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Fisheries Ecology and Benthic Habitat in Rhode Island and Block Island Sounds

for the Rhode Island Ocean Special Area Management Plan 2010

by

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Executive Summary

This study aimed to classify and map fisheries habitats and to improve understanding of the relationship between temperate demersal fish communities and benthic habitat. Fifteen sites within the RI Ocean SAMP study area were chosen for coupled acoustic surveys and bottom trawls. Full side-scan and bathymetric processing was carried out for five sites within the RI Ocean SAMP study area. Benthic surface roughness was calculated for all fifteen sites. Analysis of acoustically-derived benthic habitat variables revealed a trend toward greater habitat complexity in Block Island Sound. The demersal fish community was sampled at all fifteen sites in conjunction with the NEAMAP survey on September 30th and October 2nd, 2009. A number of spatial trends in fish community metrics were evident, such as greater fish abundance and biomass in Rhode Island Sound and greater fish community diversity in Block Island Sound. Further analyses revealed a relationship between fish community and depth, with larger, more evenly distributed fish communities in deep water habitats and smaller, more diverse communities in shallow water habitats. Coupling of benthic habitat and species-specific fish community data revealed a strong relationship between benthic habitat complexity and demersal fish community diversity, with more diverse fish communities occupying more complex habitats. Multivariate analysis identified two acoustically-derived benthic habitat variables that effect the species composition of the demersal fish assemblage, standard deviation of backscatter and number of bottom types. A larger sample size, however, is needed to determine if this relationship applies to the offshore ecosystem of Rhode Island Sound and Block Island Sound as a whole. This study provides the scientific community with a basic understanding of fish-habitat relationships in a temperate marine ecosystem and begins to elucidate the importance of benthic-pelagic coupling in supporting fish production. By understanding the role that benthic habitat plays in fish community dynamics in the transitional seas of Rhode Island Sound and Block Island Sound, we hope to guide the placement of offshore structures so as to preserve the ecological and economic value of the area.

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Abstract

This study aimed to classify and map fisheries habitats and to improve understanding of the relationship between temperate demersal fish communities and benthic habitat. Fifteen sites within the RI Ocean SAMP study area were chosen for coupled acoustic surveys and bottom trawls. Full side-scan and bathymetric processing was carried out for five sites within the RI Ocean SAMP study area. Benthic surface roughness was calculated for all fifteen sites. Analysis of acoustically-derived benthic habitat variables revealed a trend toward greater habitat complexity in Block Island Sound. The demersal fish community was sampled at all fifteen sites in conjunction with the NEAMAP survey on September 30th and October 2nd, 2009. A number of spatial trends in fish community metrics were evident, such as greater fish abundance and biomass in Rhode Island Sound and greater fish community diversity in Block Island Sound. Further analyses revealed a relationship between fish community and depth, with larger, more evenly distributed fish communities in deep water habitats and smaller, more diverse communities in shallow water habitats. Coupling of benthic habitat and species-specific fish community data revealed a strong relationship between benthic habitat complexity and demersal fish community diversity, with more diverse fish communities occupying more complex habitats. Multivariate analysis identified two acoustically-derived benthic habitat variables that effect the species composition of the demersal fish assemblage, standard deviation of backscatter and number of bottom types. A larger sample size, however, is needed to determine if this relationship applies to the offshore ecosystem of Rhode Island Sound and Block Island Sound as a whole. This study provides the scientific community with a basic understanding of fish-habitat relationships in a temperate marine ecosystem and begins to elucidate the importance of benthic-pelagic coupling in supporting fish production. By understanding the role that benthic habitat plays in fish community dynamics in the transitional seas of Rhode Island Sound and Block Island Sound, we hope to guide the placement of offshore structures so as to preserve the ecological and economic value of the area.

1 Introduction

Rhode Island Sound (RIS) and Block Island Sound (BIS) support a variety of commercial and recreational fishing activities, such as scallop dredging, otter trawling, long-lining and gill-netting. Many of these activities target specific areas with the benthic habitat characteristics thought to yield the best harvest (RI Ocean SAMP, Chapter 5). Due to the secrecy of such fishing spots, little is known about the distribution of fisheries resources and benthic habitat in RIS and BIS. Furthermore, research survey tows that are made in this area are sparse, and by the nature of the random sampling design, they are not habitat specific. Until recently, this area has been too far offshore for state surveys and too close to shore for federal surveys. While this data gap has been recognized for some time, filling it has now become a priority because of the desire to zone the area for multiple uses, including recent interest in offshore energy development, and the ongoing need to assess the status of overfished groundfish species that may be subject to cumulative impacts in this area.

The physical characteristics of marine benthic habitat have been shown to affect biological community structure in a variety of ecosystems (Luckhurst & Luckhurst 1978, Gratewick & Spite 2005). For example, Friedlander and Parrish (1998) found a distinct relationship between the rugosity and depth of benthic habitat and fish species assemblage on Hawaiian coral reefs. Unfortunately, very little is known about fish habitat use and feeding relationships in temperate, transitional waters, such as Rhode Island Sound and Block Island Sound. With the reality of offshore development rapidly approaching, it is essential to understand the basis of fish-habitat relationships, the functional role of different habitat types and the importance of benthic-pelagic coupling in supporting fish production. With global climate change shifting the range and species composition of many ecosystems, the relationship between habitat and fish community becomes even more significant. Accordingly, this study aimed to develop a baseline for measuring the cumulative effects of offshore development projects and global climate change as well as contributing a basic understanding of the fisheries ecosystem dynamics in Rhode Island's transitional waters.

