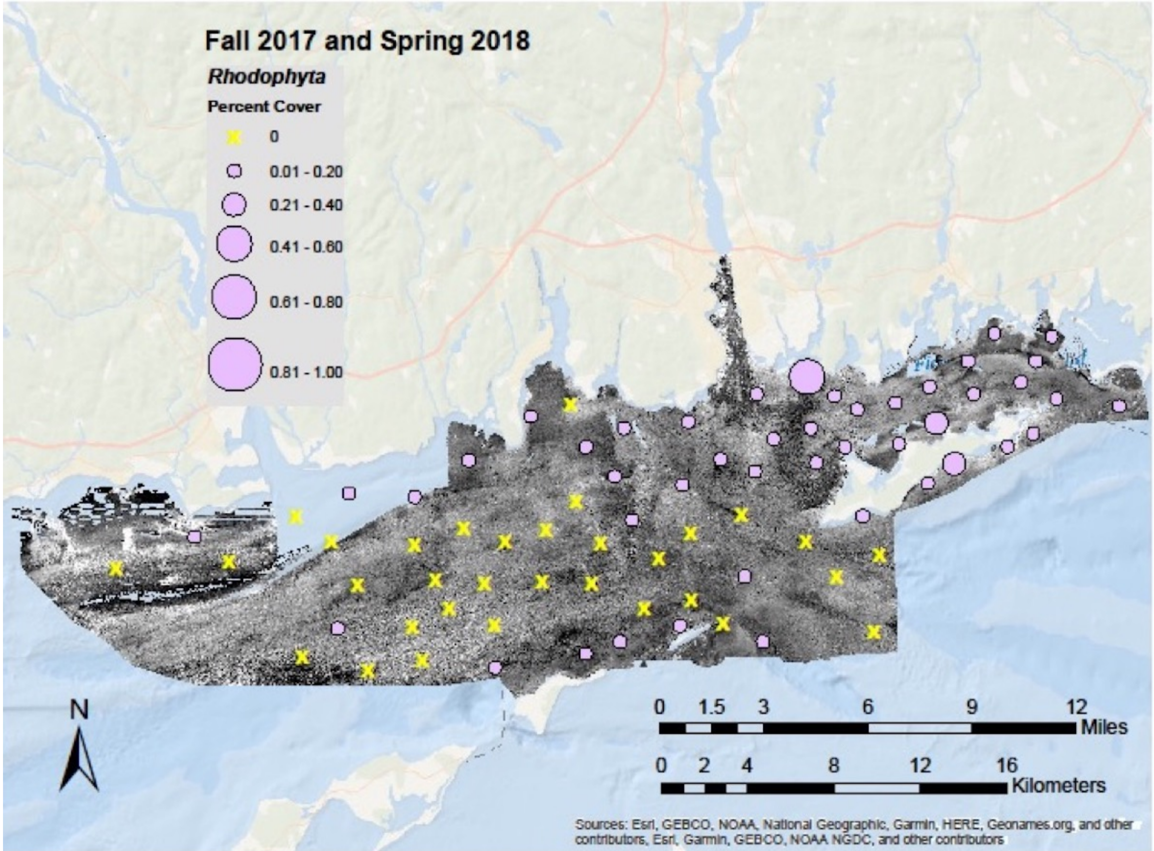


Figure 32. Rhodopyta, red algae, were nearly ubiquitous across the eastern half of the Phase II study area- from the southern edge of Fishers Island, through Fishers Island Sound, and continuing west along the coast to the Connecticut River. Densities were particularly high in Fishers Island Sound and off of Fishers Island. Numerous taxa often co-occurred, including bushy *Polysophonia* spp., thin branching *Ahnfiletia picata* and *Polyides rotundes*, and fairly broad-leafed *Chondrus crispus*. These diverse forms provide refuge for small, mobile organisms.

