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Benthic Habitat Distribution and Subsurface Geology Selected Sites from the Rhode Island Ocean Special Area Management Study Area

by

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Executive Summary

The goal of this study was to use acoustic surveys (swath bathymetry, side-scan and sub-bottom sonar) and ground-truth surveys to delineate the benthic habitat distribution, subsurface geology, and cultural resources for selected sites within the RI Ocean SAMP study area. Benthic habitat distribution and subsurface geology were examined for two large sites, one in state waters to the south of Block Island (BI) and one in federal waters (FED) in eastern RI Sound. Cultural resources were studied at BI only. A total of more than 150 square miles were surveyed and further characterized by ground-truth studies. Preliminary results of the benthic environment characterization suggest that in order to complete a bottom-up integration of the data, as has been completed for smaller-scale projects, a greater density in ground-truth samples would be necessary. The recommended approach, therefore, is to use the top-down method to describe the benthic biological assemblages found within each depositional environment type. This relationship was found to be statistically strong and significant in BI, but data are not yet available for FED. The top-down approach will produce full-coverage habitat maps for both BI and FED that describe general, broad-scale patterns in both geological and biological resources. The subsurface geology studies revealed that locations to the south of Block Island were large enough and had sufficient thicknesses of unconsolidated sediments to allow installation of foundation structures by pile driving thereby facilitating the construction of a small wind farm. In addition, the area of the buried valley structures in the central FED area and the general western FED area had a sufficient thickness of unconsolidated sediments to facilitate the installation of a larger wind farm. However further work is probably necessary to the west and to the south of The FED area to find sufficient space for a 100+ turbine wind farm.

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1. General Introduction for Benthic Habitat Distribution and Subsurface Geology

This report represents the current status of, and subsequent ground-truth and archaeology studies done for the Rhode Island Ocean SAMP (RI SAMP) between August, 2008 and the present. The RI SAMP study area is shown in Figure I-1. Some of the work is ongoing and additional data will be added to this report in the near future. The report is structured in three subsections: (1) subsurface geology and (2) benthic habitat distribution. The subsurface geology and benthic habitat sections are focused on a large survey area around the south end of Block Island, and a large survey area in Federal waters located in eastern Rhode Island Sound

2. General Background

The project team leadership consists of geologists, geophysicists, biologists, and archaeologists. The names, affiliations , and areas of expertise are summarized in Table 1, below.

Table 1: Project Science Team

NAME	AFFILIATION	EXPERTISE
John W. King	Professor, URI Graduate School of Oceanography	Geology, Geophysics, Habitat Mapping
Jon Boothroyd	Professor, URI Department of Geosciences; Rhode Island State Geologist	Geology, Geophysics, Habitat Mapping
Rob Pockalny	Marine Research Scientist, Graduate School of Oceanography, URI	Geophysics, Geology, Mapping
Sheldon Pratt	Research Associate, Graduate School of Oceanography, URI	Benthic Biology, Habitat Mapping
Sam Debow	Manager, Operations, Graduate School of Oceanography, Special Research	Ship operations, Bathymetry and Sidescan Sonar Mapping

The SAMP study area is too large (approximately 1500 square miles) to be surveyed in detail in this study. Therefore, the results of prior studies were compiled to determine the extent of existing coverage and to identify data gaps. Existing coverage was not extensive. In addition, areas that would be potential sites for development of offshore wind farms based on multiple criteria (Spaulding, et al., 2010), including minimal user conflict, were identified. Two areas were examined in detail, one within Block Island Sound (BIS) and the other in eastern Rhode Island Sound (RIS). The BIS study area (referred to as BI hereafter) is located within state waters around the south end of Block Island (Figure I-2). The Rhode Island Sound study area (referred to as FED hereafter) is located in Federal waters to the west of Martha's Vineyard.

3. General Methods for Acoustic Data Acquisition and Processing

The data for the 53.5 square mile BI study area were obtained in September 2008 on the R/V Endeavor over a period of ten days and over ten days on the R/V Eastern Surveyor during July and August of 2009. For the 68 square mile FED study area, data was collected in part during an August, 2009 4-day cruise on the EPA R/V Bold, and in September 2009 on the R/V Endeavor during a nine day cruise. During the surveys, raw data was continuously recorded in digital XTF format using Triton Isis (BI 2008) or in digital OIC format using Ocean Imaging Consultants (OIC) GeoDas (BI 2009, FED) acquisition software and monitored in real-time with a topside processor. A differential GPS assured positional accuracy (submeter horizontal accuracy) of the data. A TSS Meridian Gyroscope corrected for vessel heading (+/- 0.60° secant latitude dynamic accuracy, 0.10° secant latitude static error). A TSS DMS-05 motion reference unit (MRU) offered real-time correction of the vessel's pitch, heave, and roll (+/- 0.05° dynamic accuracy). An Applanix POS-MV system was used for motion correction o the 2009 Endeavor cruise. All survey lines were planned and logged in real-time using Hypack (version 6.2a) navigation software. Each survey was composed of parallel track lines spaced such that 100% or greater cover was achieved. Survey speed was between 4 and 6 knots.

We use a pole-mounted custom composite system that consists of a Teledyne Benthos C3D-LPM interferometric sonar to acquire swath bathymetric and sidescan sonar data. In addition, a Teledyne Benthos CHIRP III/3.5 kHz subbottom sonar system is integrated into the pole-mounted body. The subbottom system can be switched from a high-resolution CHIRP mode to 3.5 kHz mode when deeper subbottom penetration is needed. The subbottom system has a simultaneous trigger that prevents acoustic interference with the C3D system. The composite system allows simultaneous acquisition of bathymetry, sidescan, and subbottom data. The range of the bathymetry data is 10X the water depth, whereas the sidescan range is approximately 20X the water depth. In order to achieve 100 % survey coverage, the line spacing is determined based on the 10X range of the bathymetry coverage. A 100m line spacing works well in depths of 10 -15 m. Bottom penetration using the CHIRP system was limited in areas of hard bottom. In these areas we used a more powerful Datasonics Bubble Pulser system to obtain deeper penetration. The line spacing used for the Bubble Pulser was 500-1000 meters.

The raw XTF and OIC files were processed into side scan backscatter (2 m pixel resolution) and bathymetry (10 m) mosaics using Cleansweep (version 3.4.25551, 64-bit) software (Ocean Imaging Consultants, Inc., Honolulu, HI). For the side scan, bottom tracking, angle- varying gains (AVG) and look-up tables (LUT) were applied to the data as necessary to correct for water column returns, arrival angle, and to increase the signal-to-noise ratio of the backscatter returns. These corrections helped create a uniform image that most effectively displayed the features of the seafloor. The backscatter intensity mosaic is displayed on an inverse grey-scale, ranging from zero (black) to 255 (white). Backscatter intensity indicates the density, slope and roughness of the seafloor, where lighter pixels represent highly reflective (usually harder) surfaces, and dark backscatter pixels represent acoustically absorbent (usually softer) bottoms. The final side scan backscatter and bathymetry mosaics were exported as geo-referenced .tiff files and ArcGrid files, respectively.

SECTION 1: BENTHIC HABITAT DISTRIBUTION

1.1 Introduction

Maps of the benthic environment are important marine spatial planning tools for understanding the ecosystem services provided to humans (food, nutrient cycling, storm buffering, aesthetic) and for measuring the impacts of our past and future activities (resource extraction, recreation, dredging, construction) (McArthur 2010). The Interagency Ocean Policy Taskforce has identified "habitat maps" as foundational data for the management and planning of U.S. nearshore and offshore waters (IOPTF, 2009). Our operative definition of "habitat" is that of the National Oceanic and Atmospheric Administration (NOAA): "bottom environments with distinct physical, geochemical, and biological characteristics that may vary widely depending upon their location and depth; often characterized by dominant structural features and biological communities." (NOAA CSC, 2010). Further, the ICES stresses that benthic habitats consist of both abiotic (substrate, bathymetry and water energy) and biotic (flora and fauna) components (ICES 2006). The activity of "habitat mapping" has been defined as "plotting the distribution and extent of habitats to create a complete coverage map of the seabed with distinct boundaries separating adjacent habitats" representing the "best estimate of habitat distribution at a point in time, making best use of the knowledge…available at that time." (Foster-Smith et al., 2007).

A simplified list of steps to habitat mapping has been proposed by Van Lancker and Foster-Smith (2007): (1) Process coverage (side scan, bathymetry) data; (2) Process ground-truth data; (3) Integrate the coverage and ground-truth data; (4) Design and layout the habitat map. The most important step of the four outlined above is the integration step, which has been accomplished using different strategies and methods depending on the types of data available and the overall goals of the mapping project. Marine benthic habitat mapping has traditionally consisted of a "top-down" protocol where acoustic tools are used to delineate landscape-level features that are usually geological in origin, followed by the ground-truthing of these features and biological characteristics (Brown et al., 2002, Solan et al., 2003, Eastwood et al., 2006). The adoption of this approach implies that acoustic classes or geologic features contain distinct biological assemblages. As a result, the sampling scheme and subsequent data integration process, where habitats are defined, is often geology-centric (e.g., Greene et al., 1999), even when the reported purpose of the mapping is driven by management of biological resources (Kenny et al., 2003, Diaz, et al. 2004). The alternative to this "top-down" methodology is the "bottom-up" approach. The purpose of the "bottom up" protocol is to establish relationships between biological communities and environmental variables in order to delineate habitat map units. Habitat units are built based on biological similarity and are then given environmental context by establishing statistical (e.g., multivariate) relationships with associated abiotic variables (underlying geology and/or overlying oceanography). These relationships could then be used to interpolate between individual samples of fauna to create predictive biological assemblages maps (Hewitt et al., 2004, McBreen et al., 2008). Because the bottom up approach preserves organism-environment relationships, it has better potential to generate units that are ecologically meaningful (Hewitt et al., 2004, Rooper and Zimmerman, 2007, Verfaillie et al., 2009).

Integrating biotic and abiotic data presents significant challenges. One of the first challenges that arise when attempting to integrate data is in choosing which variables to include or exclude from the analyses. This choice is usually addressed by including all available variables, then statistically eliminating those that do not show relationships with the biology, for example. A second major challenge is the coverage extent and spatial resolution of the different datasets. Full coverage acoustic data can be collected rapidly over large scales and at high resolutions (2 m pixel resolution, for example). The resulting products are often used to interpret broad-scale seafloor features (several to hundreds of meters in size). Conversely, point-coverage ground-truth data are collected over coarser resolutions, and with samples typically encompassing a seafloor area of < 1 m^2. The resulting data are examined at a fine scale (individual sediment grains and organisms are resolved). Describing patterns at scales of ecological importance amidst the varying scales of data acquisition is an issue that the mapping community continues to work to address (ICES 2007). A third challenge is that both coverage and ground-truth data represent single sampling events in time, and therefore cannot always provide information about the temporal dynamics of habitats. Clues to temporal dynamics and disturbance can be found in benthic community analysis (e.g., indicator species) and geologic facies mapping (e.g., mobile sand waves) so that some generalizations may be avoided. Many of these issues are now addressed by NOAA's draft habitat scheme, the Coastal and Marine Ecological Classification Standard (CMECS) (Madden et al., 2010). CMECS was created to document and describe ecologically meaningful units using a common terminology for science, management and conservation. The CMECS structure organizes habitat data hierarchically from geologic setting to biotope (Table I-1), and provides ample opportunity to describe temporal dynamics and/or relevance. CMECS is currently seeking approval and endorsement as the national marine habitat classification standard by the Federal Geographic Data Committee.

Predicting biological communities poses challenges, as well. Studies have shown that biological communities in physically rigorous environments are adapted to high environmental variability whereas communities in more stable environments are more influenced by biological interactions such as competition and symbioses (Pratt 1973). This observation would suggest that biological community composition is more readily predictable in physically rigorous environments than in stable quiescent environments. Both types of environments exist within the RI Ocean SAMP study area.

<u>Strategy</u>

Rhode Island Sound (RIS) and Block Island Sound (BIS) are transitional seas that separate the estuaries of Narragansett Bay and Long Island Sound from the outer continental shelf (refer to Figure I-1). Providing the link between near-shore and offshore processes as well as state and federal waters, these transitional seas are both important from an ecological and management perspective. The sounds are also valuable human-use areas, e.g. for alternative energy sites, commercial and recreational fishing, boating, shipping routes and ferry routes, and tourism. In order to appropriately zone for such uses, a sound understanding of the benthic ecosystem is essential. Characterizing benthic environments is important because the organisms living there reflect long-term environmental conditions (Elliot, 1994), serve as a trophic link between primary producers and commercially and ecologically important species (e.g., fish) (Snelgrove, 1998), and affect local sedimentary processes (Gray, 1974, Rhoads, 1974).

Since it was not feasible to map benthic habitats covering the entire RI Ocean SAMP study area at a resolution (spatial or taxonomic) acceptable for marine spatial planning and management, our goal for the two study years was to describe and map relationships between the biology and abiotic (environmental) variables in two large target areas that are also prime potential sites for offshore wind development at a high overall resolution (spatial and taxonomic). We expect that many of the organism-sediment and community-environment relationships that we define will be generally applicable across the SAMP area. This information will be a valuable contribution in making scientifically valid, ecosystem-based management decisions for Rhode Island's coastal waters.

We will examine abiotic and biotic features of the benthic environment at fine scales (100 m, species-level). Using a step-wise multivariate approach, we will determine which abiotic variables best explain the pattern in benthic communities across the target study areas. We will then use a classification tree to identify habitats by grouping stations according to benthic community pattern and significant thresholds of the relevant abiotic variables. This approach has been used in estuarine habitat classification (Valesini et al., 2010) and estuarine habitat mapping (Shumchenia and King, in review), but never in offshore environments where data density tends to be much lower.

1.2 Background

Prior work

Two previous studies (McMaster, 1960, CONMAP, 2005) within the SAMP area have produced coarse resolution maps of surficial sediment type (Figure I-3 (upper panels). Two others (Figure I-3 ,lower panels) (Boothroyd and Oakley, this volume; McMullen et al., 2007-2009) have produced maps that begin to integrate depositional environment (Figure I-3, lower left panel), and transport process information (Figure I-3, lower right panel) with grain size information. All of these studies produce variations of geological "habitat" maps. The maps shown in Figure I-3 (upper panel) are produced by grain size analysis of bottom grab samples. The map in Figure I-3 (lower left panel) is produced by interpretation of bathymetry data and limited subbottom sonar and side scan data in terms of the major geoforms (e.g., moraine, lakefloor) within the study area. The map in Figure I-3 (lower right panel) is based on interpretation of high-resolution swath bathymetry and side scan sonar data in terms of geological processes but with limited ground-truth studies. The map shown in Figure I-3 (lower right panel) is the only previous benthic habitat study within the SAMP area that is based on mapping data of comparable quality to that obtained by the RI Ocean SAMP project.

The current spatial distribution and availability of mapping data of comparable quality to the mapping data obtained by the RI Ocean SAMP project is shown in Figure I-4. Note that none of the data currently available is located in areas that are considered high priority sites for wind development.

A major goal of the RI Ocean SAMP project is to produce benthic habitat maps from high-quality, complete coverage seismic studies that are extensively ground-truthed. The SAMP project acquires both geological and biological ground-truth data. Acquisition of both types of data allows us to produce a multidimensional geological habitat map that includes geoform, grain size, and depositional environment information and a biological habitat map. The distribution of recent, high-quality ground-truth data of both geological and biological data obtained by previous studies is shown in Figure I-5. Again very little previous data is available from potential high-priority sites for offshore wind development.

1.3 Methods - Construction of RI Ocean SAMP benthic habitat distribution maps

<u>Data resolution</u>

Although both side scan backscatter and multibeam bathymetry datasets were collected at very high resolution (2 m and 10 m pixels, respectively), this level of detail would be prohibitive (computation time, file sizes) in the analyses and generation of broad-scale habitats. Therefore, data were imported into ArcInfo 9.2 and aggregated to 100 m pixels. Major geophysical changes and boundaries across both study areas were still visible in the side scan backscatter and bathymetry mosaics.

<u>Acoustic analyses</u>

The mean, minimum, maximum, and standard deviation of the side scan backscatter intensity were calculated from the side scan mosaics using Block Statistics in the Spatial Analyst Toolbox. From the bathymetry dataset, the Neighborhood Statistics feature within the Spatial Analyst extension was used to calculate the mean water depth, slope and aspect using a moving-window algorithm with window size of 100 m. In addition, Neighborhood Statistics was used to derive surface roughness by calculating the standard deviation of the slope within a search radius of 1000 m (i.e. 10 pixels) (Damon, 2010). This procedure was performed on a dataset created from a set of 1.9 million National Ocean Service (NOS) soundings (Damon, 2010).

Bottom samples

Sampling sites were positioned within what appeared to be distinct geophysical bottom types based on visible boundaries in the side scan backscatter and bathymetry mosaics (Figure I-6). Sites were spread across the BI and FED study areas such that most major geophysical units contained at least one bottom sample. This approach resulted in approximately 1 grab sample per square mile within BI, with a total of 59 samples acquired over four occasions between October 2008 and August 2009 (see Figure I-6). About two grab samples per square mile (16 total) were taken within FED in December 2009. Surface samples were collected aboard the R/V McMaster using a Smith-McIntyre grab sampler (0.05 m^2 area).

Sediment samples

An ~ 25 ml sub-sample was taken from the surface of each Smith-McIntyre grab sample and analyzed using a Mastersizer 2000E particle size analyzer. The Mastersizer generated the weight percent of each Wentworth particle size fraction (e.g., very fine sand, fine sand, medium sand), along with the skewness, kurtosis, and standard deviation of the particle size distribution for the entire sample.

Macrofaunal samples

The remaining material from each Smith-McIntyre grab was sieved on 1 mm mesh and macrofauna were retained. All individuals were counted and identified to at least the genus level. A functional group designation (e.g. surface burrower, tube-builder, mobile) for each genus was made. The macrofauna abundances from the BI and FED study areas were pooled and only the species contributing to 95% of the total abundance between the two areas were included in further analyses. This eliminated genera with very low abundances.

Underwater video

Underwater video transects of roughly 200 m length were taken at 45 of the 59 sample locations within BI (stations 1-45). The data was collected over three consecutive days in June 2009 on the R/V McMaster using a video camera mounted to a sled and towed behind the vessel. A differential GPS and Hypack were used for navigation and to record the vessel tracks, which were later imported into ArcInfo. Further work is being conducted to collect underwater video for the stations within FED.

Quantitative parameters were derived from visual analysis of the BI video. Specifically, the general sediment compositions and types of seafloor (bottom) present along the transect were recorded. These data were expressed as percentages of the total of each transect (i.e. bottom type is 50% boulder field, 25% flat sand, 25% tube mat). The number of habitat types that exist within each transect was also noted. In terms of biological information, the video for each station was qualitatively examined for the presence and approximate abundance of organisms (algae, fish, invertebrates).