This study focuses on the transitional seas, Rhode Island Sound (RIS), Block Island Sound (BIS) and the adjacent inner shelf, which separate the estuaries of Narragansett Bay and Long Island Sound from the outer continental shelf (Figure 1). Providing the link between near-shore and offshore processes as well as state and federal waters, these transitional seas are both ecologically and economically important. To appropriately zone for offshore development in these transitional seas, a sound understanding of the fisheries ecosystem dynamics is essential. By investigating the distribution and relationship of benthic habitat complexity and demersal fish community within RIS and BIS, we hope to contribute information to assist in creating scientifically sound, ecosystem-based management decisions for Rhode Island's coastal waters.

2 Background

This study builds upon the baseline characterization, presented in RI Ocean SAMP Chapter 5, Section 510.7. The baseline characterization used data from bottom trawl surveys conducted between 1999 and 2008 in and around the RI Ocean SAMP area. Analyses revealed a strong seasonal effect, with higher biomass in the fall and lower biomass in the spring, as well as a trend in depth, whereby survey sites at deeper depth were characterized by the highest biomass (RI Ocean SAMP Chapter 5, Appendix A). Differences in survey methodology as well as natural interannual variability in fish stocks, however, confounded spatial analyses. This study aimed to develop a more comprehensive characterization of the benthic habitats and fish communities within Rhode Island Sound and Block Island Sound and their relationship with each other.

3 Methods

Acoustic mapping and bottom trawling were used to classify fisheries habitats, based on benthic habitat characteristics and site-specific fisheries data. Fifteen sites were chosen for habitat mapping and bottom trawling based on existing maps of bottom sediment composition (McMaster, 1960), side-scan sonar data (King, unpublished; Knebel et al., 1982; Driscoll, 1992), interpretation of NOAA hydrographic surveys (McMullen et al., 2007, 2008) and fishing location maps prepared by David Beutel in consultation with the mobile gear, fixed gear and recreational fishing sectors.

3.1 Habitat Mapping

Habitat mapping was conducted aboard the OSV Bold from August 24-29, 2009. All mapping was conducted with GSO's Teledyne/Benthos C3D/CHIRP III bathymetry/side-scan sonar instrument. Combining high-resolution imagery and wide-swath bathymetry, this system is ideal for fisheries habitat mapping. The swath width was 240m at 30m water depth. At this depth, roughly 4 square miles can be mapped in 8 hours.

3.1.1 Side-scan and Bathymetry

Bathymetry data were processed to produce a mosaic with CARIS software, whereas the side-scan data were processed with QuesterTangent(QT) Sideview software to obtain a bottom classification based on the acoustic characteristics. A combination of visual discrimination and the QT Sideview classification was used to identify initial polygons of similar bottom type. ArcInfo was used to create a bottom type classification map for each site. Bottom type classifications were based on acoustic and geological characteristics (e.g. soft return with smooth texture; boulder field; hard return with sand waves).

Due to time constraints, a subset of five sites was selected for full side-scan and bathymetric analysis. The selected sites provide an accurate representation of the acoustic and biological features of Rhode Island and Block Island Sound as a whole. The sites selected for full side-scan and bathymetric analysis were I, J, P, Q and U (Figure 1).

Bathymetry and side-scan data were analyzed in ArcGIS to obtain depth and backscatter profiles of each site. The minimum, maximum, mean and standard deviation of backscatter and depth were calculated for each site at 2 meter, 25 meter and 50 meter resolutions (Table 1). Rugosity was calculated from bathymetry data with the Benthic Terrain Modeler Toolbox in ArcMap. The mean and standard deviation of backscatter and depth were independent of all other factors and were, therefore, included in analysis. In order to account for small-scale variability in benthic habitat, two-meter resolution was used in all analyses.

The number of bottom types and number of habitat interfaces within each site were also included as factors in statistical analysis (Table 1). The number of distinct bottom types, as indicated by side-scan imagery, was determined from the bottom type classification map created in ArcInfo (Figure 2). Bottom type classification was based on backscatter intensity, ranging from white to black. Light backscatter patterns represent harder surfaces, such as boulders, shell, and sand, whereas dark backscatter represents softer bottom types, including mud, silt, and clay. The number of bottom types was determined by counting the patches of unique backscatter intensity occurring within each site. A habitat interface was defined as a boundary between two bottom types. The number of habitat interfaces at each site was determined by overlaying bottom trawl tracklines on the bottom type classification map and counting the number of habitat interfaces crossed by each sites's trackline.

3.1.2. Benthic Surface Roughness

Measurements of benthic surface roughness, as derived in the surface roughness map in the RI Ocean SAMP Ecology Chapter (Chapter 2, Figure 2.26), were used to measure the habitat complexity for each site (Figure 4). In this case, benthic surface roughness is measured as the standard deviation of the slope within a 1000 meter radius. The minimum, maximum, range, mean and standard deviation of benthic surface roughness were calculated for each site with ArcMap (Table 1).

3.2 Fish Community Dynamics

3.2.1. Bottom Trawling

The demersal fish community was sampled in conjunction with the ongoing NEAMAP survey, which is conducted by scientists at the Virginia Institute of Marine Science (VIMS) aboard the 90' FV *Darana R*, captained by James Ruhle (http://www.neamap.net/). Sampling was conducted in Block Island Sound on September 30th and in Rhode Island Sound on October 2nd, 2009.