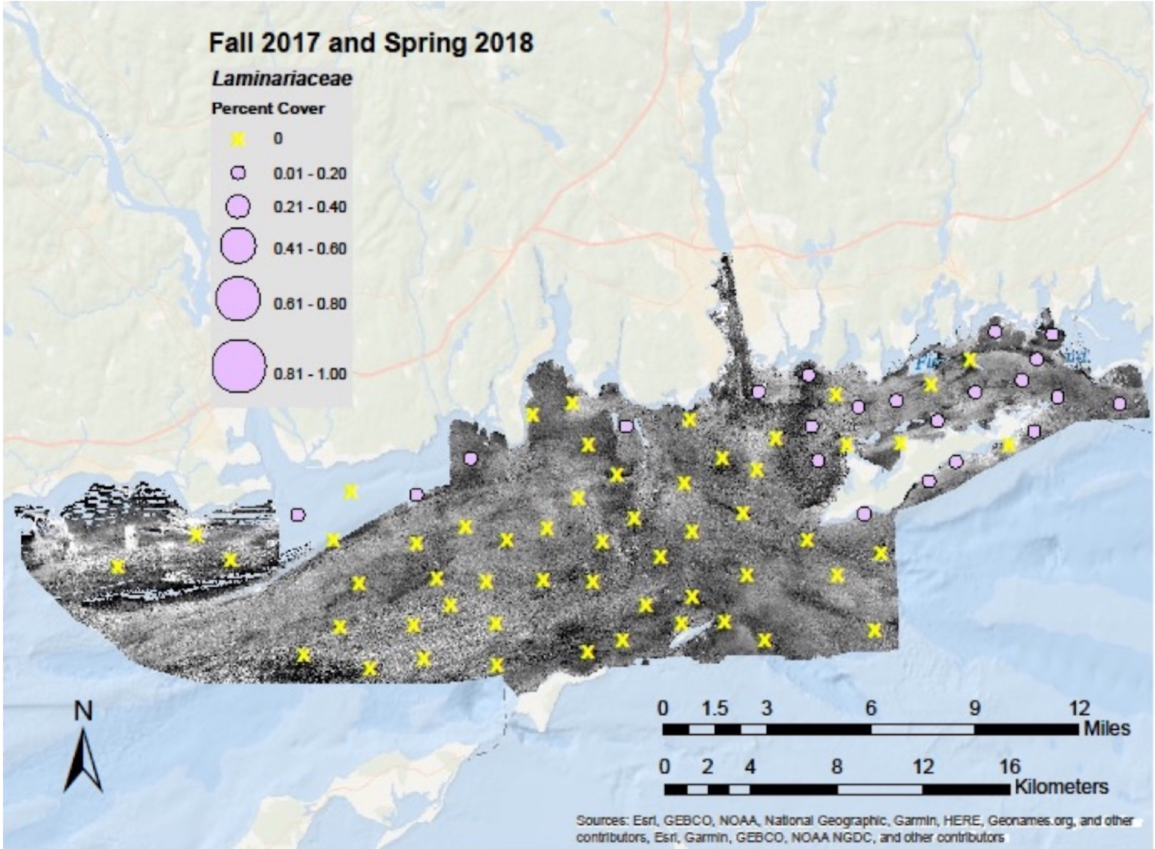


Figure 33. Although less abundant than Rhodophyta, kelp, algae in the Family Laminariaceae, were similarly distributed. While mostly present as single fronds, kelp was dominant in isolated locations, especially the shallow rocky reefs at the mouth of the Thames River. Despite their sparse concentrations, kelp play a structuring role when present, limiting light availability to the bottom and even disturbing attached organisms via abrasion due to the movement of their fronds in tidal currents (Jacques et al. 1983; Grace 2004). Kelp increases habitat complexity and even provides a substrate for other organisms.

4.0 DISCUSSION

The results presented in this preliminary report, along with associated data and GIS shape files, are intended to inform ongoing discussions and analyses regarding renewable energy development projects that are being planned. This report focuses on the sea floor ecology of eastern Long Island Sound as the currently proposed buried power cables traverse and potentially affect the seafloor. Basic grab sample and image analyses are complete so the results provided here are essentially in final form, although some final corrections and adjustments may still be required. We present data across the entire Phase 2 study area to provide spatial context. It is also important to acknowledge that while the results presented here have gone through degrees of review within subgroups of the project teams, the results are preliminary with final review and preparation of final project reports in progress. A geodatabase providing shapefiles for the ecological data presented here is available by request (contact information on cover page).

5.0 ACKNOWLEDGEMENTS

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