Benthic geologic environments

Within the BI, the extent of the Quaternary depositional environments were interpreted from high resolution side-scan sonar and bathymetric images, sub-bottom seismic reflection profiles, as well as surface sediment grab samples and underwater video imagery. Environments interpreted with map units > 10 of square kilometers correspond to the Geoform level in CMECS, and include moraines, glacial lakefloor basins, deltas, alluvial fans and shelf valleys.

Refined Quarternary depositional environments are equivalent to the subform level in CMECS and represent the modern (Late Holocene) processes acting on the study area, and are known as benthic geologic habitats. Benthic geologic habitats are spatially recognizable areas of the seafloor with geologic characteristics different from adjacent units, and are mapped with units < 10 square kilometers (most polygons were < 1 square kilometers). These map units include information on the surface sediment characteristics, bed roughness, and includes depositional environments such as sand wave fields, low-energy depositional basins, and depositional cobble gravel pavement. The benthic geologic habitats are named based on a combination of Quaternary depositional environment, surface sediment grain size and a descriptor of the bed configuration or any other pertinent information. As an example, areas on the Quaternary moraine with coarse sand with small dunes would be mapped as (ISM csd), for an Inner Shelf Moraine, coarse sand with small dunes.

Integration of abiotic and biotic data

A suite of abiotic variables were generated from the multiple layers of data (side scan backscatter, bathymetry, sediment samples, underwater video) at each bottom sampling station (Table I-2). Of the 75 stations, two were excluded from the statistical analysis because they did not have accompanying acoustic data (BI 44 and 45). Another nine sites were removed due to there being little or no sediment recovered by the Smith-McIntyre grab sampler (BI 4-6, 18, 30, 608, 1308, 1408, and FED 2). Typically, unsuccessful grabs are an indication the seafloor is comprised of coarse sediments not easily recoverable. Underwater video was taken at seven of the excluded sampling stations. For six of the stations, the video confirms the samples were located in areas of coarse sediments (gravels, cobbles, boulders). It is unclear why no grab was collected at the remaining station, as the video indicates it is located in fine-grained sand.

In PRIMER 6, a draftsman plot was created to assess the correlation between the variables. Variables that were highly correlated, and, therefore, redundant ($r > 0.85$) were eliminated from the analysis. The variables were then normalized to correct for differences in units, and a resemblance matrix was created based on the Euclidean distance metric.

The macrofauna abundance data were 4^{th} root transformed to reduce the influence of highly abundant genera and the Bray-Curtis similarity index was used to create a matrix of station-similarity.

Univariate analysis

The Pearson correlation coefficient, r, was used to investigate the relationship between surface roughness, macrofaunal diversity (total # genera per site) and abundance (total # individuals per site). It was hypothesized that surface roughness would be positively correlated ($r >> 0$) with both macrofauna diversity and abundance.

Multivariate analyses

An analysis of similarity (ANOSIM) was performed on the Bray-Curtis similarity matrix of the macrofaunal abundances using benthic geologic environment as a factor. ANOSIM tests the null hypothesis that there are no differences between groups of samples (the biotic Bray-Curtis similarity matrix) when examined in the context of an a-priori factor (benthic geologic environment) (Clarke and Gorley, 2006). An R value of 0 indicates there are no differences between groups (i.e. null hypothesis is accepted), while an R value greater than 0 (null hypothesis rejected) reflects the degree of the differences. The test is permuted 999 times to generate a significance level ($p < 0.05$ used here).

The macrofauna similarity matrix and abiotic variables were subject to the BIOENV procedure in PRIMER 6. The BIOENV approach identifies a subset of abiotic variables that best “explains” macrofaunal composition (Clarke and Gorley, 2006). The approach analyzes the extent to which the abiotic parameters match the biological data by searching for high rank correlations between variables in the two matrices (the abiotic Euclidean distance matrix and the biotic Bray-Curtis similarity matrix). BIOENV outputs the highest Spearman rank correlation coefficient between a combination of abiotic variables and the biotic similarity matrix. The maximum number of variables permitted in the output was capped at five. This procedure was performed twice. The first BIOENV routine (BIOENV + video) included the underwater video variables in addition to the remaining abiotic parameters and was performed on only the 38 BI stations. All variables must be present at all stations in order to run BIOENV. Since no underwater video variables were available in FED, the second run of BIOENV (BIOENV + BI & FED) was conducted without underwater video variables in order to include all 64 stations between BI and FED.

The variables selected as important by the BIOENV were then entered into the LINKTREE procedure in PRIMER 6 to classify the macrofauna data according to patterns in these important abiotic variables. LINKTREE groups the macrofauna samples by successive binary division using the abiotic variables as drivers and maximizing the ANOSIM R value at each division (Clarke and Gorley, 2006). The ANOSIM R was constrained to be greater than 0.30 and the minimum group size was set at two. Each resulting class is defined by a suite of biological samples and quantitative thresholds of the abiotic variable(s). An ANOSIM was performed on the LINKTREE classes to test the hypothesis that there are no significant ($p < 0.05$) differences in the macrofaunal assemblages among LINKTREE classes. The similarity percentages (SIMPER) routine was then used to determine the within-class similarity of the resulting LINKTREE classes and to identify the genera contributing most to the similarity.

Mapping

Due to the lack of spatial auto-correlation (e.g. samples closer in space will be more similar than those further away) of the grain size point samples, traditional interpolation methods (e.g. Ordinary Kriging, Inverse Distance Weighting) could not be used to create full-coverage data layers. Instead, a conservative approach was taken to create the benthic habitat maps in order to preserve the accuracy of the maps. For this approach, the maps were created by classifying pixels (64, 100 m pixels) for which abiotic data were available in ArcInfo. The habitat classes follow the LINKTREE classification and are labeled according to the LINKTREE threshold defining each class and the dominant genus within each class.

1.4 Results

Acoustics

The side scan backscatter mosaics reveal both BI and FED have heterogeneous benthic environments (Figure I-7). Interpreted bottom types include sheet sands, sand waves, and boulder fields, along with flat sandy and muddy environments. The bathymetry, slope, and surface roughness of the two areas (Figures I-8, I-9, I-10) also reflect heterogeneity in varying degrees of smooth and rough bottom.

The mean side scan backscatter intensity (100 m resolution) within BI and FED ranged from 40.99 to 239.13 and the standard deviation varied from 7.35 to 98.61 (Table I-3). Bathymetry (100 m resolution) ranged from 13.8 m to 44.0 m. The slope was between 0.01˚ and 1.54˚ and the standard deviation of the slope (measure of surface roughness) was between 0.05˚ and 1.39˚. The aspect had a range of 9.36˚ to 354.21˚. BI appears to have a more variable benthic environment, as evidenced by wider ranges in the acoustic variables (backscatter, slope) and their standard deviations (refer to Table I-3).

Bottom Samples

Sediment samples

Between both study areas, medium grained sand is the dominant sediment (32.48%), followed by coarse sand (29.34%) and fine sand (15.32%) (Table I-4). Medium sand comprised as much as 76.34% of sediment samples, while coarse sand and fine sand comprised as much as 69.57% and 57.82% of sediment samples, respectively. Similar to the acoustics, BI seems to exhibit more heterogeneous sediment characteristics, as evidenced by a much larger standard deviation of the grain size (90.6 μm to 459.8 μm range for BI versus a range of 105.9 μm to 302.4 m for FED).

Macrofaunal samples

More than 20,500 individuals belonging to11 phyla and 173 genera were sampled across the 64 stations within the BI and FED study areas (Table I-5). Both areas were dominated by three phyla, Crustacean, Polychaete, and Mollusc (Figure I-11). In terms of spatial distribution, the most abundant genera were *Lumbrineris* (recovered at 68% of the stations sampled), small surface burrowing polycheates, *Unciola* (46%), small surface burrowing amphipod (crustaceans), and *Glycera* (42%), large deep burrowing polycheates. With regards to counts of individuals, the most abundant genera were *Ampelisca* (comprised 33.0 % of the total individuals), *Byblis* (11.7%), and *Leptocheirus* (6.2%), all tube-building amphipods.

The average biodiversity (total number of genera per sample) between both study areas was 23, ranging from 6 to 40 genera (Table I-6). The average abundance (total number of individuals within each sample) within BI and FED was 324 and ranged between 12 and 2,333 individuals. The highest biodiversity was found within BI at stations 37 and 39, with both samples having 39 genera present, followed by BI station 16 (38 genera) (Figures I-12 and I-13). The highest abundance also occurred within BI at station 39 (# of individuals > 2,000), followed by BI stations 2, 1, 37, and 16 (# of individuals > 1,000). The stations with the lowest biodiversity are BI 24 (6 genera), BI 3 (7 genera), and BI 23 and 42 (9 genera each). The lowest abundance was found at BI stations 3 and 24 (each sample recovered 12 individuals) and BI 25 (25 individuals).

Overall, the BI stations were more diverse, with 11 phyla and 156 genera (versus 8 phyla and 75 genera within the FED stations). In addition, BI had a higher average abundance and wider ranges of both abundance and diversity.

<u>Underwater video</u>

The underwater video dataset currently does not include transects collected within FED or BI stations 108 through 1408. Therefore, the findings presented below are preliminary and may change as additional data is included into the analyses.

The underwater video transects showed that the majority of the stations (30 of 45 stations) within BI had bottom environments comprised of flat surfaces characterized by little relief (Table I-7). Sediment composition for these areas varied widely ranging from fine sand to cobble. Numerous stations (18) exhibited areas of fine or coarse grained sand ripples. Boulder fields were noted at ten stations. At four stations the seafloor was comprised of soft sediments and dominated by dense tube-mats. The number of bottom types along each station transect ranged from one to 11, with one bottom being the most common (27 of 45 stations).

The first BIOENV procedure, BIOENV + video, identified a subset of five variables as most influential to the macrofaunal assemblage composition (Rho = 0.641). The single variable having the highest correlation with the biology was percent coarse sand of the grain size analysis (correlation = 0.362). The five variables comprising the best correlation were percent fine sand from the grain size analysis, percent fine sand as identified from the video analysis, maximum backscatter intensity, water depth, and surface roughness.

Benthic geologic environment

The dataset for the benthic geologic environment currently does not include the FED study area. Therefore, the findings presented below are preliminary and may change as additional data is included into the analyses.

Four Quaternary (glacial) depositional environments were interpreted from the high-resolution bathymetry data, including; Moraines, delta plain, alluvial fan and lakefloor basins (Figure I-14). The depositional environments were arbitrarily separated into geographic regions: North of the moraine shoal southwest of Block Island is considered Block Island Sound, and north of the moraine shoal southeast of Block Island is Rhode Island Sound; south of the moraine shoals is the Inner Continental Shelf. The moraines were separated into to two categories; Moraine Shoal for the two segments of moraine continuous with Block Island, dominated by outcrops of boulder gravel, and sandy Inner Shelf Moraines south of the moraine shoals. The moraine shoal that forms Southwest Ledge is as shallow as 6 m below sea-level and waves break on it during storms. The formation of the Inner Shelf Moraine and the concentration of boulder gravel on the inner shelf south of the moraine remain enigmatic. The Inner Shelf Moraine may represent the maximum advance of the Laurentide Ice Sheet at Block Island, or ice tectonics as the ice margin fluctuated and deformed the stratified (Alluvial fan) deposited in front of the ice margin.

Map unit MS bgc (Moraine Shoal boulder gravel concentrations) is spatially the most extensive depositional environment, covering 30 square kilometers (11.6 square miles; 21.7% of study area) within BI. Portions of the inner shelf moraine, and extending onto the inner shelf south of the moraine is a large sand wave field, with orientations suggesting sediment transport in both an east to west and southeast to northwest directions, or towards Block Island Sound. Crest to crest spacing of the sand waves average 100 m, but range from 10 to 300 m, and are likely active only during storm events.

Extending south from the moraine shoals, two broad areas interpreted to represent alluvial fans that were deposited by braided rivers graded to either a glacial lake on the inner shelf south of the study area, or to the Late Wisconsinan low-stand marine shoreline. This area is dominated by sandy and gravelly depositional environments, and map unit GAF csd (Glacial Alluvial Fan coarse sand with small dunes encompasses 29 square kilometers (11.3 square miles, 21.3% of BI study area) and GAF pgcs (Glacial Alluvial Fan pebble gravel coarse sand, 13 square kilometers (5.1 square miles, 9.5%). The small dunes in map unit GAF csd represent wave orbital bedforms, and are ubiquitous in depositional environments with coarse sand throughout the study area. Crest to crest spacing averages 1 m, and ranges from 0.75 to 2 m (Clifton, 1976). Based on the water depth and grainsize within this unit, the velocity needed to form these bedforms can be estimated at 0.75 – 1.5 m s^{-1}. At a depth of 25 m, these velocities are reached with a minimum wave height of 4 – 5 m, with a period of 10 seconds (Komar, 1976; Sherwood, 2007).

North of the moraine at Southwest Ledge, a relatively flat area at -30 m below present sea-level is interpreted as a glacial delta that formed when the ice front was at the small segment of Moraine in the northwest corner of the study area. This probably represents a small glacial lake that existed between the ice front and moraine that was filled by the prograding delta. The surface sediment characteristics of this unit are dominated by pebble gravel and coarse sand depositional environments.

Two deeper areas (30 – 40 m below present sea-level) on the western and northern end of the study areas were mapped as depositional basins, and are dominated by fine-grained (silt to silty sand sized) sediment. The northern basin was interpreted as a lakefloor basin, and underwater video and sub-bottom seismic reflection data suggests that the lakefloor may crop out in portions of this map unit. The depositional basin on the western edge of the study area extends into Block Channel and occupies a closed depression (> 40 m water depth). Lakefloor was not identified in video or seismic data from this map unit, so it was not further classified as a lakefloor depositional basin.

There were fifteen different depositional environment types in BI sampled for macrofauna (Table I-9). However, four of these contained only a single macrofauna sample, and therefore pairwise statistical comparisons were not possible for these types. This issue reduces the power of the ANOSIM test, but the global R value may still be indicative of general patterns. The results of the ANOSIM using BI depositional environment type as a factor indicate that there are significantly different macrofaunal assemblages among depositional environment types (global $R = 0.556$, $p = 0.001$). Each depositional environment was labeled for the most abundant genus within samples retrieved there (Figure I-15).

The depositional environments within FED have not yet been distinguished; the relationship between these environments and the biology will, however, be assessed in detail in the near-term. The data from both areas will be pooled to determine the influence of depositional environment type on macrofauna composition.

<u>Integrating biotic and abiotic data</u>

The Pearson correlation coefficient rejected the hypothesis that surface roughness (a measure of habitat complexity) has a positive correlation with macrofauna biodiversity and abundance (r = -0.001 and 0.087, respectively).

The second BIOENV procedure, BIOENV + BI & FED, again identified a subset of five abiotic variables as being the most correlated the macrofaunal composition (Rho = 0.544). The variables responsible were percent fine sand, percent medium sand, percent coarse sand, maximum backscatter intensity, and surface roughness. Percent coarse sand was the single variable best correlated (Rho = 0.453) with the macrofaunal assemblage.

The LINKTREE created using the subset of abiotic variables identified in the BIOENV + BI & FED procedure resulted in 16 classes (Figure I-16). Of the 16 classes, 11 classes were comprised of only BI samples, two of only FED samples, and three contained samples from both BI and FED. The BI area contained 14 LINKTREE classes, whereas five were found within FED. The number of samples in each class ranged from 2 to 11. Each class is defined by a quantitative threshold of one of the five input variables (Table I-9). Percent fine sand was responsible for three of the thresholds, maximum backscatter intensity, surface roughness, and percent medium sand were responsible for five, two, and five thresholds, respectively. A number of these thresholds are defined over a narrow range (refer to Table I-9); for example, split "K" divides to the left at percent medium sand greater than 44.89 and to the right at percent medium sand less than 43.32. The ANOSIM indicated there are strong differences (R = 0.646, p = 0.001) between the macrofaunal assemblage among LINKTREE classes.

Within each LINKTREE class, the most abundant genus was determined (Table I-10). For four classes, the two most abundant genera were noted because both genera showed very high abundances compared to other genera present. Most commonly, *Ampelisca* was the most abundant genus, being dominant or sharing dominance for seven classes. Two other genera were found to be most abundant for more than one class; *Byblis* was dominant or shared dominancy for three classes and *Polycirrus* did so for two classes.

SIMPER results showed that the genus most responsible for the within-class similarity of each LINKTREE class were either polychaetes, or crustaceans and contributed between 39.69% and 11.02% to the within-class similarity (refer to Table I-10). In total, SIMPER identified nine genera for the 16 classes. The genera indicated for multiple classes were *Lumbrineries,* which was responsible for the greatest similarity for four classes, *Ampelisca* for three, and *Byblis* and *Protohaustorius* for two. The same genus was the most abundant and the most responsible for the within-group similarity for seven of the 16 classes, five of which were the tube-building amphipods *Byblis* or *Ampelisca* (refer to Table 10).

<u>Mapping</u>

The benthic habitat maps included 64 pixels of 100 m resolution (Figure I-17). The maps contained 16 benthic habitat classes, as identified in the LINKTREE procedure. The habitats were classified according to their LINKTREE threshold and the dominant genus in terms of abundance (Figure I-18). Four classes are classified by the two most abundant genera because both genera showed very high abundances relative to the other genera present. Ten of the 16 classes are classified by tube-building amphipods, with *Ampelisca* accounting for seven of these classes. The class defined by *Polycirrus-Lumbrineries* occurred most often, encompassing 11 pixels within BI, followed by the class *Leptocheirus*, having 6 pixels within BI. Classes identified by *Byblis* (shown in light pink), *Protohaustorius*, *Mytilus*, *Ampelisca-Byblis*, and *Ampelisca* (shown in light grey) were the least dominant, each with two occurrences. BI and FED only share three classes, all defined by amphipods: *Byblis* (shown in dark purple), *Ampelisca-Byblis*, and *Ampelisca* (shown in bright pink).

1.5 Discussion

Maps of the distribution of benthic habitats are valuable tools for numerous ecological and management reasons, including understanding ecosystem patterns and processes, determining environmental baselines, impact assessment, and conservation efforts. The purpose of this study was to construct benthic habitat maps for two areas, BI and FED, within the RI Ocean SAMP study area using methods not before applied to offshore environments. To generate the habitat maps, a bottom-up methodology was employed to integrate multiple types of data over various scales and establish relationships between macrofaunal communities and environmental parameters.

Macrofauna diversity and abundance were linked. Stations with the highest diversity also had the highest abundance (BI 39, 37, 16) and diversity was particularly high in samples containing tube-building organisms. This association between diversity and tube-builders suggests tube-mat structures provide valuable habitats. Ellingsen (2002) suggested polychaete tube-mat structures may increase sediment heterogeneity (i.e. habitat complexity), and, as a result, positively influence benthic ecosystems. It is also possible that tube-builders positively interact with other genera (predator, prey, competition), which results in increased diversity.