Bottom trawls were used to obtain habitat-specific fish and invertebrate species composition at fifteen sites in Block Island and Rhode Island Sounds (Figure 1). Each tow was conducted with a 400 x 12 cm, three-bridle, four-seam bottom trawl, paired with a set of Thyboron, Type IV 66" trawl doors. All tows were 20 minutes in duration with a target tow speed of 3.1 knots.

The catch was processed at sea by a team of scientists from VIMS and URI. Once on board, the catch from each station was sorted by species and size class. Aggregate weights, counts and individual length measurements were recorded from all species collected.

3.2.2. Univariate Analysis

For analyses of total catch data, abundance and biomass were summed over all species caught during bottom trawling (Table 2). Hill's N1 and N2 were used as indexes of diversity and evenness, respectively (Hill 1973). For spatial analyses, the shipping lane to the east of Block Island acted as the delineation between Block Island Sound and Rhode Island sound. The shipping lane runs in a nearly straight line between 41°25'35''N, 71°23'22''W and 41°06'06''N, 71°23'22''W (RI Ocean SAMP, Chapter 7, Section 720.2). Trawls sites located to the west of the shipping lane were considered to be in Block Island Sound, while trawl sites located to the east of the shipping lane were considered to be in Rhode Island Sound (Table 3).

NEAMAP depth strata and tow depth were used to investigate the relationship between depth and fish community dynamics (Table 3). NEAMAP depth stratum was determined for each trawl site based on pre-existing bathymetric maps, while NEAMAP tow depth was measured at the start of each trawl. Depth strata were defined as follows: Stratum 1: 20-40ft, Stratum 2: 40-60ft, Stratum 3: 60- 90ft, Stratum 4: 90-120ft, Stratum 5: >120ft. Comparisons of fish community metrics (i.e. abundance, biomass, diversity and evenness) were conducted among depth strata. Univariate regressions of tow depth against abundance, biomass, diversity and evenness were also conducted to investigate the relationship between the demersal fish community and depth.

3.2.3. Multivariate Analysis

Primer 6.0 was used to calculate a Bray-Curtis similarity index from fourth-root transformed fish abundance data from each site. This index measures similarities in species assemblage composition between sites. A multi-dimensional scaling plot (MDS plot) was derived from the similarity matrix to ordinate the sites in two dimensions. Individual ANOSIMs were used to test for the affect of location (Block Island Sound v. Rhode Island Sound) and depth strata on the fish assemblage.

3.3. Benthic Habitat and Fish Community Integration

Benthic habitat variables of the selected stations (i.e. backscatter, depth, rugosity, bottom type heterogeneity) were integrated with species-specific demersal fish community data in Primer 6.0. Table 1 lists all abiotic variables included in these analyses. A Draftsman plot, consisting of pairwise scatterplots, was used to select uncorrelated benthic habitat variables. Variables marked with an asterisk in Table 1 did not exhibit strong relationships with other variables and were, therefore, included in further analyses. All benthic habitat factors were normalized prior to analysis.

A multivariate algorithm, BIOENV, was used to identify the combination of abiotic benthic habitat variables that best explains the biotic structure of the selected stations. The Linktree function was used to split the stations into groups based on abiotic habitat features. These

Linktree-defined groups were further analyzed with SIMPER to investigate the contribution of individual species to the within-group similarity and between-group disparity.

Univariate regressions were conducted to investigate the relationship between acoustically-derived benthic habitat features and fish community characteristics (i.e. abundance, biomass, diversity and evenness).

Benthic surface roughness was also integrated with species-specific demersal fish community data in Primer 6.0. A Draftsman plot was used to select non-correlating benthic surface roughness variables, as previously described. Table 1 lists all roughness variables included in these analyses. The BIOENV function was used to match benthic surface roughness features to fish assemblage patterns throughout the SAMP area. The Link-tree function was used to identify groups of trawl sites with similar benthic surface roughness, providing a categorical ordination of roughness for each site. An ANOSIM was used to test for the affect of categorically defined benthic surface roughness on fish assemblage.

Univariate regressions were used to investigate the relationship between benthic surface roughness and fish community characteristics (abundance, biomass, diversity and evenness).

4 Results

4.1 Habitat Mapping

4.1.1. Side-scan and Bathymetry

Benthic habitat maps of the selected stations in Rhode Island Sound and Block Island Sound were constructed from side-scan backscatter and bathymetry data (Figure 2 and Figure 3). The minimum, maximum, mean, and standard deviation of backscatter and bathymetry for sites I, J, P, Q and U are given in Appendix I. Maps of bottom rugosity within sites I, J, P, Q and U are shown in Figure 4. There was a strong correlation ($r>0.9$) between low-resolution and high-resolution factors within these sites, indicating that benthic habitat is dominated by large-scale features, such as sand waves.

4.1.2. Benthic Surface Roughness

A map of the benthic surface roughness within Block Island Sound and Rhode Island Sound is given in Figure 5. The minimum and maximum of benthic surface roughness were highly correlated with both the mean and standard deviation of benthic surface roughness and were, therefore, excluded from further analysis. The range, mean and standard deviation of benthic surface roughness were applied as environmental variables in the multivariate integration with fish community data (Table 1).

4.2 Fish Community Dynamics

Abundance, biomass, diversity and evenness of the fish community at all 15 sites are given in Table 4. Figure 6 and figure 7 show the relative abundance and biomass of the demersal fish community in the spatial context of Rhode Island Sound and Block Island Sound.