Pratt (1973) reported that suspension feeders (such as tube-building amphipods) physically dominate hard surfaces, but, despite this, a diverse range of fauna (deposit feeders, predators, browsers) reach high densities in mature epifaunal assemblages. Pratt (1973) also noted that within Rhode Island Sound there was a correlation between the presence of the amphipod, *Ampelisca agassizi*, and the abundances of several infaunal species including detritus feeding amphipods, isopods, cumaceans, and a polycheate, *Prionospio malmgreni*.

Environmental conditions may explain the reason for the stations with the lowest macrofauna diversity also having the lowest abundance (BI 24, 3, 25, 42). Comparison of stations BI 24 and BI 42 (both classified as *Protohaustorius*, defined by maximum backscatter intensity less than 123.16) and BI 25 (classified as *Byblis*, defined by medium sand greater than 65.76%) with the grain size analysis, underwater video, and benthic geologic environment indicate that these sampling stations occur within the inner shelf moraine on large-scale medium and coarse grained sand waves or sheets. Station BI 3 (classified as *Polycirrus*, defined by medium sand less than 13.77%) is located on the moraine shoal within an area of boulders and very coarse grained material. The existence of sand waves, sheets, and ripples suggest sediment mobility. Therefore, these dynamic environments may present conditions too stressful for many genera, as organisms living in these areas must be adapted for movement in sand and be able to recover from burial (Pratt 1973).

Station BI 23, is unique in the BI and FED study areas because it has low diversity (9 genera), but high abundance (680 individuals), with the genus *Byblis* accounting for 97% of this abundance. This station exhibits biologic characteristics contradictory to typical assemblages with tube-building amphipods, as described by Pratt (1973) and discussed above. The reason this environment can support *Byblis*, but few other genera (including other tube-builders) is not resolved. Data from the underwater video, benthic geologic environment and grain size analysis show that BI 23 is located within the glacial alluvial fan in a sandy, rippled environment, which may partly explain the low diversity. BI station 23 may have low diversity and high abundance if the area has underwent a recent disturbance event and is in the process of recovery. A study of disturbance from dredge spoil on a stable sand area found that amphipod species, including *Byblis*, were among the early colonizers of the spoil material (Pratt 1973).

There is a high degree of benthic habitat heterogeneity within BI and FED. This heterogeneity is evidenced by there being little to no spatial autocorrelation (e.g. samples closer in space are more similar than those further away) between percent fine, medium or coarse sand samples within BI or FED. Sediment samples were collected at a density of one (BI) or two

(FED) samples per square mile, suggesting habitat changes occur over spatial resolutions (i.e. scales) as small as one-half square mile. Additional evidence of habitat heterogeneity over small scales is found in the LINKTREE results, where the thresholds used to define benthic habitat classes occur over narrow ranges of the abiotic variables (refer to Table I-9).

The scale at which the environmental parameters and acoustic patterns are examined is important. This importance can be seen in the results of the BIOENV procedures (+ video and + BI & FED). For example, the macrofauna patterns within BI and FED are linked to sediment characteristics at both fine and broad spatial scales. The fine scale link is with the grain size from the analysis of the sediment sample (i.e. percent fine, medium, and coarse sand). Similar sediment-macrofauna relationships have been observed in a number of previous studies (Gray, 1974, Rhoads, 1974, Chang et al.,1992, Snelgrove and Butman,1994, Zajac et al., 2000, Ellingsen, 2002, Verfaillie et al., 2009). A broad-scale link between sediment and macrofauna is seen with the bottom type cover (i.e. percent fine sand bottom) of the underwater video. Other studies (Brown and Collier, 2008, Rooper and Zimmerman, 2007, Kendall et al., 2005), have also found underwater video metrics (such as sediment composition) to be valuable in constructing and classifying habitat maps. Recognizing this, our aim is to incorporate underwater video analyses in both BI and FED habitat maps when the full datasets are available.

The reason for the broad-scale link between macrofauna and the maximum backscatter intensity of the side scan sonar mosaic (100 m resolution) is unclear. Studies have shown positive correlations between backscatter intensity and grain size (Goff et al., 2000, Hewitt et al., 2004, Collier and Brown, 2005). Therefore, perhaps the maximum backscatter intensity represents a macrofauna-sediment link.

The relationship between macrofauna patterns and surface roughness (a measure of environmental heterogeneity) within BI and FED also occurs over a broad scale. This finding supports that of previous studies (Gray, 1974, Ellingsen, 2002), which reported positive relationships between habitat variety and species diversity, following the rationale that a greater degree of sediment heterogeneity offers more potential niches, and therefore, allows for higher diversity (Rosenzweig, 1995).

Scale is important also in assessing the relationship between surface roughness and macrofaunal diversity and abundance. The univariate analysis showed very little correlation between surface roughness and either diversity or abundance, while both multivariate BIOENV procedures (BIOENV + video and BIOENV + BI & FED) showed strong surface roughness-macrofaunal assemblage composition. We hypothesize the reason for this mismatch is related to the statistical method and the scale at which the macrofaunal and abiotic data within BI and FED were examined. Multivariate analyses tend to be more sensitive than univariate methods to small changes in faunal composition (Gray et al., 1990, Warwick and Clarke, 1991, 1993). The BIOENV routine considers the composition of the macrofaunal assemblage for each station, while the Pearson correlation coefficient utilizes a summary statistic for the diversity and abundance at each station. Because of this difference, the BIOENV procedure may discern finer scale relationships between the biology and the abiotic variables. For example, one or more genera may be influencing the results of the BIOENV if a strong link exists with one or more abiotic parameters. Such links were found by Olsgard and Somerfield (2000) who reported polychaetes exhibited the strongest relationship to the environmental parameters. Similarly, in another study (Ellingsen, 2002), molluscs, followed by polychaetes, had stronger connections to the environmental variables than that of crustaceans and echinoderms.

The LINKTREE classes can be split into two categories – classes with tube-building amphipods (8 classes on left side of LINKTREE) and those with few to no amphipods (non-amphipod classes) (8 classes on right side of LINKTREE). This division begins at the first split of the LINKTREE (split “A”, based on percent medium sand). Their prominence in structuring the linkage tree classes highlights the influence of tube-building amphipods on the composition of macrofaunal assemblages. Despite this influence, the macrofauna composition of all LINKTREE classes was significantly different (ANOSIM global $R = 0.646$, $p = 0.001$), suggesting that factors other than amphipod presence contribute to assemblage composition.

The majority of the benthic habitat classes (13) were contained solely within BI or FED, suggesting the macrofaunal assemblages vary between the two study areas and primarily have their own associations with the environment. If the goal of the mapping effort was to characterize the finest-scale abiotic-biotic relationships in both areas, the observed degree of separation between BI and FED classes makes the case for conducting separate analyses and generating separate maps for each study area. From a management perspective, overly-site-specific analyses and maps may not be as useful as a geographically-broad analysis that allows habitat comparisons between areas. Our approach addresses the latter point, and the results indicate that BI and FED may differ fundamentally in terms of how species utilize the benthic environment.

Temporal variability can present a challenge to benthic habitat mapping, both in data collection and in creating final products. In terms of data collection, it is possible seasonal differences in macrofaunal community composition are reflected in our results. However, Steimle (1982) reported there were no clearly defined seasonal changes between biological communities examined in February and in September within BIS. He also presented evidence to suggest BIS is a relatively stable environment. In addition, a study by Vincx et al. (2007) pooled biological data spanning 10 years and all seasons.

With regards to temporal variability and creating final products, benthic habitat maps often do not reflect the temporal dynamics of mobile features since they are created using abiotic and biotic datasets representing single sampling/survey events in time. However qualitative descriptors of temporal patterns/variability may be inferred from the abiotic and biotic data. For example, stations BI 22-25 are unstable physical environments (mobile sheet sands, sand waves, sand ripples) and characteristics (abiotic and biotic) of the benthic habitats in these areas may change. Temporal variability may be indicated by the presence of opportunistic species that reflect recent habitat disturbance, or the presence of large, long-lived individuals that indicate a more stable environment and potentially lower temporal variability in macrofauna composition (Pearson 1978).

1.5.1 Future work

The narrow ranges of the LINKTREE thresholds indicates that our statistical methods were very sensitive to environmental and biological characteristics, and argues for including additional data types (e.g. sediment organic content, average annual surface chlorophyll concentration, rugosity, nutrient availability, and trophic interactions) in the future that may help refine abiotic-biotic relationships and habitat patterns.

The high degree of environmental heterogeneity within BI and FED impedes our ability to confidently interpolate the grain size point samples into full-coverage data layers using traditional methods (such as Ordinary Kriging and Inverse Distance Weighting). Our concern of retaining accuracy is echoed by Brown and Collier (2008), who remarked interpolation methods can often lead to erroneous assumptions in the resulting map, particularly if the degree of seafloor heterogeneity in terms of surficial geology and biota is high. Consequently, taking a conservative approach and constructing benthic habitat maps for BI and FED retaining the original extent of the available abiotic data was the most accurate approach. Future studies will examine the linear relationship between the grain size data (point-coverage) and acoustic data (full-coverage) to assess the possibility of interpolating the grain size data via linear regression.

1.6 Conclusion

In the BI and FED areas within the RI Ocean SAMP study area, we used data integration methods (e.g., bottom-up instead of top-down) not before applied to offshore environments. Although the bottom-up approach identified five abiotic variables that influenced macrofauna composition, spatial heterogeneity in these abiotic variables prevented broad-scale extrapolation of habitat units using this method. Given a higher spatial density of bottom samples, this problem could be rectified.

Absent further sampling, the most promising solution is to use the top-down approach to describe the benthic biological assemblages found within each depositional environment (geological habitat) type. This relationship was found to be statistically strong and significant in BI (although less than the relationship defined with the bottom-up method), but data are not yet available for FED. Given the greater degree of habitat heterogeneity in BI, it is likely that the top-down approach will be successful in FED as well. The top-down approach will produce full-coverage habitat maps for both BI and FED that describe general, broad-scale patterns in both benthic geological and biological resources.

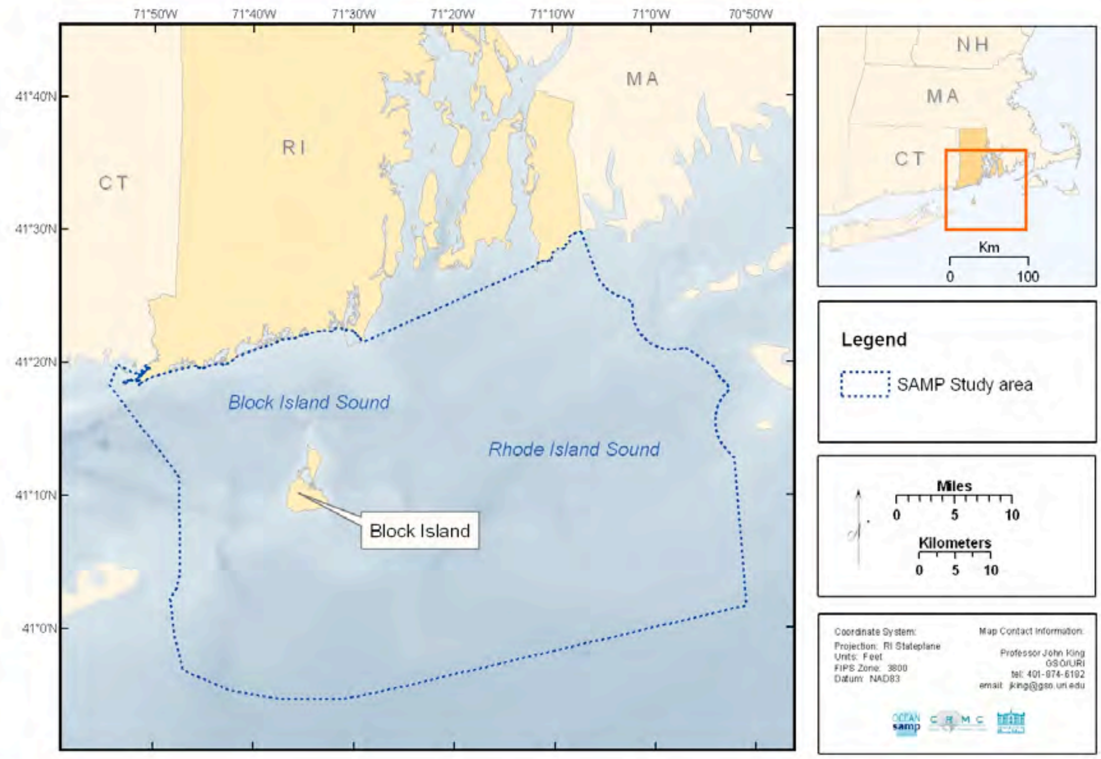


Figure I-1. RI Ocean SAMP study area.

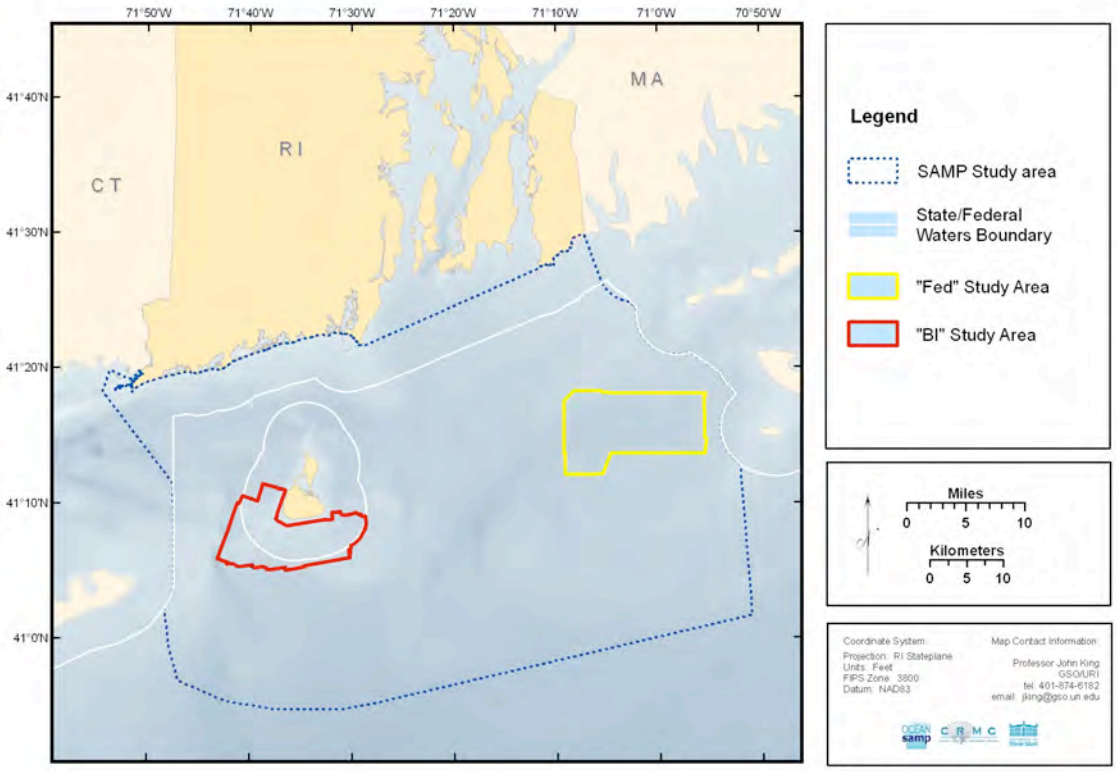


Figure I-2. Locations of BI and FED study areas within RI Ocean SAMP study area.

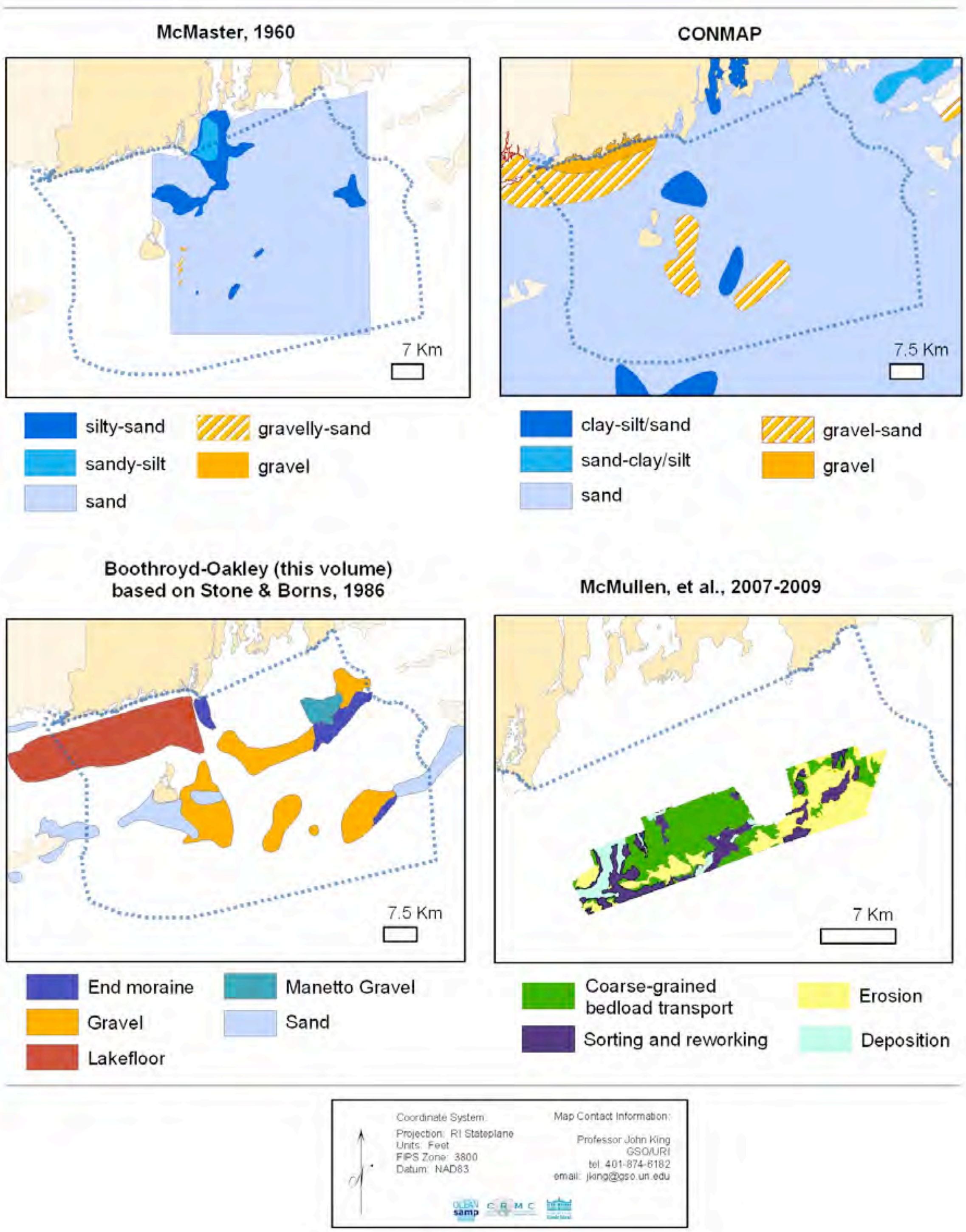


Figure I-3. Results of previous studies of surficial sediments in RI Ocean SAMP study area.