4.2.1. Univariate Analyses

Univariate analysis of fish community data revealed apparent trends towards higher abundance and biomass in Rhode Island Sound as compared to Block Island Sound (Figure 8). Overall species diversity, as defined by Hill's N1, was higher in Block Island Sound, while species evenness, as defined by Hill's N2, was higher in Rhode Island Sound (Figure 8). As a community becomes more diverse, the distribution of species abundance is expected to become less even, and, therefore, an inverse relationship between diversity and evenness is expected (Hill 1973). The trends toward greater evenness and higher abundance in Rhode Island Sound indicate that larger fish communities tend to have a more even species distribution.

Analysis of fish community data by depth revealed an apparent increase in fish abundance and biomass with depth (Figure 9, Figure 10). Inverse trends in diversity and evenness were also evident, with decreasing diversity and increasing evenness with depth (Figure 9, Figure 10). These results indicate that fish communities residing in deeper water are larger and less diverse than fish communities residing in shallower water.

4.2.2. Multivariate Analysis

A multidimentional scaling plot (MDS) was created as a visual representation of the unique species compositions at each of the sites within Block Island Sound and Rhode Island Sound (Figure 11). Each point on the MDS plot represents the species composition of one trawl site. Points that are closer together have more similar species composition than distant points.

ANOSIM analyses indicate that Block Island Sound and Rhode Island Sound support different communities of demersal fish (Figure 12, $R = 0.113$, $p= 0.1$). ANOSIM analyses also indicate that depth strata influences the species composition of demersal fish communities within Rhode Island Sound and Block Island Sound (Figure 13, $R=0.332$, $p=0.011$).

The BVStep analysis identified 11 species that account for most of the pattern in demersal fish and invertebrate community composition within the SAMP area (Table 2, p=0.953, p=0.01). These species are alewife, atlantic herring, black seabass, bluefish, butterfish, goosefish, quahog, round scad, silver hake and spiny dogfish. Although these species may not be the most abundant within the SAMP area, they are of ecological importance in defining the local marine community structure. When attempting to predict the effects of development and exploitation on the demersal fish assemblage of the SAMP area, it is essential to consider these community-shaping species.

4.3. Benthic Habitat and Fish Community Integration

Together, standard deviation of depth and number of bottom types, resulted in the highest rank correlation between biotic and abiotic variables (BIOENV: rho=0.709). A permutation test, however, indicated that, within the five selected sites, the aforementioned rank correlation between biotic and abiotic variables has a high probability of occurring due to chance alone (BIOENV: p=0.496). A number of benthic habitat variables most likely affect the fish community in Rhode Island's offshore waters, but the small number of sites included in these analyses prevents identification of such variables.

Based on the similarity of their abiotic features, the selected stations were divided into three groups. Group 1 included sites J and U. Group 2 included sites I and P. Group 3 included site Q only. Analysis of biological similarity within these groups, revealed a 62.4% similarity between stations J and U and a 75.4% similarity between stations I and P (SIMPER). Two pelagic species, butterfish and squid, accounted for most of the biological similarity.

Univariate regression analyses revealed a positive relationship between the number of bottom types and diversity as well as an inverse relationship between the number of bottom types and total abundance (R^2=0.691, p=0.081; R^2= 0.836, p=0.029, Table 5). There was no apparent relationship between the standard deviation of depth and total abundance or diversity (Table 5).

A relationship between large-scale benthic surface roughness and species distribution was also identified. Together, the mean and standard deviation of benthic surface roughness resulted in a rank correlation of 0.392 (BIOENV: rho=0.392). A permutation test indicated that the correlation between benthic surface roughness and the species composition of the demersal fish assemblage was not due to chance alone (BIOENV: p=0.02). When defined categorically, however, benthic surface roughness was not significantly related to the demersal fish assemblage (ANOSIM: R=0.163, p=0.117).

Univariate regression revealed a weak inverse relationship between roughness and total abundance and a positive relationship between roughness and total biomass (Roughness v. Abundance: R^2=0.057, p=0.391; Roughness v. Biomass: R^2=0.300, p=0.034). These results suggest that a larger number of small fish (i.e. bait fish and juveniles), inhabit less complex benthic habitats, while a smaller number of large fish (i.e. top predators) inhabit more complex benthic habitats. Univariate regression also indicated that there is no apparent relationship between roughness and species diversity (R^2=0.014, p=0.679). There was, however, an evident trend towards higher benthic surface roughness in Block Island Sound (Figure 14).

5 Discussion

The fisheries ecosystem of Rhode Island and Block Island Sounds is influenced by a number of factors, such as location, depth, bathymetric complexity, habitat heterogeneity and benthic surface roughness. Understanding the relationship between these factors and the fish populations of Rhode Island's transitional seas will help to guide ecologically-sound spatial management decisions.

Spatial variability of the demersal fish community within Rhode Island and Block Island Sounds is apparent in the results from this study (Figure 6, Figure 7, Figure 8). As seen in figure 8, there is a pattern towards higher abundance and biomass of the fish community in Rhode Island Sound. This pattern may be related to the spatial variability in primary production. It has recently been suggested that primary production is higher in Rhode Island Sound than in Block Island Sound (Nixon et al. In press). If the typical bottom-up ecological model is followed, increased production in Rhode Island Sound would lead to increased fish abundance. The results of this study indicate that this is, indeed, the case (Figure 8).