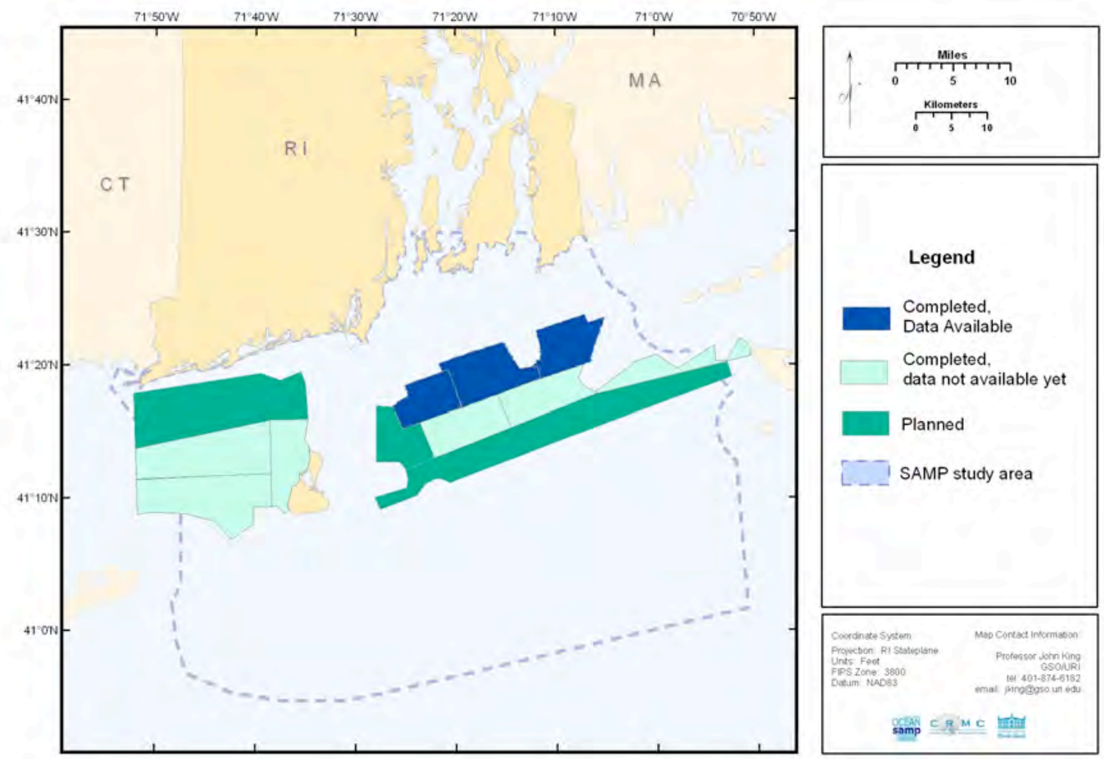


Figure I-4. High-resolution swath bathymetry and side-scan sonar surveys within RI Ocean SAMP study area by NOAA.

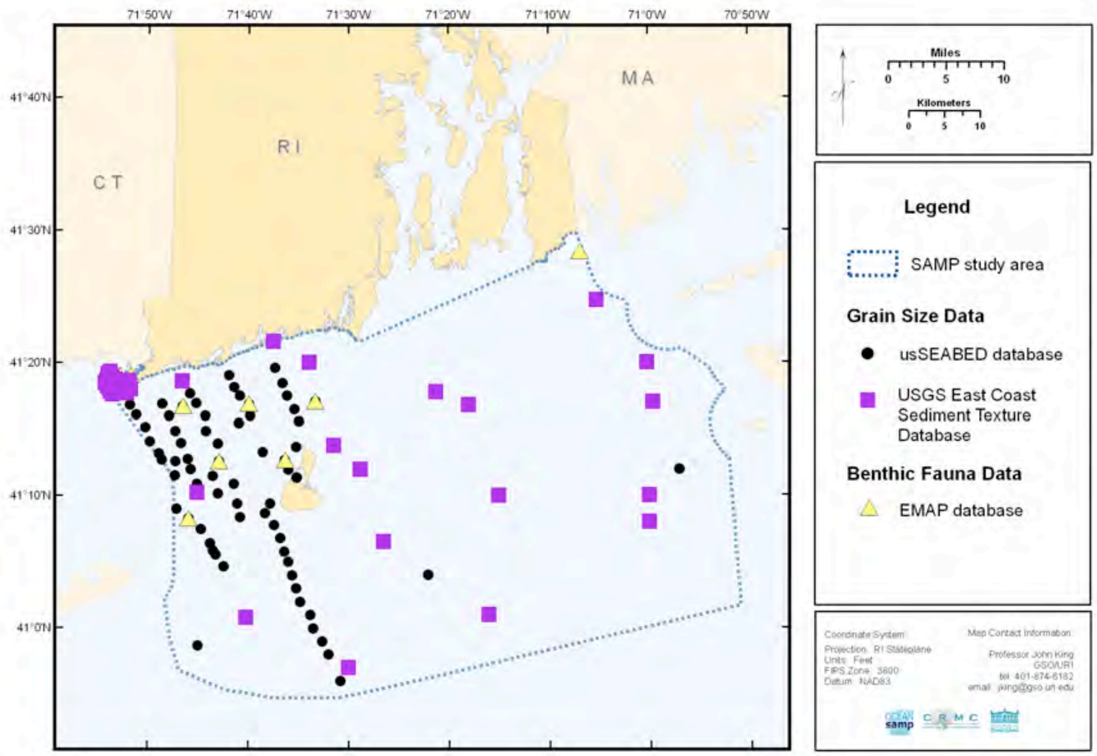


Figure I-5. Previous ground-truth studies within RI Ocean SAMP study area. EMAP 2002, U.S. Geological Survey 2005, usSEABED, 2005.

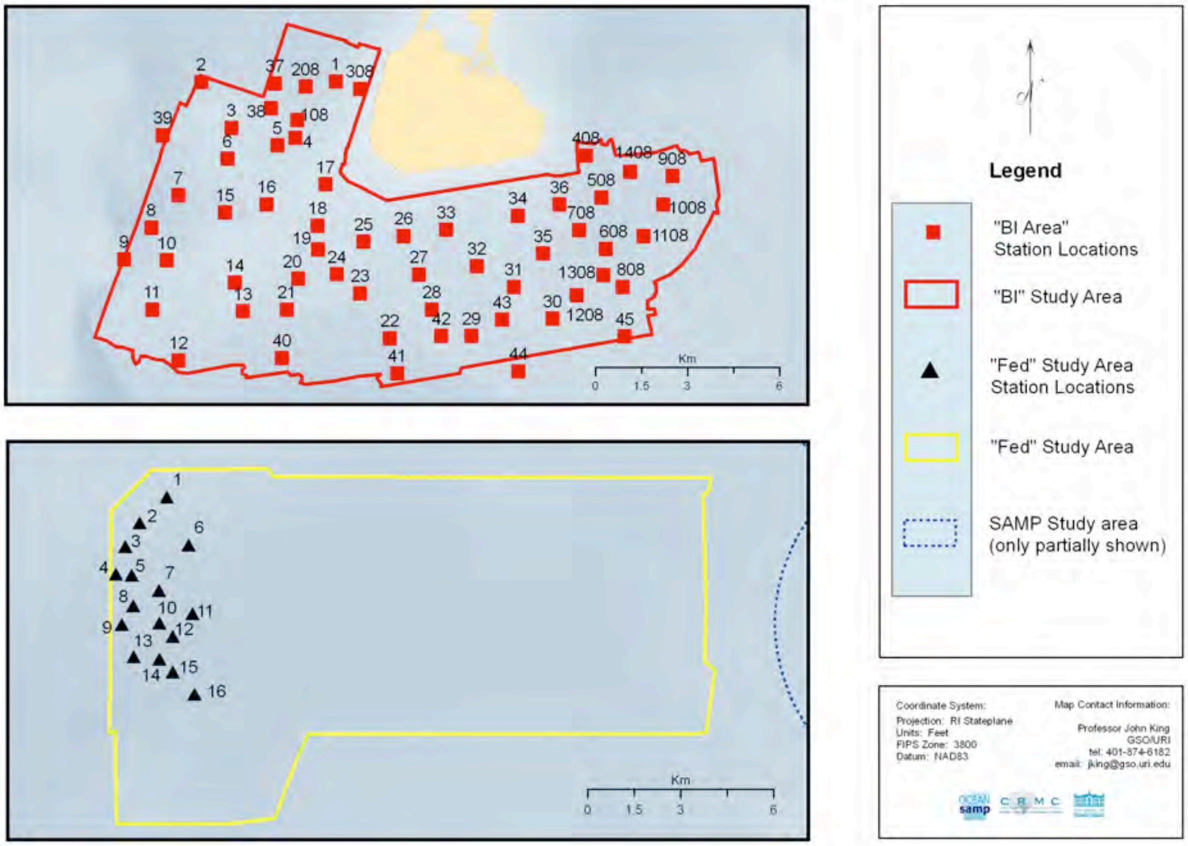


Figure I-6. Locations of the samples taken within BI and FED. Bottom samples were collected at all locations. Underwater video was collected for BI stations 1-45 only. BI samples 44 and 45 were removed from this study because they did not have accompanying acoustic data. In addition, BI samples 4, 5, 6, 18, 30, 608, 1308, 1408, and FED 2 were eliminated from the study because little to no material was recovered in the bottom sample.

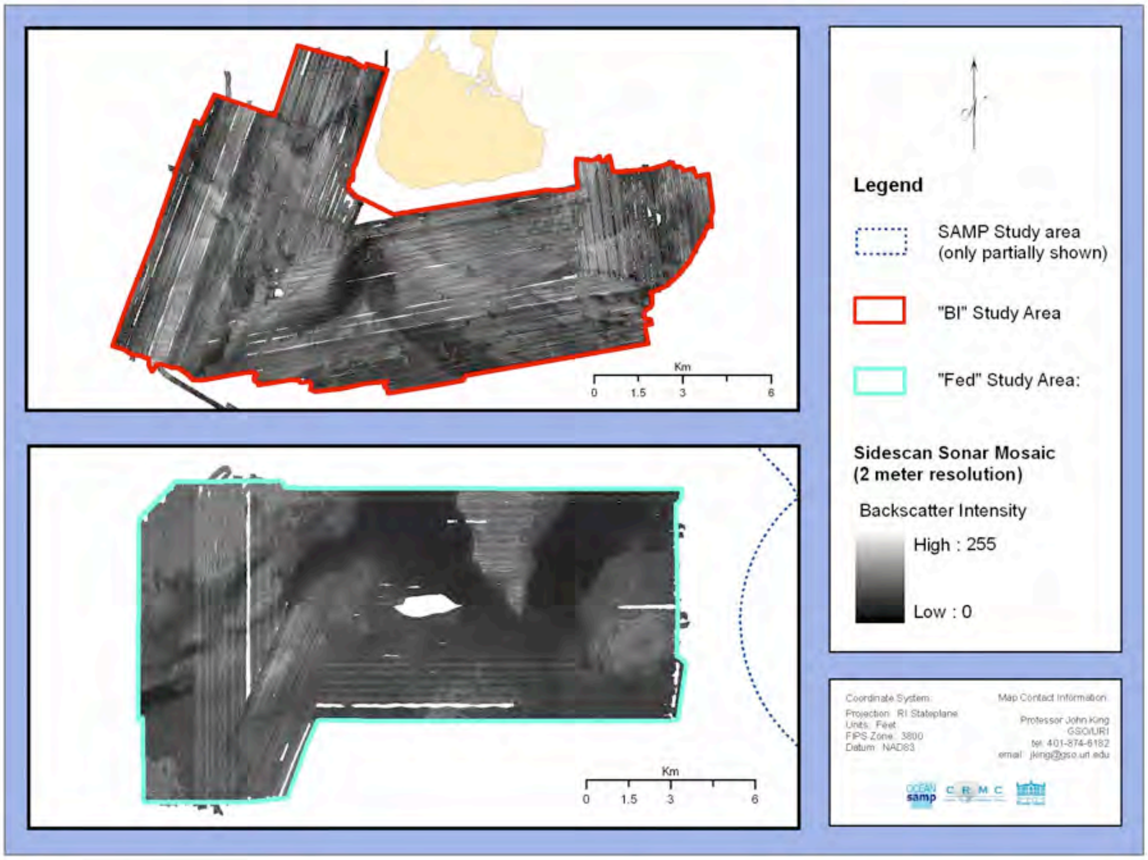
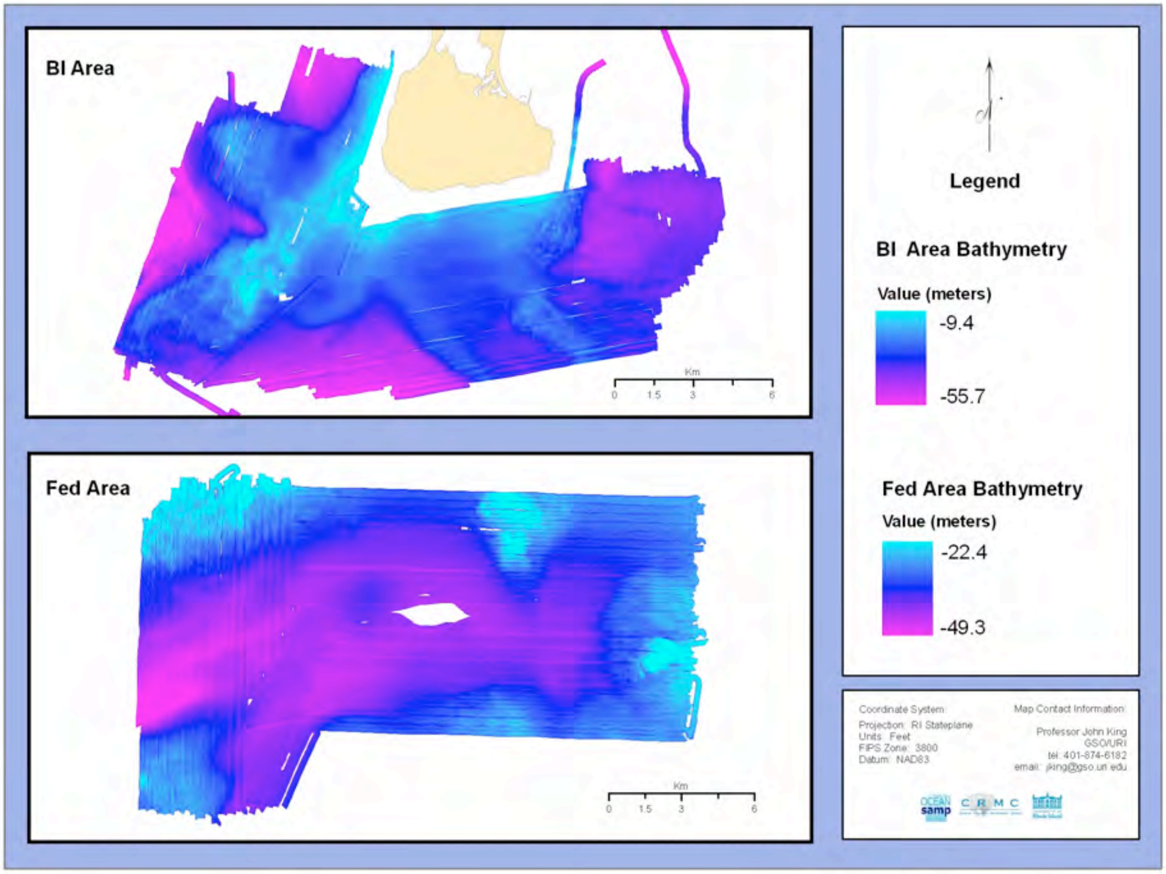


Figure I-7. Side-scan sonar mosaics of BI and FED. The mosaic is displayed on an inverse grey-scale. White (255) represents high backscatter intensity and black (0) represents low backscatter intensity, indicative of reflective (usually harder) surfaces and absorbent (usually softer) surfaces, respectively. The pixel resolution of the mosaics is 2 m. For the statistical analyses, the pixels were aggregated to 100 m resolution (not shown).



I-8. Bathymetry of BI and FED. Water depth ranges from 9.4 m to 55.7 m, with light blue signifying shallower depths and purple signifying deeper depths. Note the scales for BI and FED are different, so as to visually enhance the features within each area. The pixel resolution of the mosaics is 10 m. For statistical analyses, the pixel resolution was aggregated to 100 m (not shown).

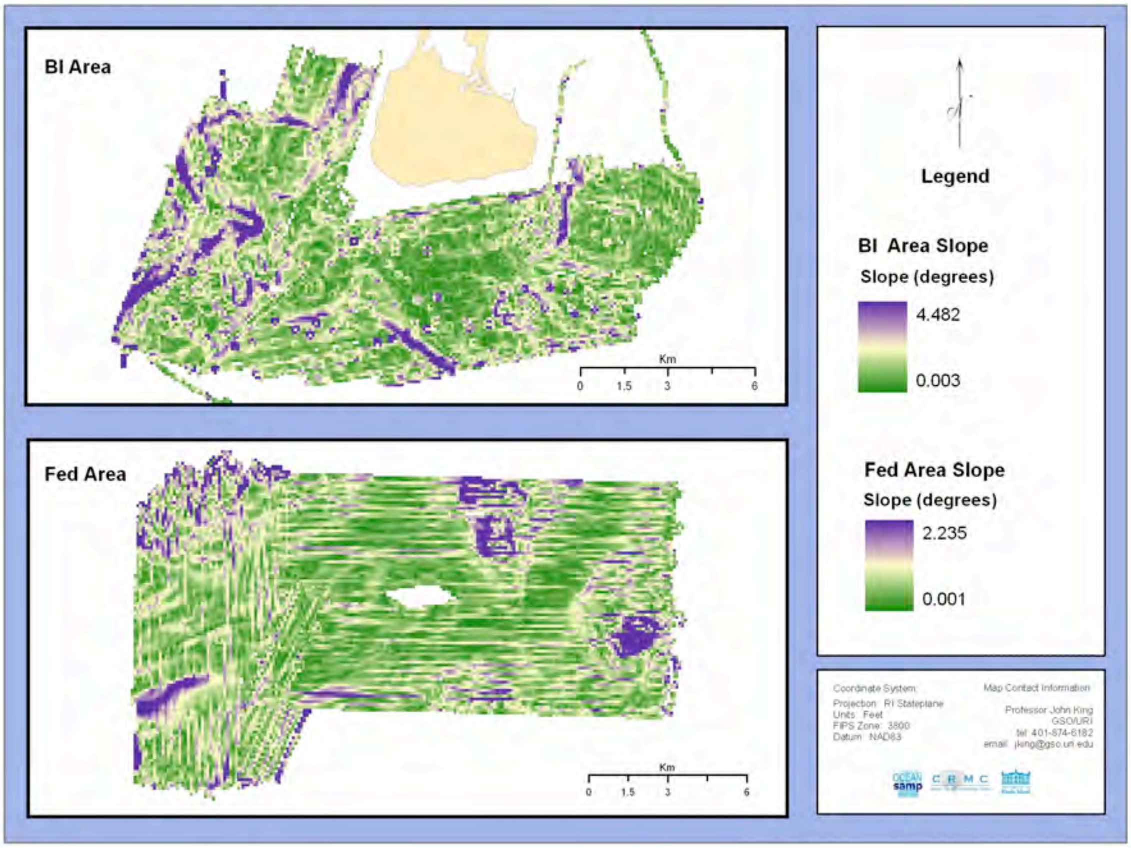


Figure I-9. Slope of BI and FED. The slope is measured in degrees, with purple indicating high slope values and green representing low slope values. Note the scales for BI and FED are different, so as to visually enhance the features within each area. The slope was calculated at 100 m pixel resolution.