While the size of the fish community appears to be larger in Rhode Island Sound, the species diversity appears to be higher in Block Island Sound (Figure 8). A general paradigm about marine benthic communities is that, as bottom complexity increases from smooth sand and mud to rock and cobble, ecological complexity and diversity increase. Areas with high bottom roughness correspond with prime fishing areas for several species targeted by commercial and recreational fisheries. Analysis of benthic surface roughness data indicates that Block Island

Sound contains more complex bottom terrain, making it more diverse than Rhode Island Sound (Figure 14). The high benthic habitat complexity of Block Island Sound supports a unique and more diverse demersal fish community (Figure 8, Figure 13). Identifying highly complex habitats from acoustic parameters and protecting them from anthropogenic influence will be a key tool in promoting ecosystem stability and resiliency in Rhode Island's transitional seas.

The preference of demersal fish for specific depth ranges has been observed in a variety of ecosystems (Persohn et al. 2009; Sonntag et al. 2009). The fish of Rhode Island and Block Island Sounds are no exception to this phenomenon. In this study, survey sites at deeper depth were characterized by the highest biomass, while survey sites at shallower depths were characterized by higher species diversity (Figure 9, Figure 10). This pattern suggests that deeper habitats support many of the most abundant demersal fish species within Rhode Island and Block Island Sounds, while shallower habitats support a more diverse and less abundant community of fish. When aiming to protect specific fish species, determining the location of the preferred depth range within the management area is essential. Creating small closed areas around the preferred habitat of a threatened species may provide the key to stock recovery.

The relationship between benthic habitat features and fish abundance and assemblage has been well documented in coral reefs and seagrass beds, but there has been little research in temperate, deep water environments, such as Block Island Sound and Rhode Island Sound (Aut & Johnson 1998; Christensen et al. 2003; Eriksson et al. 2006). The presumed relationship is that the more heterogeneous the habitat, the more species it can support (Eriksson et al. 2006). Through paired geological and biological sampling this study identified two biologically influential benthic habitat features: standard deviation of depth and the number of bottom types. The standard deviation of the depth is a measure of bathymetric complexity that is related to rugosity, while the number of bottom types is a measure of habitat heterogeneity. Our analyses indicate that habitat complexity and heterogeneity may have an effect on the species distribution within the demersal fish community, but our small sample size prevents definite conclusions (BIOENV: rho=0.709, p=0.496). The strong positive relationship between the number of bottom types and diversity within the selected stations, however, clearly indicates that the habitat-biology relationship so often seen in coral reefs and seagrass beds also applies to the temperate, deep-water environment of Rhode Island and Block Island Sounds. Understanding the functional importance of benthic habitat features, such as bathymetric complexity, to the demersal fish community is essential in developing strategies for rebuilding fish stocks important to Southern New England.

Differences in fish assemblage are most pronounced between areas with vastly different bottom types (i.e. sandy v. rocky bottom) (Gomelyuk 2009; Kendall et al. 2004). However, the acoustic surveys and fish trawls employed in this study mainly survey sandy bottom areas in order to avoid gear damage. To develop a full understanding of the functional importance of benthic habitat to the demersal fish community in Block Island and Rhode Island sound, a greater variety of bottom types must be mapped and sampled. We plan to use modified acoustic surveys, underwater videography and beam trawls to sample rocky benthic habitats in the near future. Utilizing data from a diverse range of bottom types would increase the accuracy of this analysis and provide a more reliable conclusion concerning the effect of bottom complexity on fish assemblage composition in Rhode Island and Block Island Sounds.

6 Conclusions

Based on 15 bottom trawls and 5 coupled acoustic surveys, the following conclusions can be made about the fisheries ecology and benthic habitats of Rhode Island and Block Island Sounds:

- Total abundance and biomass of the demersal fish community is higher in Rhode Island Sound than Block Island Sound.
- Diversity of the demersal fish community, as represented by Hill’s N1, is higher in Block Island Sound than Rhode Island Sound.
- Benthic habitats in deep water support a larger, more evenly distributed community of small fish, while benthic habitats in shallow water support a smaller, more diverse community of larger fish.
- The benthic habitat complexity in Block Island Sound is greater than the benthic habitat complexity in Rhode Island Sound.
- Bathymetric complexity and habitat heterogeneity influence the species composition of the demersal fish community within Block Island and Rhode Island Sound, but additional sites must be analyzed to make a confident conclusion about this abiotic-biotic relationship.
- Our understanding of the role that benthic habitat plays in fish community dynamics in Rhode Island Sound and Block Island Sound will help to guide the placement of offshore structures so as to preserve the ecological and economic value of the area.

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Figure 1. RI Ocean SAMP study area and location of acoustic survey and bottom trawls sites. The red dashed line represents the boundaries of the SAMP area. The solid orange lines represent the boundaries of acoustically surveyed sites. Thick yellow lines represent bottom trawl track-lines. Each site with coupled geological-biological data is labeled with a letter. Sites selected for full acoustic analysis are highlighted in red.