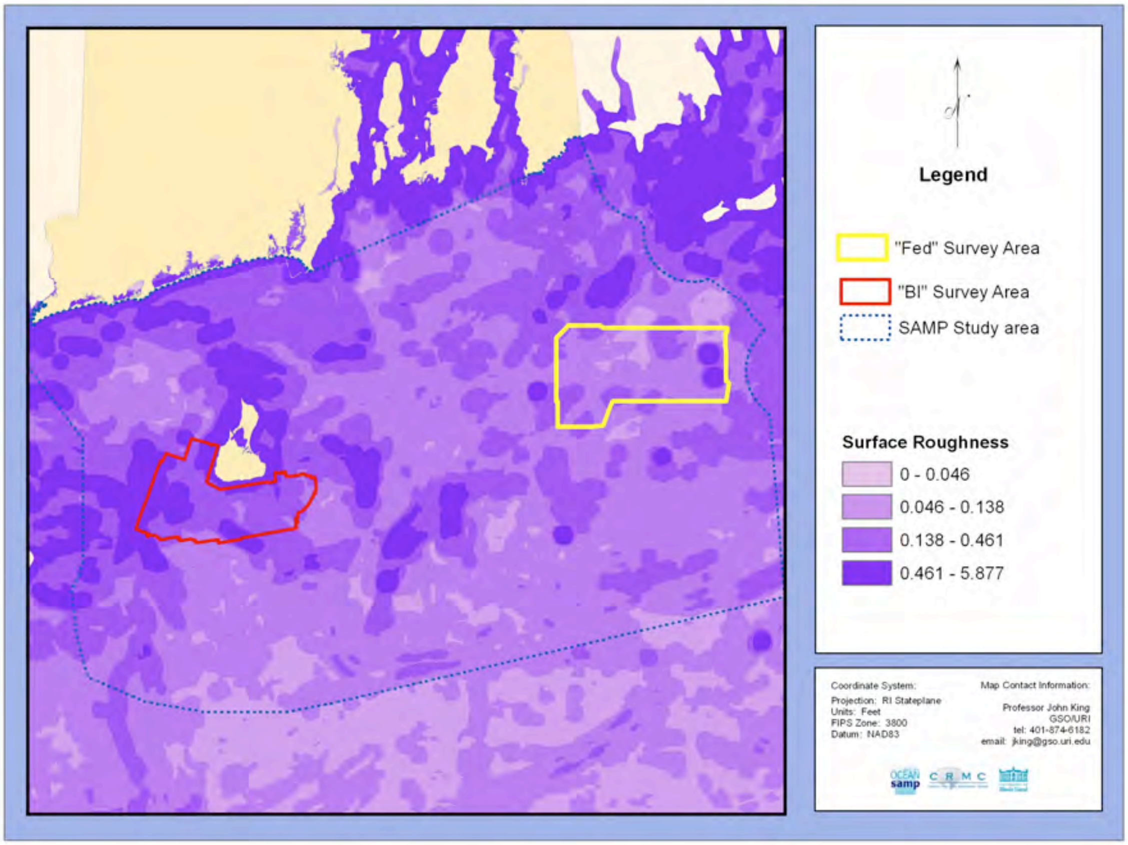


Figure I-10. Surface roughness of the RI Ocean SAMP study area. Surface roughness is reflects environmental heterogeneity. The dark purple is indicative of high heterogeneity and light purple signifies low heterogeneity. The red and yellow polygons represent the BI and FED study areas, respectively. The data layer is 100 m pixel resolution and is calculated by taking the standard deviation of the slope within a 1000 m radius.

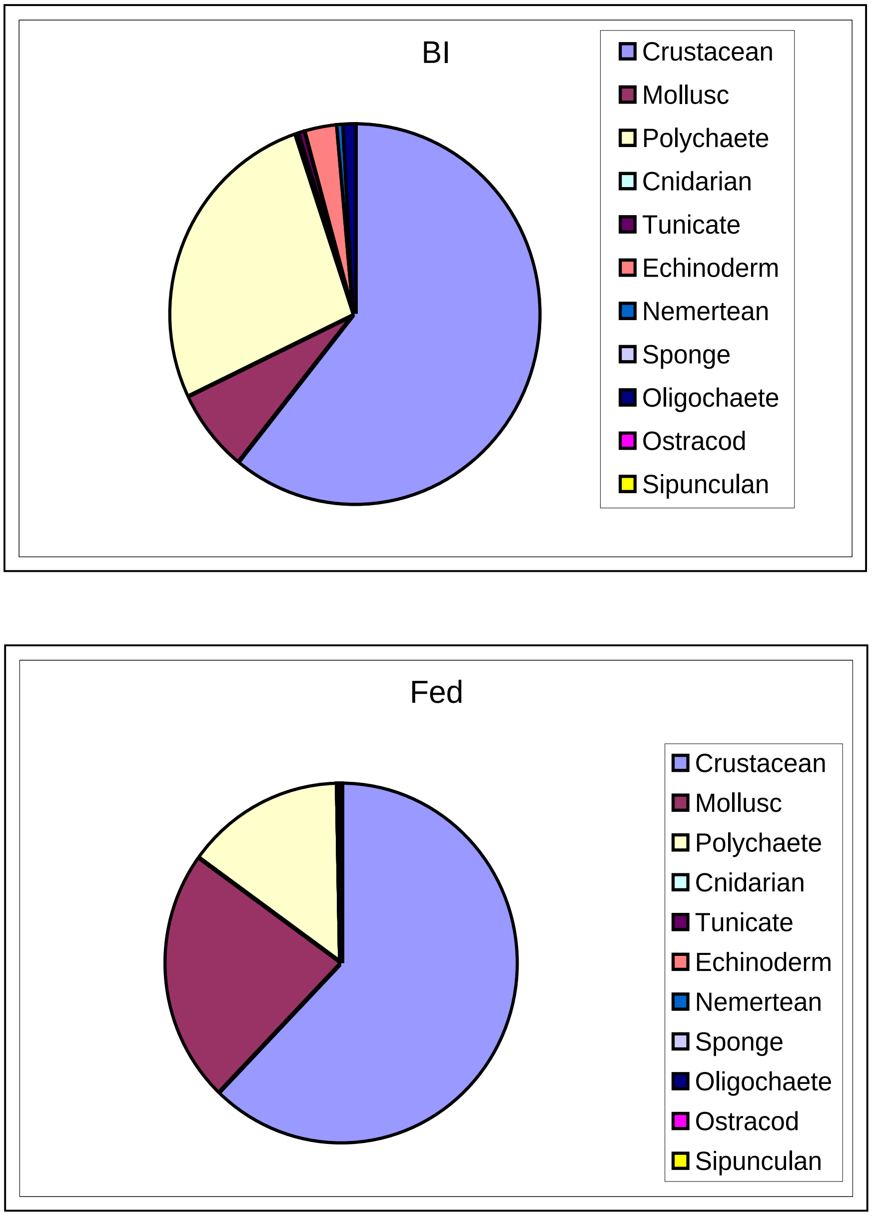


Figure I-11. Pie charts showing the Phyla composition of BI and FED. Crustaceans are the dominant phylum within both study areas. For BI, the second and third most prominent phyla are Polychaetes and Molluscs. This is reversed for FED, with Molluscs being more dominant than Polychaetes. A total of 11 phyla were recovered within BI and FED. All 11 phyla are seen within BI and 8 are present within FED.

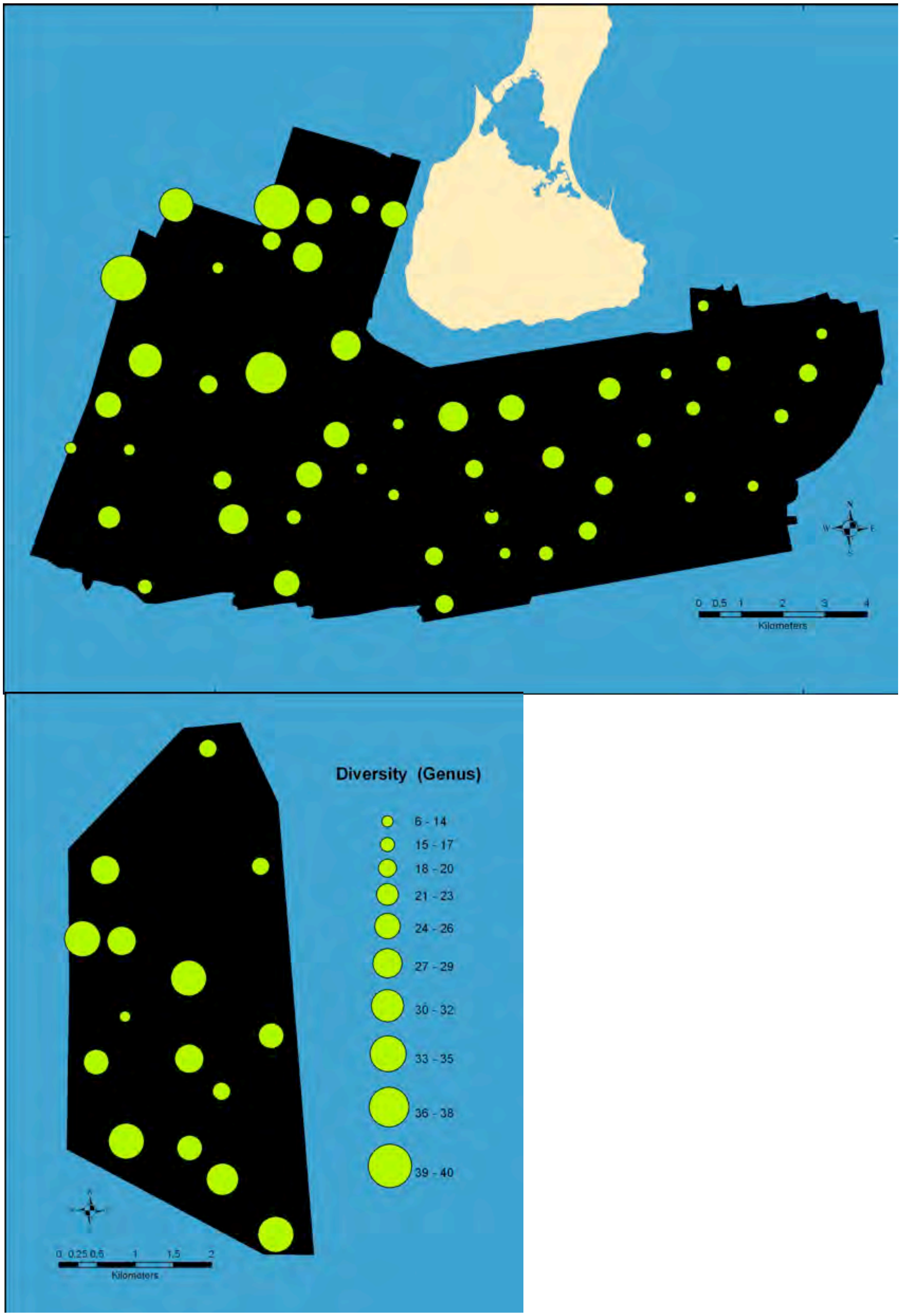


Figure I-12. Bubble plot of diversity within BI and FED. The size of the bubble is proportional to the diversity (measured at the genus level) at each station. Note the scales are the same for both BI and FED to allow comparison between study areas.

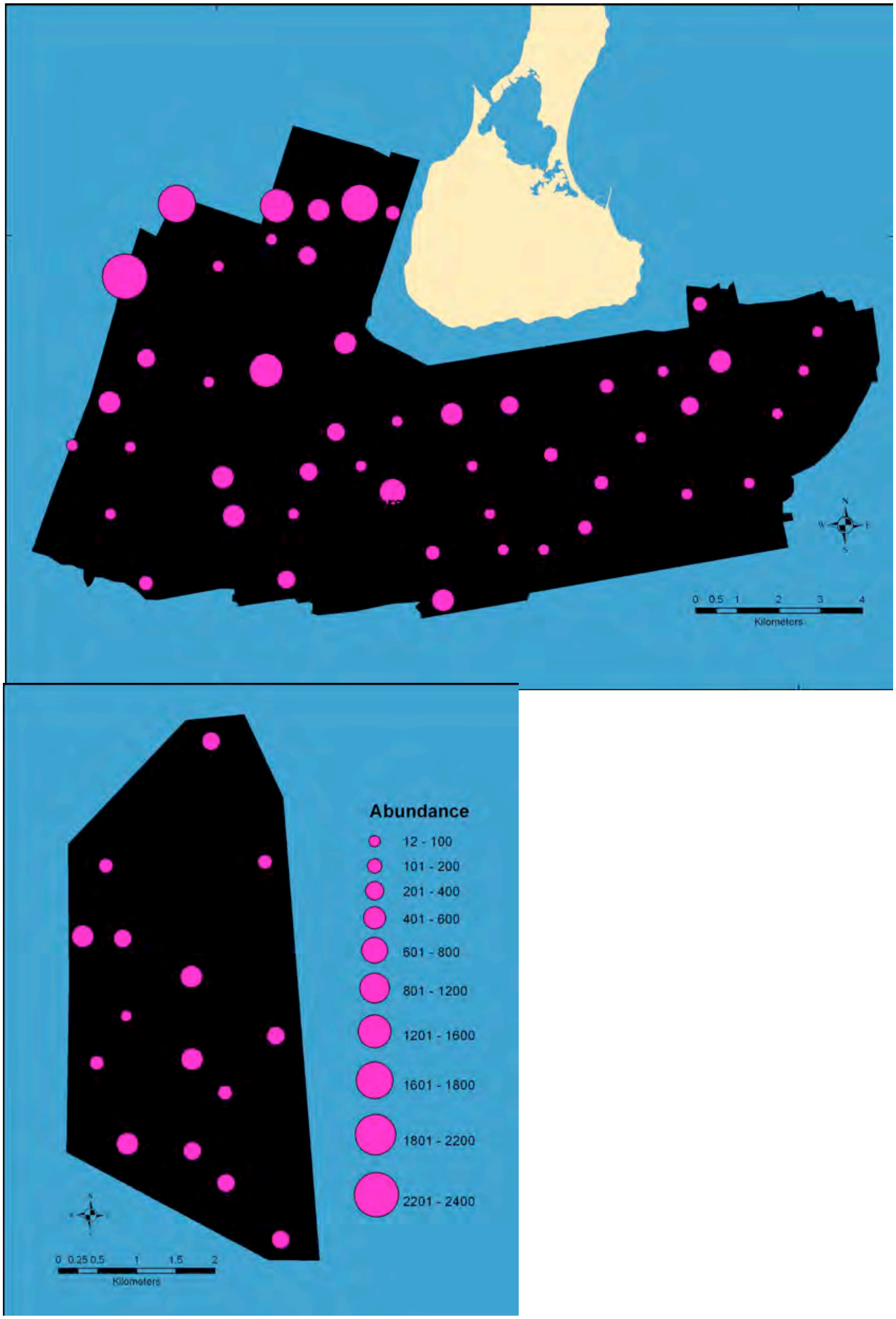


Figure I-13. Bubble plot of abundance within BI and FED. The size of the bubble is proportional to the diversity (measured at the genus level) at each station. Note the scales are the same for both BI and FED to allow comparison between study areas.

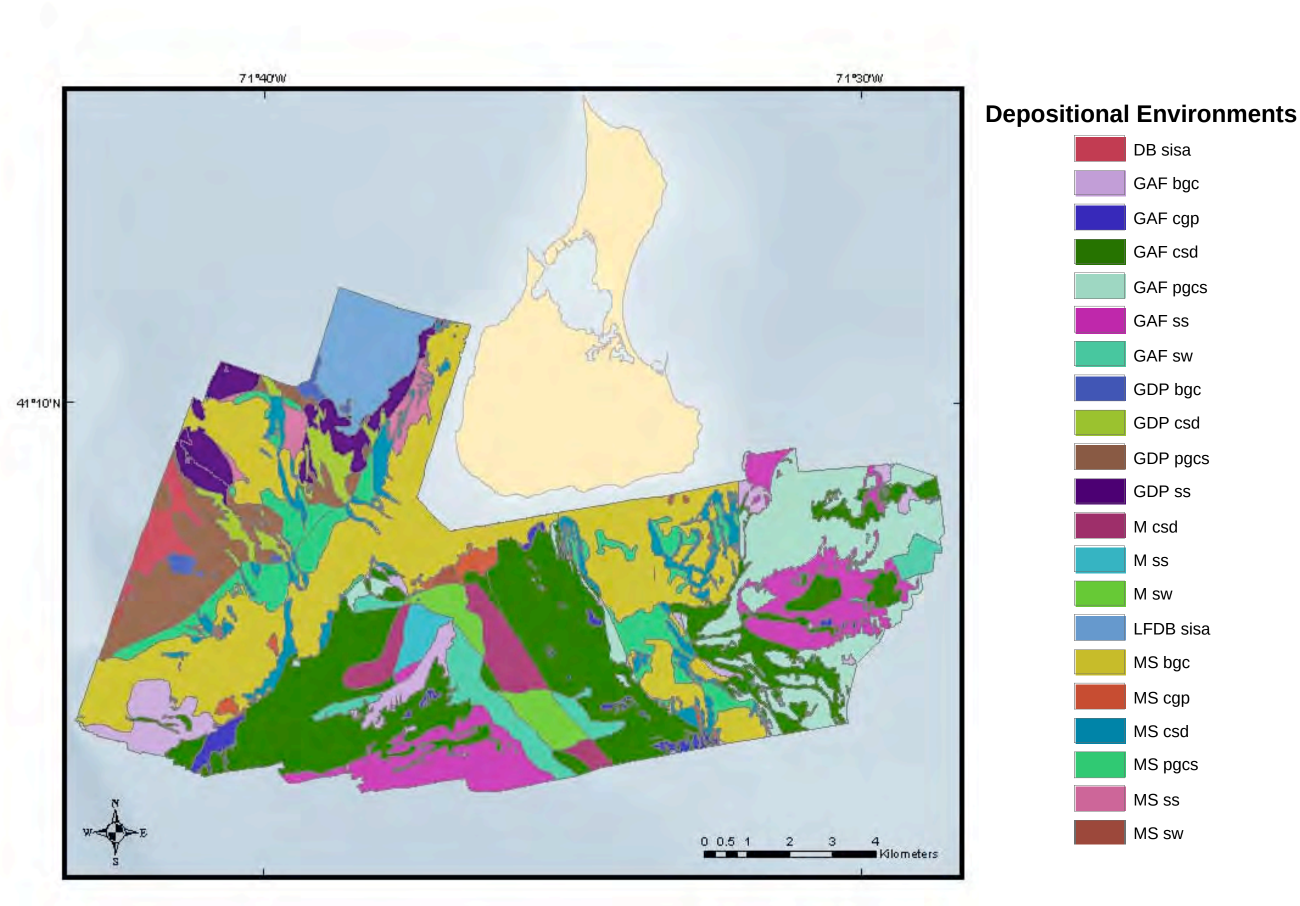


Figure I-14. Benthic geologic environment of BI. The environments were derived from side-scan imagery, sub-bottom profile imagery, sediment samples, and underwater video. The polygons are labeled by depositional environment units, reporting form (capital letters) followed by facies (lower case letters). The abbreviations are as follows: Form: DB = Depositional Basin; GAF = Alluvial Fan; GDP = Glacial Delta Plain; M = Moraine; MS = Moraine Shelf; LFDB = Lake Floor/Depositional Basin; Facies: sisa = silty sand; bgc = boulder gravel concentrations; cgp = cobble gravel pavement; csd = coarse sand with small dunes; pgcs = pebble gravel coarse sand; ss = sheet sand; sw = sand waves.

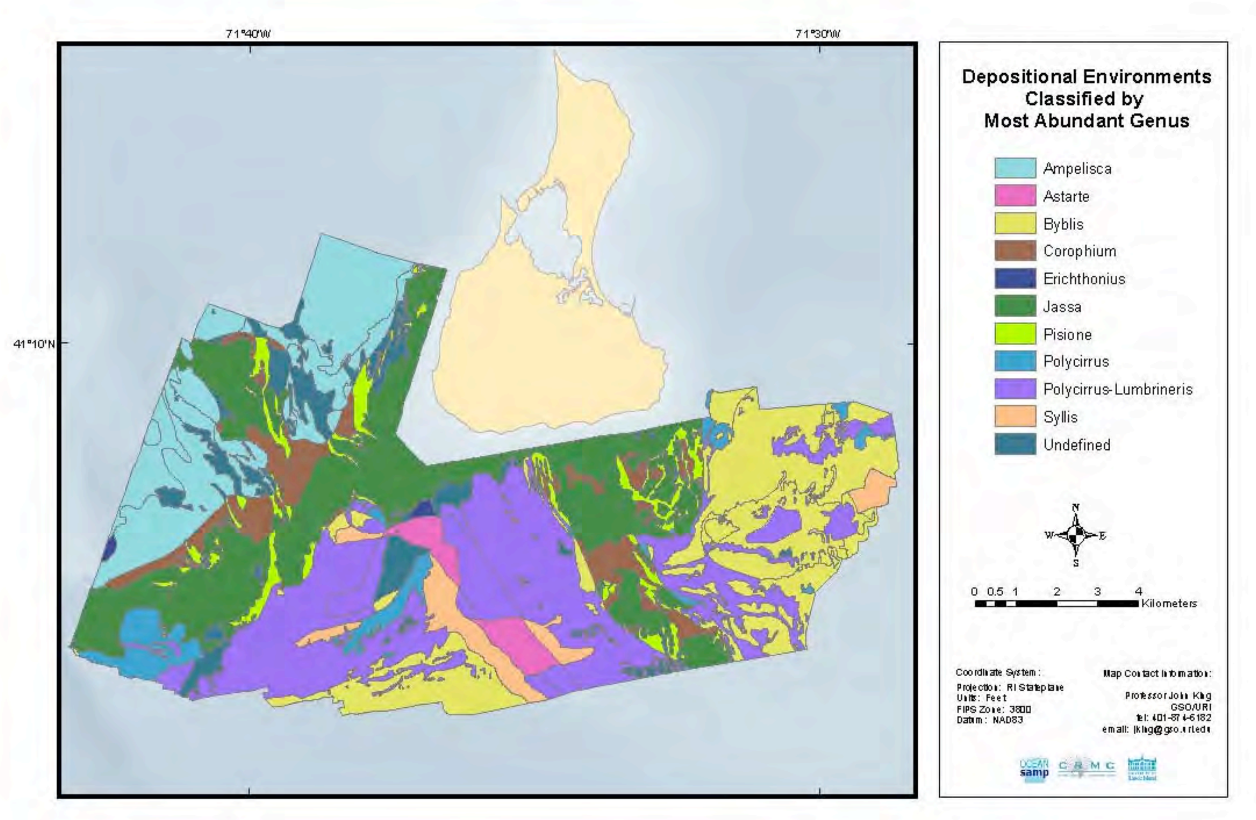


Figure I-15. Genus-defined benthic geologic environment of BI. The depositional environments were labeled by the most abundant genus, as determined from the bottom samples. An ANOSIM revealed the macrofaunal assemblages within each environment are significantly different (global R = 0.556, p = 0.001).

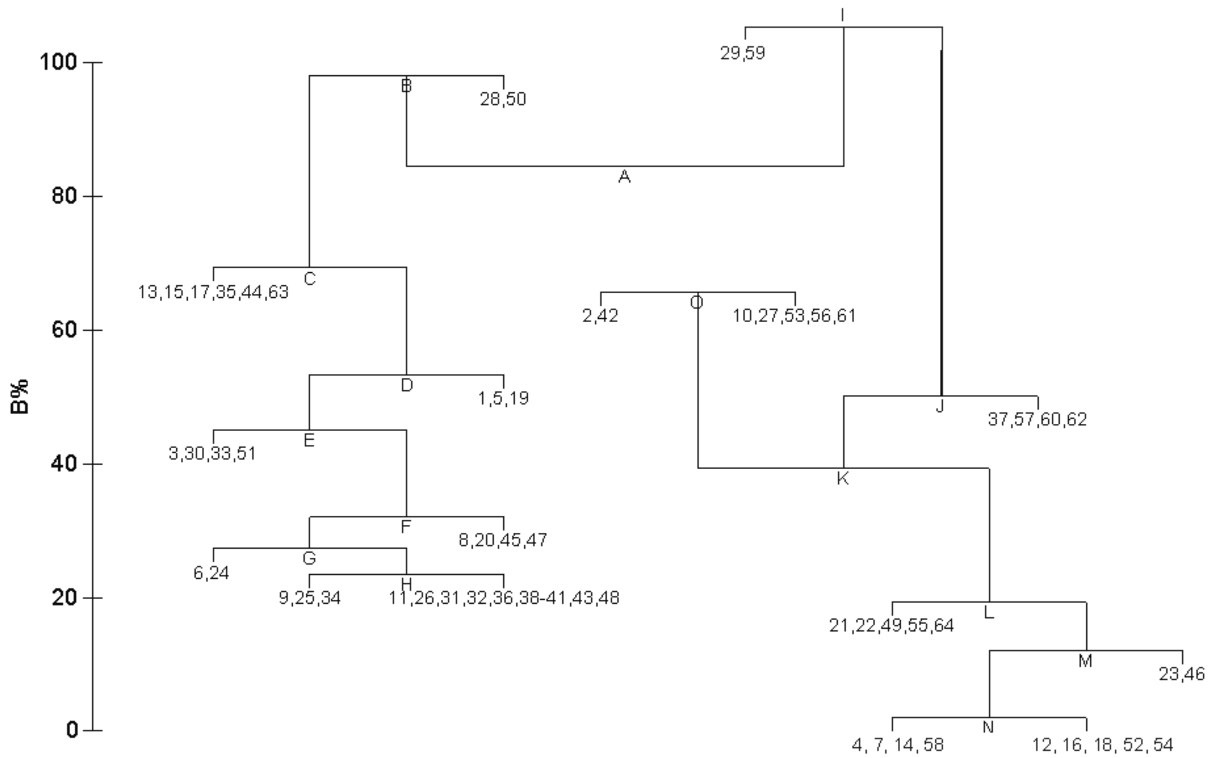
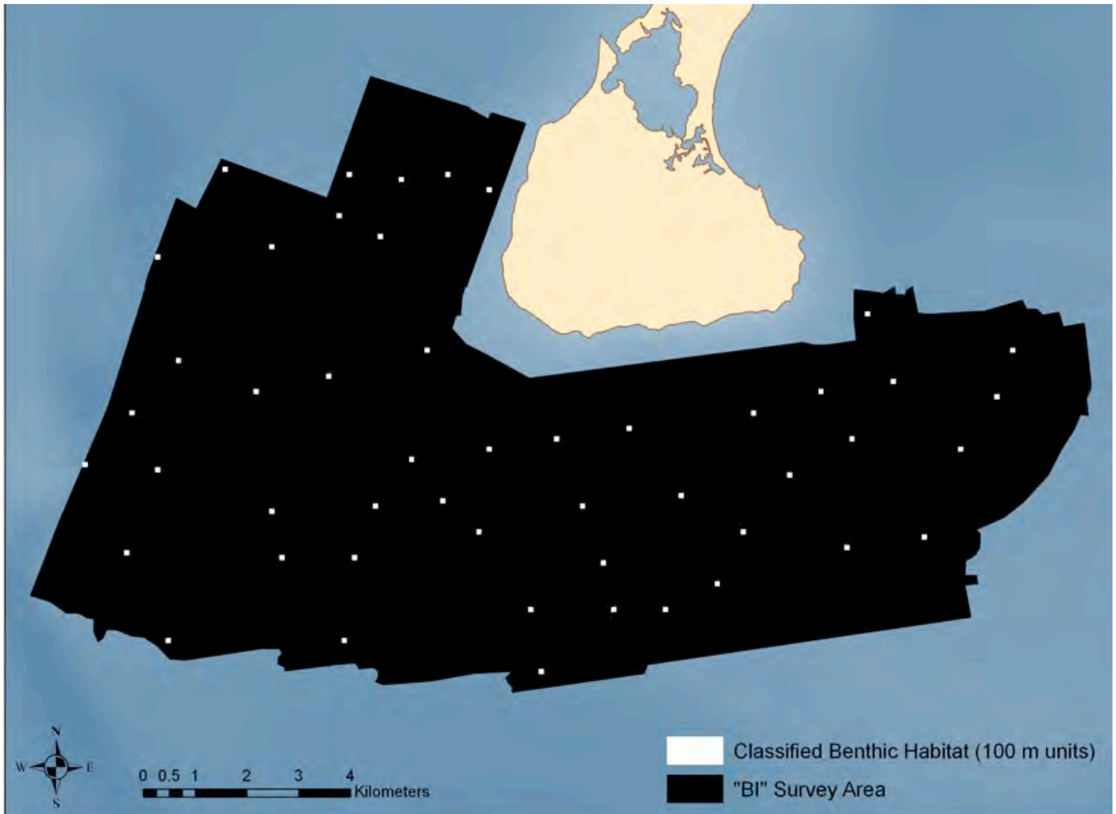


Figure I-16. LINKTREE output for BI and FED. The linkage tree identified 16 classes within BI and FED. Each class is defined by a quantitative threshold of one the five abiotic variables identified in the BIOENV procedure. Note that BI and FED share only 3 classes, while 11 classes contain only BI samples and two classes contain only FED samples. The threshold for each split is listed in Table I-9.



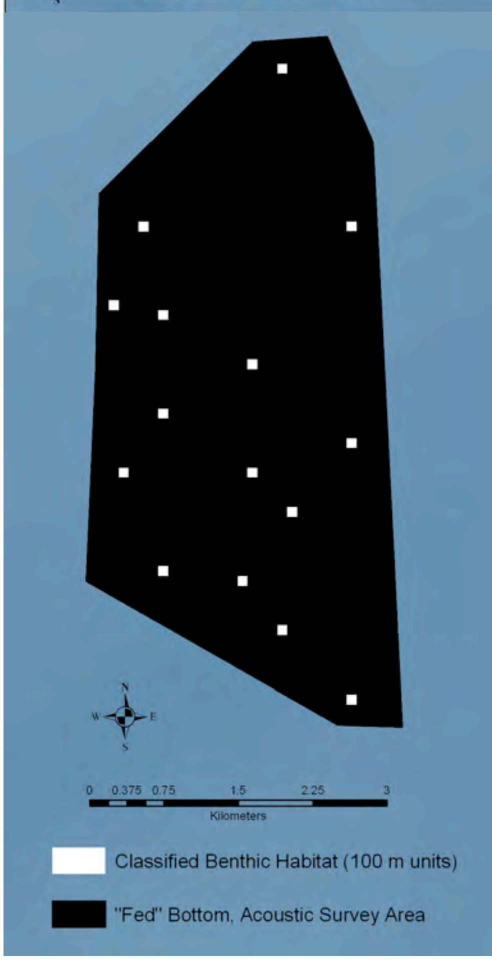


Figure I-17. Spatial extent of classified benthic habitats within BI and FED. The habitat map is comprised on 64, 100 m resolution pixels. Full-coverage benthic habitat maps are not possible at this time because of unsuccessful interpolation attempts due to the fact that the grain size datasets (derived from sediment analysis of the point-coverage bottom samples) are not spatially auto-correlated.

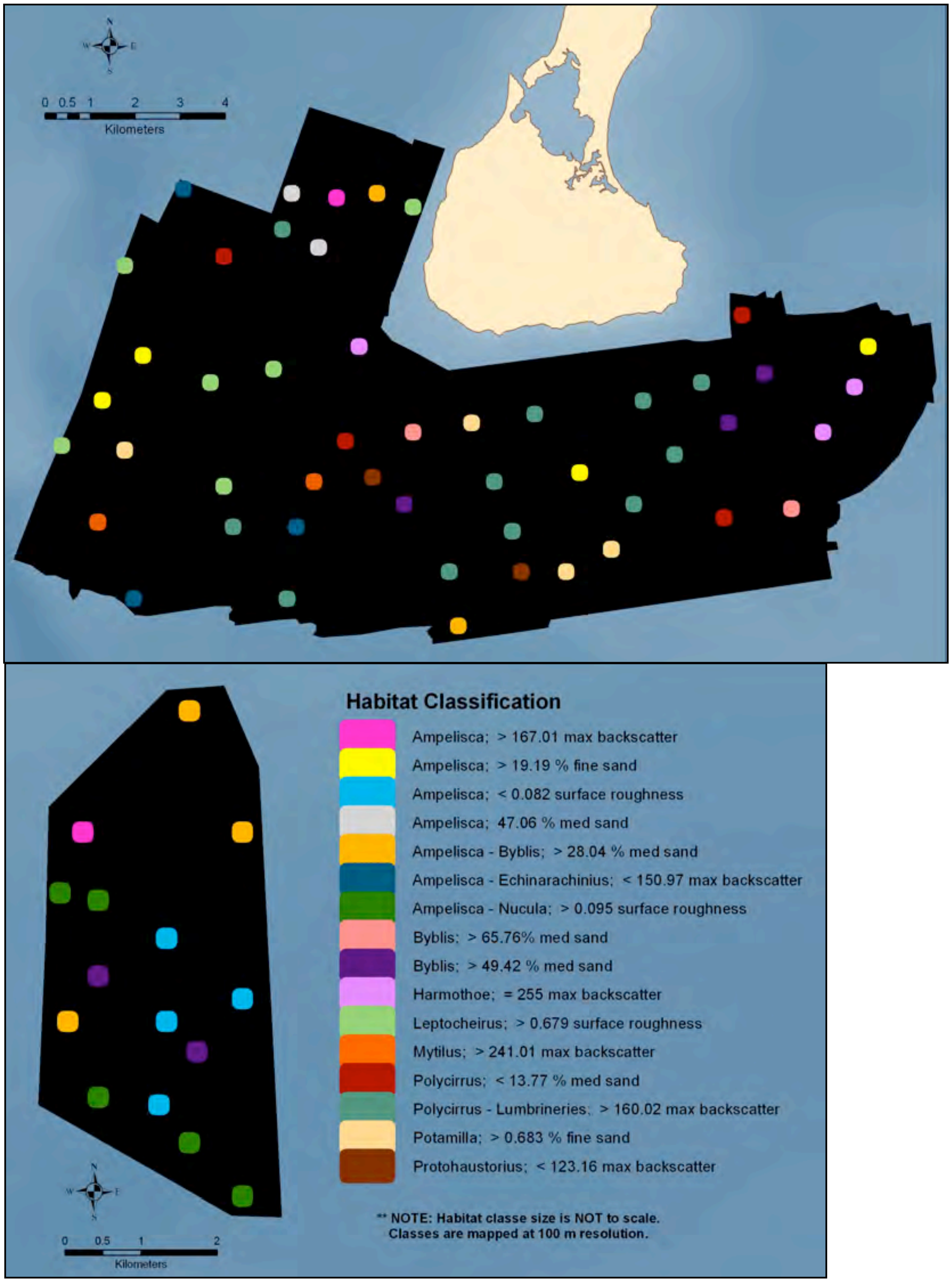


Figure I-18. Benthic habitat classification map for BI and FED. The benthic habitats were classified by the most abundant genus and the associated abiotic threshold. For four classes two genera were used in the classification because both showed high abundances. A total of 16 habitat classes were identified from the analyses. There are 14 habitats present within BI and 5 within FED. Note habitat class size is NOT to scale. Classes are mapped at 100 m pixel resolution (see Figure I-17)

Table I-1. Structure of the Geoform, Surface Geology, and Benthic Biotic Components with examples in NOAA's Coastal Marine Ecosystem Classification Standard (CMECS) (Madden, et al., 2010).

System	> Marine
> Subsystem	> Nearshore subtidal

Geoform Component	**> Coastal Region**	> New England seaboard lowland
	> Physiographic Setting	> Coast
	> Geoform (coastal)	> Moraine
	> Subform	> Moraine top
	> Anthropogenic Geoform	> Jetty
Surface Geology Component	**> Class**	> Unconsolidated Substrate
	> Subclass	> Sand
Benthic Biotic Component	**> Class**	> Faunal Bed
	> Subclass	> Epifauna
	> Biotic Group	> Tube-building amphipods
	> Biotope	> *Ampelisca* community

Table I-2. List of abiotic and biotic variables used in the study. The source, type of coverage attained, and the resolution of each variable is also listed. In total, 19 abiotic variables were included in the statistical analyses and 2 biotic variables.