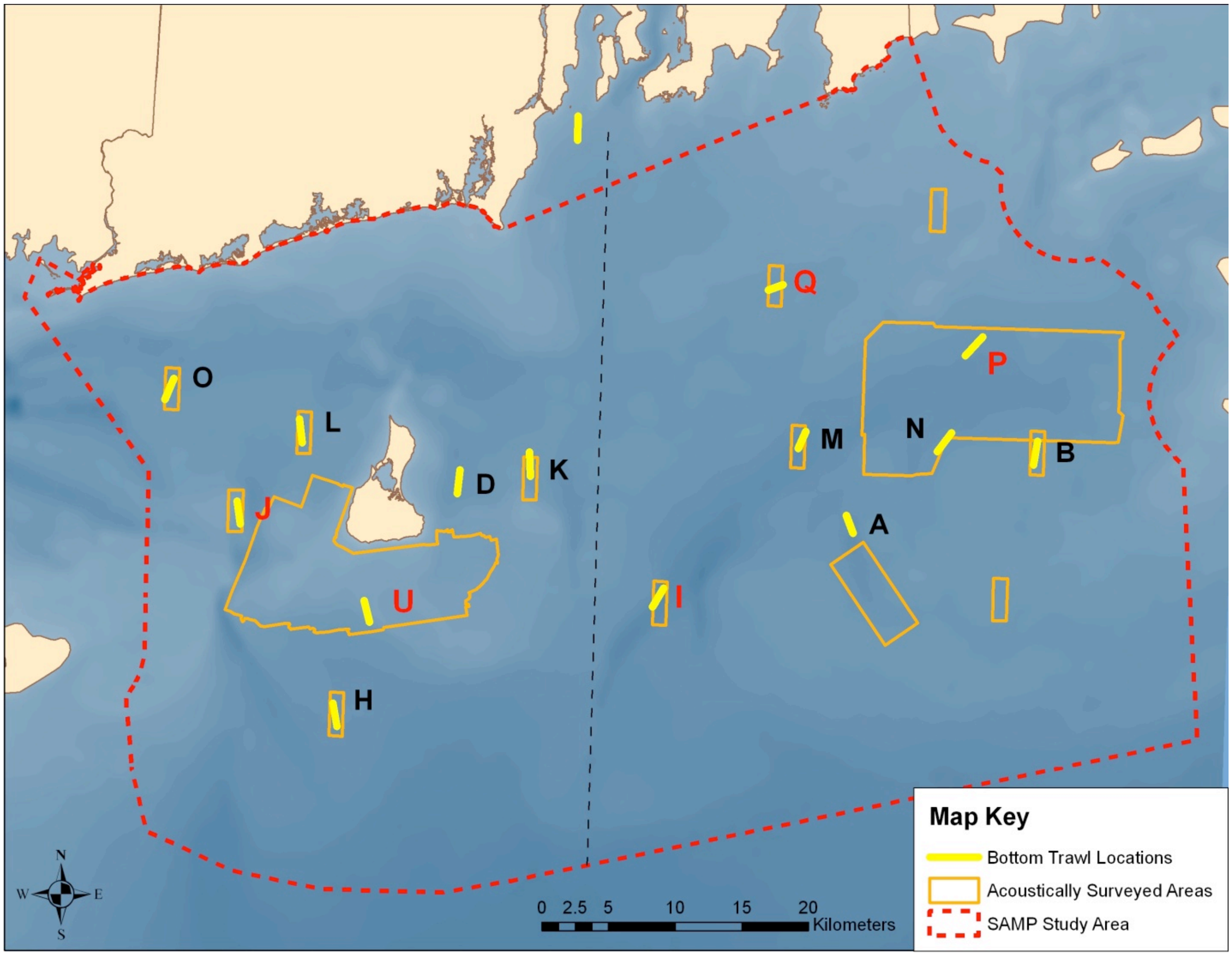

Figure 2. Side-scan backscatter of sites selected for full acoustic analysis (I,J,P,Q,U). Bottom trawl tracklines are represented by solid yellow lines. Light backscatter patterns represent highly reflective (harder) surfaces, such as boulders, shell, and sand, whereas dark backscatter represents less reflective (softer) bottom types, including mud, silt, and clay.

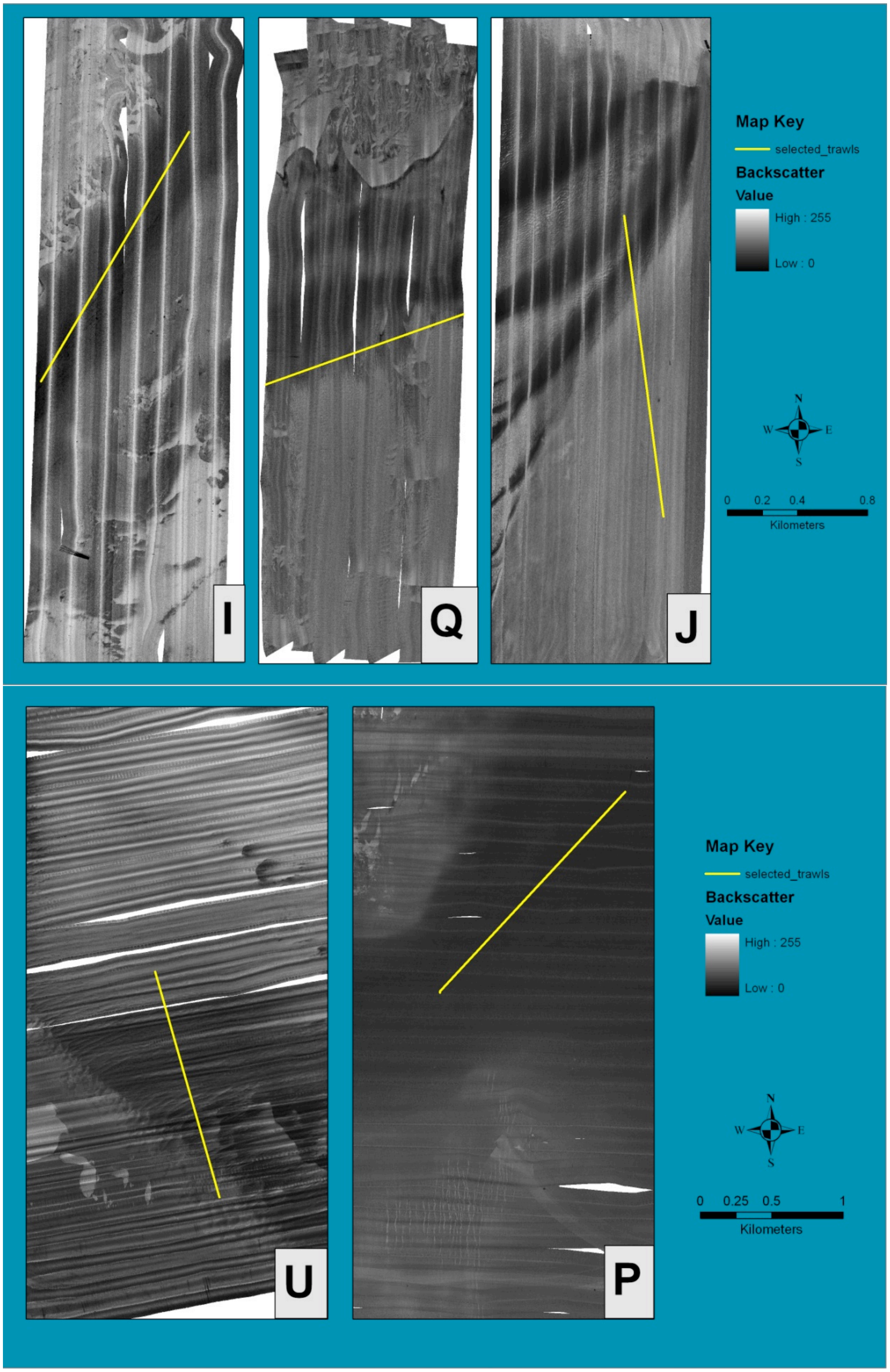

Figure 3. Bathymetry of sites selected for full acoustic analysis (I,J,P,Q,U). Light blue represents shallower water and dark pink represents deeper water. Bottom trawl tracklines are represented by solid yellow lines.