Source	Coverage	Resolution (m)	Variable
Backscatter	Continuous	100	Mean
			Maximum
			Minimum
			Standard Deviation
Bathymetry	Continuous	100	Water Depth (m)
			Aspect (degrees)
			Slope (degrees)
			Surface Roughness (Std Dev of Slope within 1000 m Radius)
Video	Transect	44 stations	Grain Size (%)
			Bottom Type (%)
			Number of Patches
Grain Size	Point	64 stations	% Clay
			% Fine Silt
			% Course Silt
			% Very Fine Sand
			% Fine Sand
			% Medium Sand
			% Coarse Sand
			% Very Coarse Sand
Biology	Point	64 stations	Identificantion (genus level)
			Counts (individuals)

Table I-3. Ranges of the acoustic variables within BI and FED. Note the wider ranges exhibited by BI for all of the acoustic variables.

Acoustic Variables (100m)	**Range**		
	BI	**FED**	**BI and FED**
Mean Backscatter Intensity	40.99 - 239.13	69.39 - 146.48	40.99 - 239.13
Max Backscatter Intensity	88 - 255	95 - 178	88 - 255
Min Backscatter Intensity	1 - 110	1 - 85	1 - 110
Standard Deviation of Backscatter	10.86 - 98.61	7.35 - 17.59	7.35 - 98.61
Water Depth (m)	13.82 - 38.63	31.89 - 44.01	13.82 - 44.01
Slope (degrees)	0.01 - 1.54	0.02 - 0.47	0.01 - 1.54
Surface Roughness (Std Dev of Slope w/in a 1000m Radius)	0.09 - 1.39	0.05 - 0.22	0.05 - 1.39
Aspect (degrees)	9.36 -352.27	89.68 - 354.21	9.36 - 354.21

Table I-4. Percent composition and ranges of the grain size from analysis of the sediment samples within BI and FED. BI is dominated by medium and coarse grained sands and fine and medium sands dominate FED. Within both study areas, the dominant sediment is medium and coarse grained sands. The stations within BI exhibit wider ranges for most of the sediment variables and for the standard deviation of the grain size (um).

Sediment Variables	**Percent Composition**		
	BI (%)	**FED (%)**	**BI and FED (%)**
% Clay	1.61	5.38	2.45
% Fine Silt	3.40	10.19	4.91
% Course Silt	0.84	2.53	1.22
% Very Fine Sand	1.45	11.97	3.79
% Fine Sand	9.91	34.24	15.32
% Medium Sand	33.41	29.25	32.48
% Coarse Sand	36.01	5.98	29.34
% Very Coarse Sand	13.36	0.46	10.50
Sediment Variables	**Range**		
	BI	**FED**	**BI and FED**
% Clay	0 - 20.12	1.84 - 9.22	0 - 20.12
% Fine Silt	0 - 36.79	2.04 - 23.40	0 - 36.79
% Course Silt	0 - 8.43	0.48 - 9.16	0 - 9.16
% Very Fine Sand	0 - 9.89	0.41 - 28.45	0 - 28.45
% Fine Sand	0 - 57.82	3.92 - 46.97	0 - 57.82
% Medium Sand	0.43 - 76.34	8.73 - 57.54	0.43 - 76.34
% Coarse Sand	0.27 - 69.57	0.27 - 32.00	0.27 - 69.57
% Very Coarse Sand	0 - 62.73	0 - 3.44	0 - 62.73
Standard Deviation of Grain Size, um	90.56 - 459.78	105.86 - 302.42	90.56 - 459.78

Table I-5. Number phyla, genera, and individuals recovered within BI and FED.

	BI	FED	Combined
Total Number of Phyla	11	8	11
Total Number of Genera	156	75	173
Total Number of Individuals	16,269	4,464	20,733

Table I-6. Diversity and Abundance within BI and FED. Diversity is defined as the number of genera per station. Abundance defined as is the number of individuals per station.

	BI	FED	Combined
Range of Diversity per Station	6 - 40	14 - 38	6 - 40
Mean Diversity per Station	21	28	23
Range of Abundance per Station	12 - 2,333	38 - 555	12 - 2,333
Mean Abundance per Station	332	298	324

Table I-7. General description of underwater video collected at BI stations. Video was only obtained for BI stations 1-45. The most common bottom type was flat surface, for which the sediment composition ranged from coarse sand to cobble. The most common sediment type was coarse sand. Over half of the stations exhibited one bottom type throughout the 200 m transect.

Underwater video parameters	# of Stations
Bottom Type	
Dense Tube-mat	4
Flat surface	21
Rippled surface (regular pattern)	9
Rippled surface (irregular pattern)	9
Boulder field	10
Sediment Type	
Fine sediment (silt, clay, fine sand)	6
Fine sand	4
Coarse sand	30
Gravel	13
Cobble	9
Boulders	11
# Bottom patches	
1	26
2	3
3	1
4	2
5	3
6	1
7	7
8	3
9	0
10	2
11	1

Table I-8. Description of the depositional environments. The environments in bold font are those with the greatest spatial extent within BI. The unit is labeled by form (capital letters) followed by facies (lower case letters). The abbreviations are as follows: Form: DB = Depositional Basin; GAF = Alluvial Fan; GDP = Glacial Delta Plain; M = Moraine; MS = Moraine Shelf; LFDB = Lake Floor/Depositional Basin; Facies: sisa = silty sand; bgc = boulder gravel concentrations; cgp = cobble gravel pavement; csd = coarse sand with small dunes; pgcs = pebble gravel coarse sand; ss = sheet sand; sw = sand waves.

Unit	Area (km sq)	Coverage (%)	# Biology Samples
AF bgc	5.01	3.63	2
AF cgp	1.44	1.04	0
AF csd	**29.39**	**21.30**	**14**
AF pgcs	**13.16**	**9.54**	**5**
AF ss	**10.26**	**7.44**	**2**
AF sw	4.49	3.25	2
DB sisa	1.84	1.34	0
GDP bgc	0.67	0.48	0
GDP csd	2.23	1.61	0
GDP pgcs	6.91	5.00	4
GDP ss	4.26	3.09	3
LFDB sisa	5.44	3.94	4
M csd	3.52	2.55	1
M ss	1.03	0.75	1
M sw	2.72	1.97	2
MS bgc	**29.97**	**21.72**	**5**
MS cgp	1.04	0.75	0
MS csd	5.67	4.11	1
MS pgcs	7.71	5.58	2
MS ss	1.59	1.15	0
MS sw	0.34	0.24	1

Table I-9. LINKTREE thresholds. The branch to the left side of the LINKTREE is listed first and the branch to the right side of the LINKTREE is listed second in brackets. For example, for Class A, the stations on the left side of the split have a threshold of < 8.55 % fine sand and the stations on the right side of the split have a threshold of > 9.39 % fine sand. Note that many of the thresholds are defined by narrow ranges of the abiotic variables.

Linktree Thresholds		
Class		
A	% fine sand	< 8.55 (> 9.39)
B	max backscatter	> 128.05 (< 123.16)
C	surface roughness	> 0.679 (< 0.609)
D	max backscatter	< 247.81 (> 255)
E	% fine sand	> 6.83 (< 6.23)
F	% medium sand	> 15.84 (< 13.77)
G	max backscatter	> 241.01 (< 226.01)
H	max backscatter	< 150.97 (> 160.02)
I	% medium sand	> 65.76 (< 57.59)
J	% fine sand	> 19.19 (< 16.18)
K	% medium sand	> 44.89 (< 43.32)
L	% medium sand	> 28.04 (< 27.79)
M	max backscatter	< 154.00 (> 167.01)
N	surface roughness	< 0.082 (> 0.095)
O	% medium sand	< 47.06 (> 49.42)

Table I-10. Description of LINKTREE classes. For each class, the comprising stations, the most abundant genus, and the genus most responsible for the within-class similarity (as identified by the SIMPER procedure) is listed. The classes marked with ** are the seven classes for which the same genus is the most abundant and is the most responsible for the within-class similarity.

Class	Comprising Stations	Most Abundant Genus	Genus Most Responsible for Within-Class Similarity
1	BI 25, 808	*Byblis*	*Protohaustorius* (39.69 %)
2**	BI 24, 42	*Protohaustorius*	*Protohaustorius* (30.49 %)
3	BI 9, 14, 15, 16, 39, 308	*Leptocheirus*	*Corophium* (11.15 %)
4	BI 17, 1008, 1108	*Harmothoe*	*Glycera* (15.19 %)
5	BI 10, 26, 29, 43	*Potamilla*	*Lumbrineries* (25.47 %)
6	BI 3, 19, 408, 1208	*Polycirrus*	*Polygordius* (22.47 %)
7	BI 11, 20	*Mytilus*	*Pisione* (16.83 %)
8	BI 2, 12, 21	*Ampelisca-Echinarachinius*	*Lumbrineries* (26.07 %)
9**	BI 13, 22, 27, 28, 31, 33, 34, 35, 36, 38, 40	*Polycirrus-Lumbrineries*	*Lumbrineries* (11.20 %)
10	BI 7, 8, 32, 908	*Ampelisca*	*Unciola* (16.27 %)
11**	BI 1, 41; FED 1, 6, 9	*Ampelisca-Byblis*	*Byblis* (17.46 %)
12	BI 208; FED 3	*Ampelisca*	*Lumbrineries* (16.5 %)
13**	FED 7, 10, 11, 14	*Ampelisca*	*Ampelisca* (13.93 %)
14**	FED 4, 5, 13, 15, 16	*Ampelisca-Nucula*	*Ampelisca* (11.02 %)
15**	BI 37, 108	*Ampelisca*	*Ampelisca* (12.95 %)
16**	BI 23, 508, 708; FED 8, 12	*Byblis*	*Byblis* (36.81 %)
** Same genus is most abundant and most responsible for within-class similarity			

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SECTION II: SUBSURFACE GEOLOGY

II.1 Introduction

The goal of the subsurface geology studies as to determine if the subbottom sediments were unconsolidated and thick enough to readily install structures by pile-driving. We used a high resolution sonar to characterize the subsurface geology of the study area. We interpreted the depth to a hard subsurface lithology only, and did not examine the details of the overlying soft sediments.

II.2 Background

Prior studies by McMaster, *et al*., 1968, and a series of U.S. Geological Survey surveys (McMullen, *et al*., Needell and Lewis, 1984, Poppe, *et al*., 2002) provide good coarse-resolution coverage of the northern part of the SAMP area, and very limited coverage of the southern part of the SAMP area. The trackline coverage of the these surveys is shown in Figure II-1. Additional information and interpretation from the USGS surveys, as well as a significant number of GIS datalayers, are available online through a series of digital data releases and Open File reports. Online addresses are included with the references. The McMaster, *et. al.* (1968) data is not available in digital format

II.3 Methods

Sub-bottom seismic data were obtained with a 400-Hz bubble pulser towed profiling system along GPS-navigated survey lines. The target vessel speed was 4 kts with a shotpoint interval of 0.25 s, which resulted in an along-track shotpoint interval of 0.5 m with a maximum seismic penetration of 200 m (assuming 1600 m/s seismic velocity of sediments). A digital sampling interval of 100 ms along individual traces results in a 2 mm vertical sampling interval.

Seismic data were collected in two primary survey areas (Fig. 2): 1) Block Island, along the southern half of the island extending from the shoreline out to 5-10 km offshore, and 2) Federal Area, southwest of Martha's Vineyard in an 8 km x 18 km rectangular region surrounding the WHOI buoy field. The Block Island seismic data were collected on several cruises aboard the 28' R/V McMaster during July (14^{th}, 15^{th} and 29^{th}) and August (6^{th}) of 2009.

Typical spacing between adjacent lines was about 0.5-1 km with more widely spaced crossing tie lines. The seismic data from the Federal Area were collected aboard the R/V Endeavor during cruise EN468 from September 17 to September 25, 2009. Seismic operations were limited by daylight and weather conditions during the latter cruise; so seismic trackline spacing is more variable (0.5-3 km) in this region.

Post-processing of the sub-bottom seismic data involved two steps: band-pass filtering and time-dependant normalization. A band-pass filter was applied to each seismic line with a low-cut frequency of 300-400 Hz and a high-cut frequency of 1000-2000 Hz. The band-pass frequency ranges were chosen qualitatively from a matrix of seismic panels with incremental variations in frequencies. The time-dependant normalization was achieved with automatic gain control with a window length of 50-100 ms and a gain of 1-1.5 dB. As with the band-pass filtering, the automatic gain control parameters were chosen based on a matrix of varying window length and gain.

II.4 Results

Representative examples of interpreted processed seismic data from each region are shown in Figure 3 and 4. A sediment thickness map of the Federal Area was generated by digitizing the sediment-water interface and the deepest visible reflection in the processed seismic data (Figure 5). The along-track location of each reflector was digitized at least every 200 m and wherever significant changes in reflector depth occurred. Linearly interpolated and geo-referenced seismic horizons were then generated with SonarWeb software from which sediment thickness estimates at each shot-point were calculated. These geo-referenced sediment thickness estimates were used as input in contouring and two-dimensional surface-fitting algorithms from Generic Mapping Tool to create sediment isopach maps. It should be noted that these sediment thickness estimates and associated isopach maps represent minimum sediment thicknesses; there likely exists deeper sediment/sediment or sediment/basement interfaces.

II.5 Discussion

The comparison of sediment isopach maps from previous USGS surveys and our recent survey in the Federal Area provides several useful observations. First, in the eastern half of the survey area, the sediment thickness estimates from both surveys are very similar and indicate sediment thicknesses in excess of 100 m. These thicker sediments correlate to darker regions in the sidescan data and appear to represent two southward-merging buried valleys. The brighter regions in the side-scan data are associated with thinner sediments (< 20 m). Second, in the central portion of the survey area, both sets of seismic data identify a NW-SE trending ridge buried by a thinner sediment layer (< 20 m). Finally, in the westernmost portion of the survey area, both surveys indicate increased sediment thickness; however, the sediment is significantly thicker in the USGS survey data. The most likely reason for the difference is the inability of our recent data to resolve the deeper seismic reflections; the closely spaced seismic lines in the recent data do not have crossing tie-lines and the sea state was significantly degraded during the collection of these survey lines. Therefore, the interpretation from the USGS study is likely to be more representative of the region. It is also interesting to note that a correlation between sediment thickness and side-scan reflectivity does not exist in the western half of the survey area, so side-scan reflectivity alone may not be appropriate to infer relative sediment thickness.

The subsurface geology can be interpreted in terms of effort required to install wind turbines. Ease of construction is based on the technology needed to install wind turbines in areas with specific subbottom types. Subbottom sediment types that are unconsolidated and thick enough to allow pile-driving as the installation technology are rated between 1 and 3, with 1 being the easiest. Any lithology that would require drilling for installation of piles would be rated greater than 3. For example, Figure II-6 shows interpreted construction efforts within the BI study area.

II.6 Conclusions

The subsurface geology studies allow us to identify areas that would be suitable for the installation of foundation structures by pile-driving. It is apparent from Figure II-6 that most areas located to the south of Block Island are suitable for installation of piles by pile-driving including the site proposed by DeepWater Wind shown by the yellow dots (representing borehole locations).

Our studies of the FED indicate that there are also suitable locations in the central to western part of the survey area for installation of piles by pile-driving.

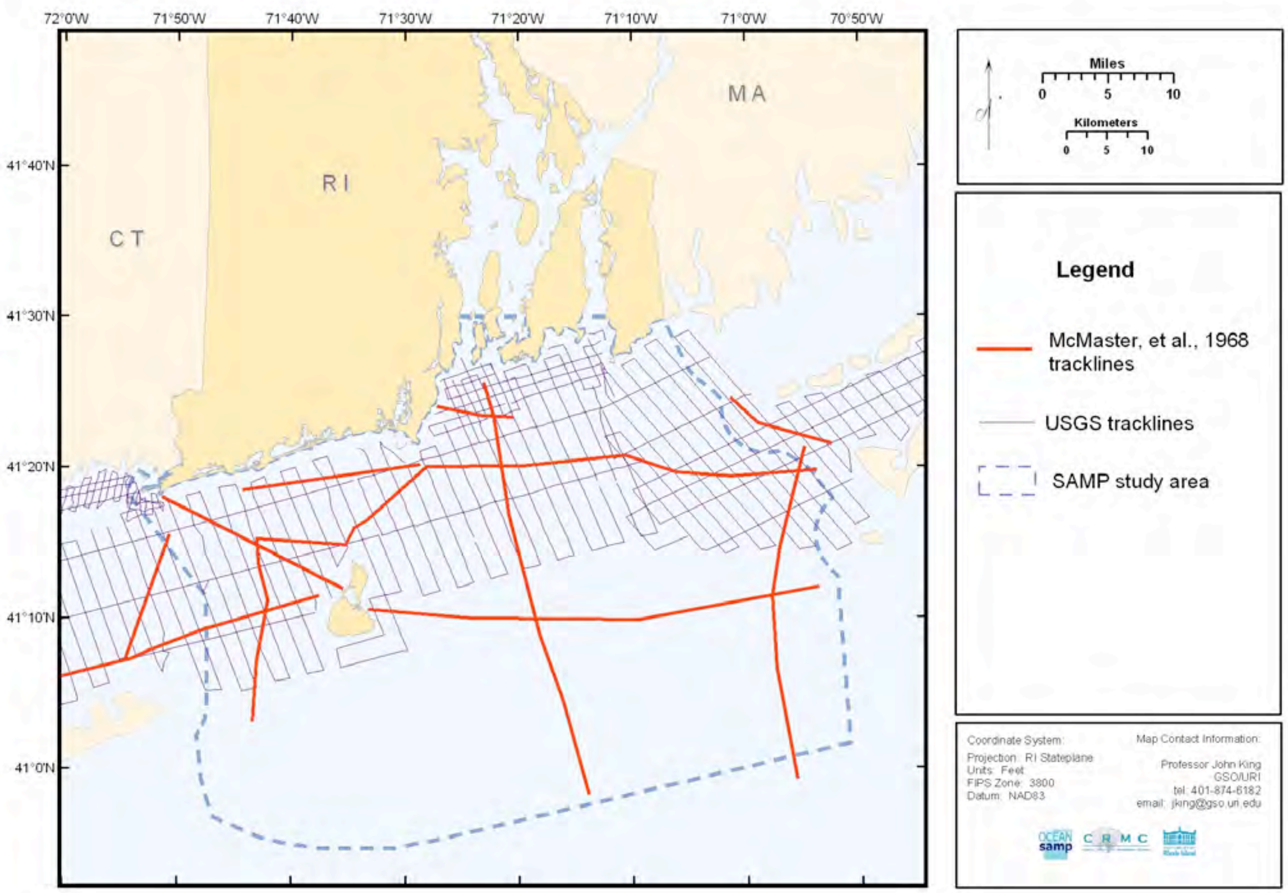

Figure II-1. Map showing locations of previous subbottom surveys within the SAMP area.

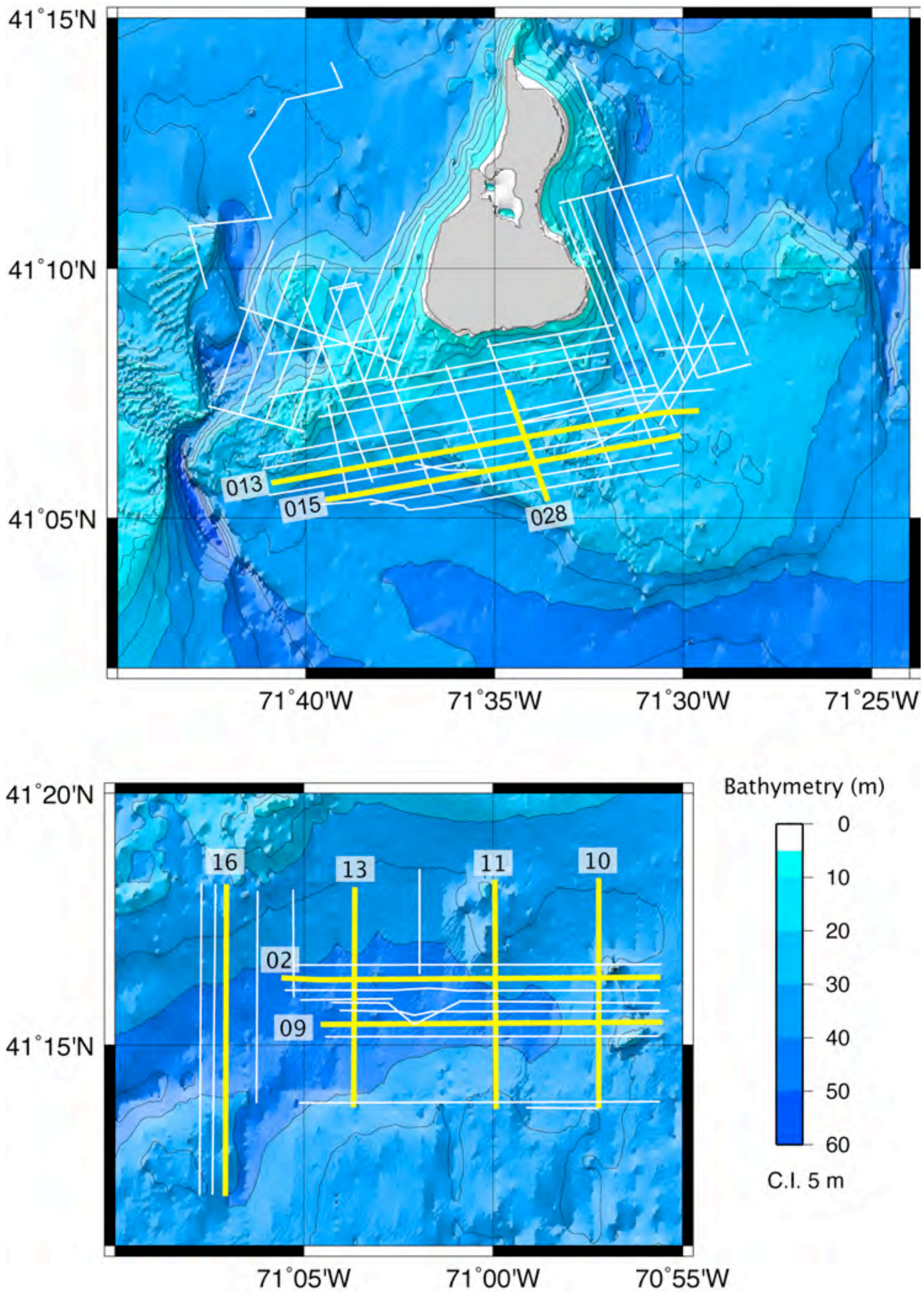

Figure II-2. Sub-bottom seismic tracklines (white lines) superimposed on bathymetry (http://www.ngdc.noaa.gov/mgg/coastal/crm.html) for the Block Island (top) and the Federal (bottom) survey areas. The yellow lines identify the location of seismic sections shown Figures 3 and 4.

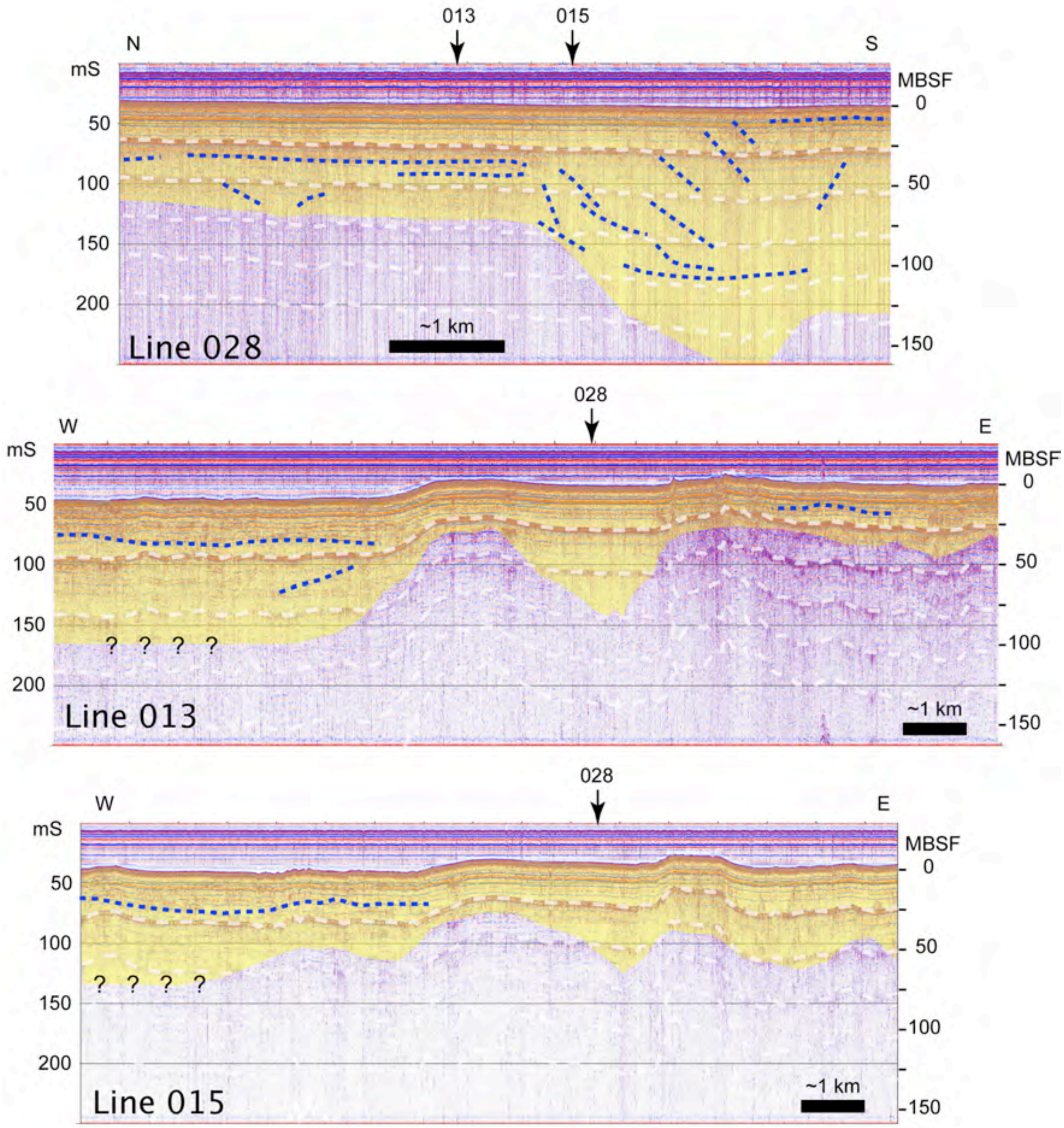

Figure II-3. Processed seismic cross-sections of selected lines from Block Island survey area (see Fig 2, top) with sub-bottom interpretations. The yellow regions correspond to the sediment-water interface at the top and the deepest visible reflection at the bottom. The questions marks indicate sections of the seismic record where our identified deepest reflector extends below the resolvable depth limit. Multiple reflections of the sediment-water interface (white dashed lines) and internal reflectors (blue dashed lines) within the identified sediment package are indicated. The location of crossing lines are indicate with arrows and appropriate line number. The vertical axis of the section is plotted as two-way travel time (milliseconds) and thickness of the sediment section (MBSF, meters below seafloor), assuming a seismic velocity of 1500 m/s.

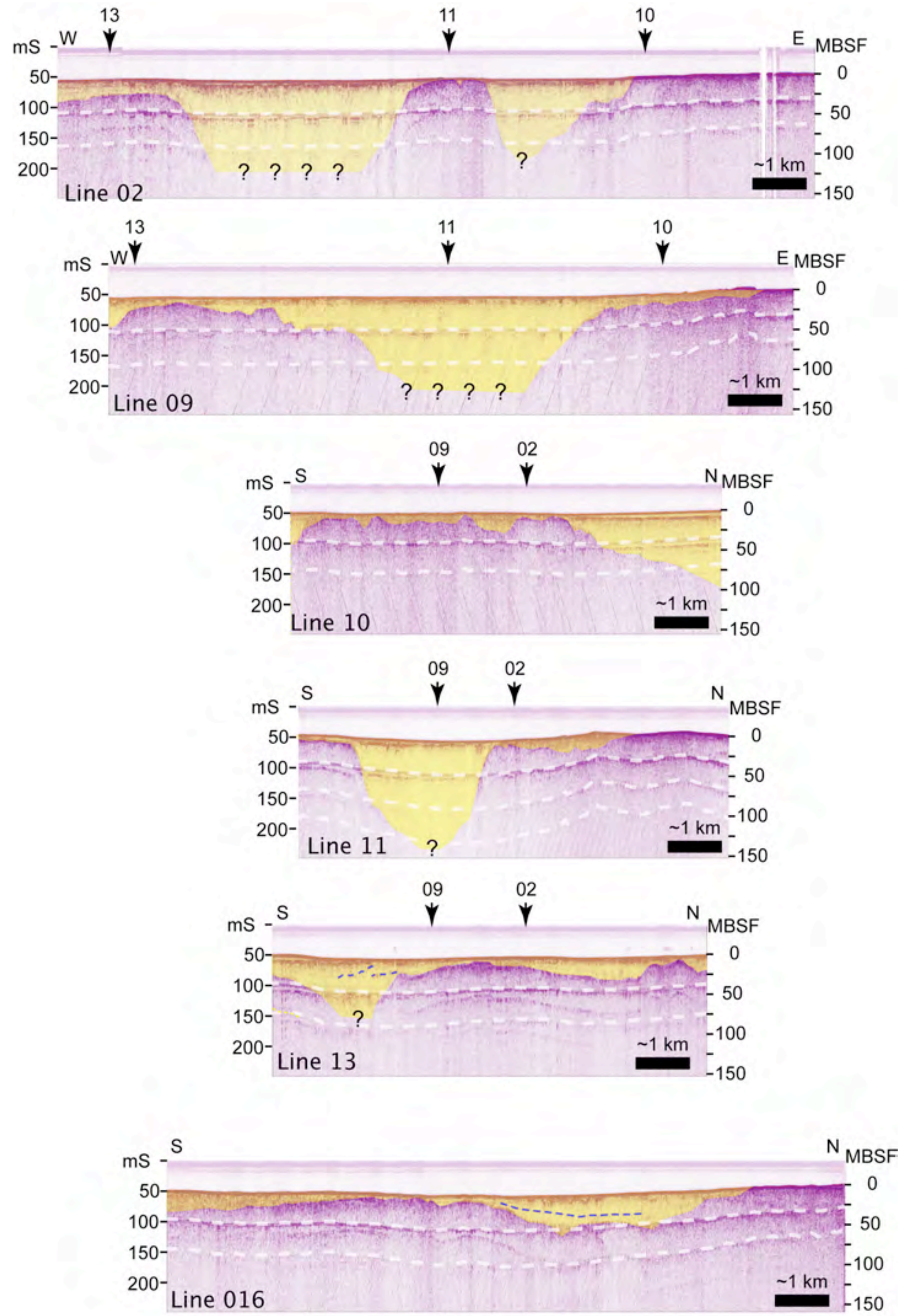

Figure II-4. Processed seismic cross-sections of selected lines from Federal survey area (see Fig 2, bottom) with sub-bottom interpretations. Axes labels and highlighted attributes are the same as in Figure 3.

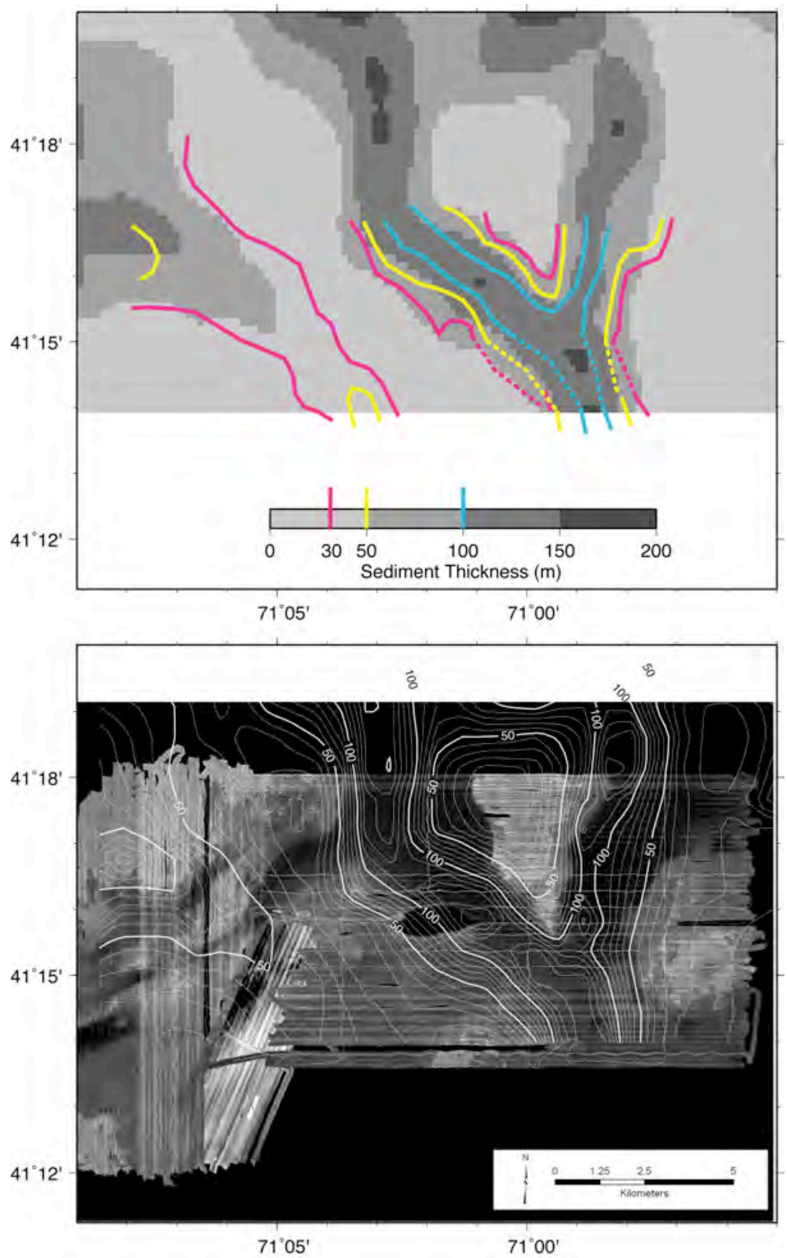

Figure II-5. (top) Sediment isopach of the Federal survey area comparing our sediment thickness estimates (colored contours) with a previous study (gray shading) by O'Hara, [1980]. (bottom) Sediment thickness contours from the O'Hara study are overlain on side-scan reflectivity.

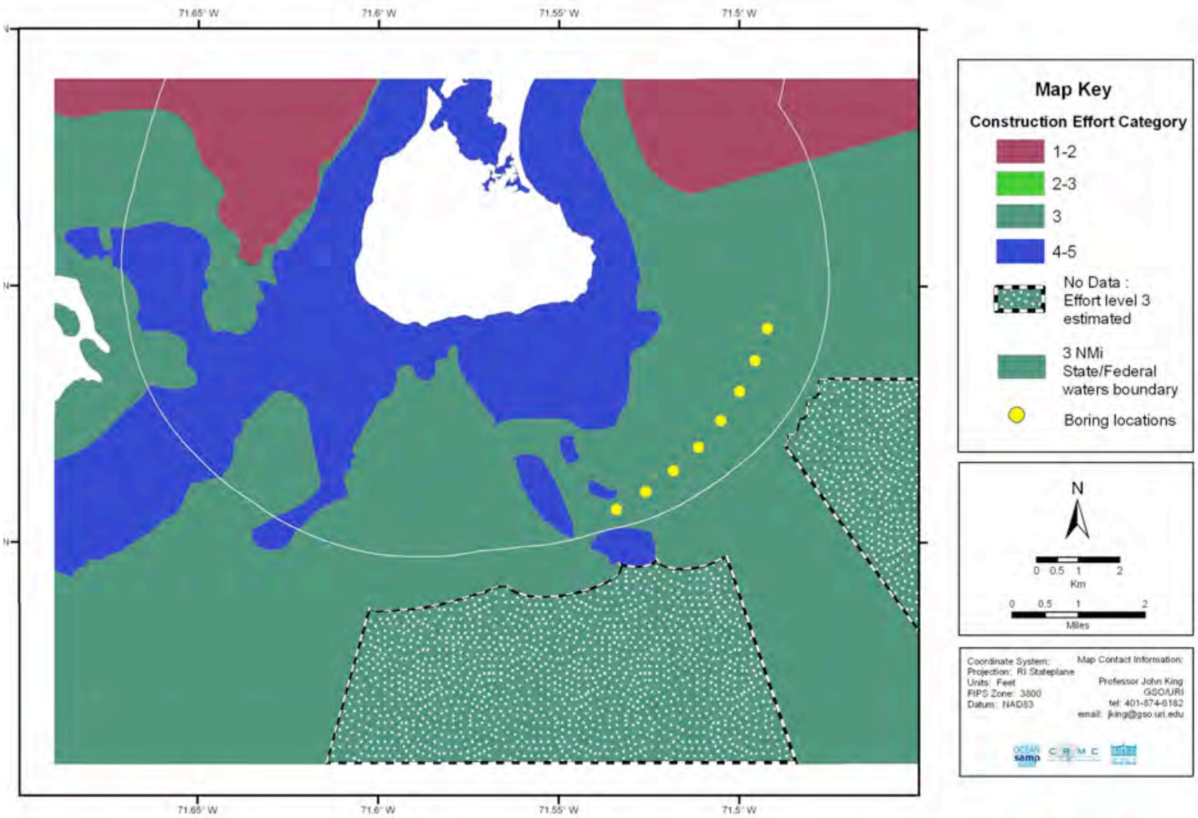

Figure II-6. Map showing ease of construction for wind turbines in the BI study area.

II.7 References

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