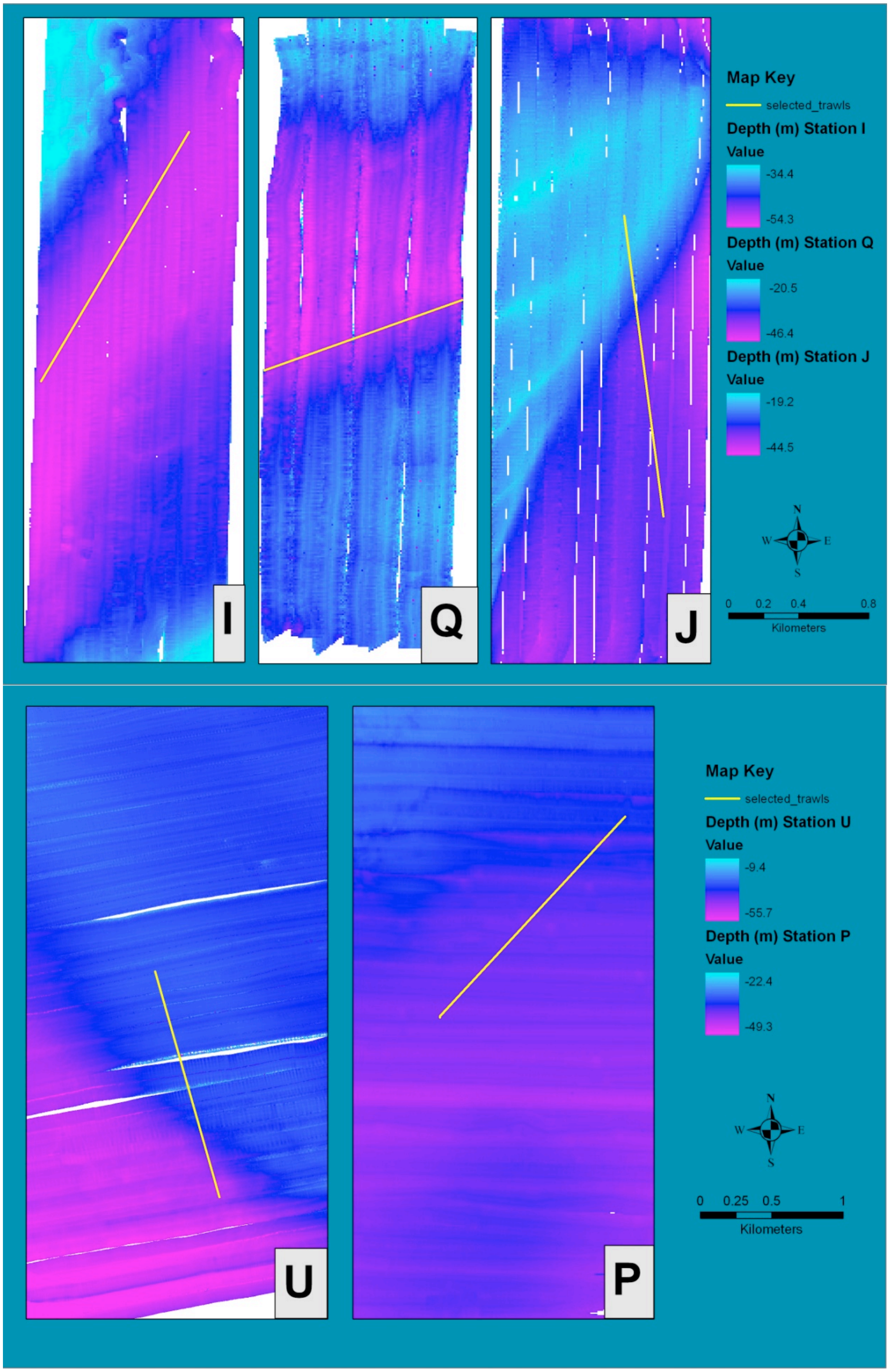

Figure 4. Rugostity of sites selected for full acoustic analysis. Rugosity was calculated from bathymetry data with the Benthic Terrain Modeler Toolbox in ArcMap. Bright yellow represents high rugosity and dark blue represents low rugosity. Bottom trawl tracklines are represented by solid yellow lines.

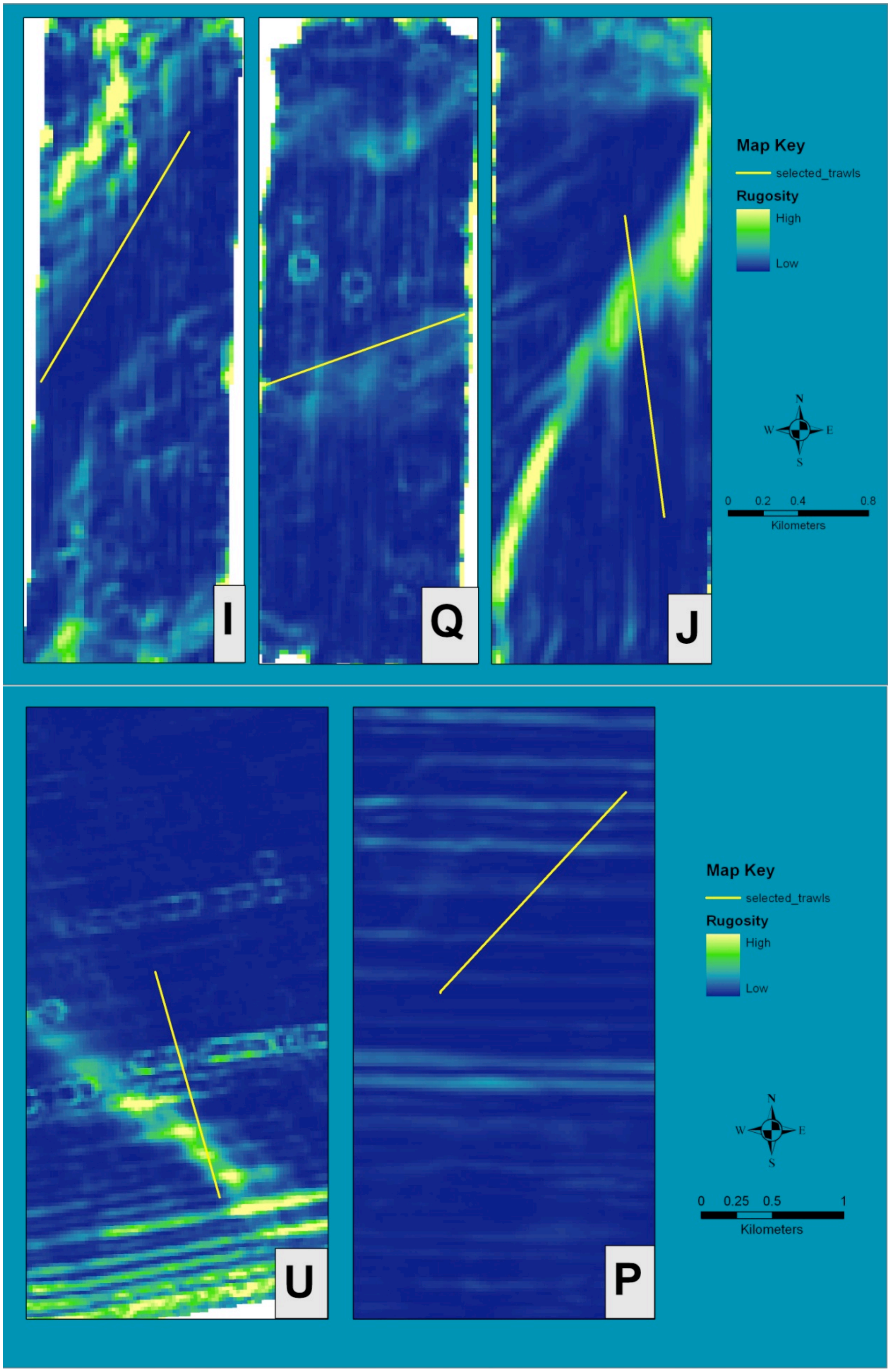

Figure 5. Map of benthic surface roughness in Rhode Island Sound and Block Island Sound. Light colors indicate low roughness and dark colors indicate high roughness. The RI Ocean SAMP area is outlined by a dashed red line. The solid orange lines represent the boundaries of acoustically surveyed sites. Thick yellow lines represent bottom trawl track-lines.

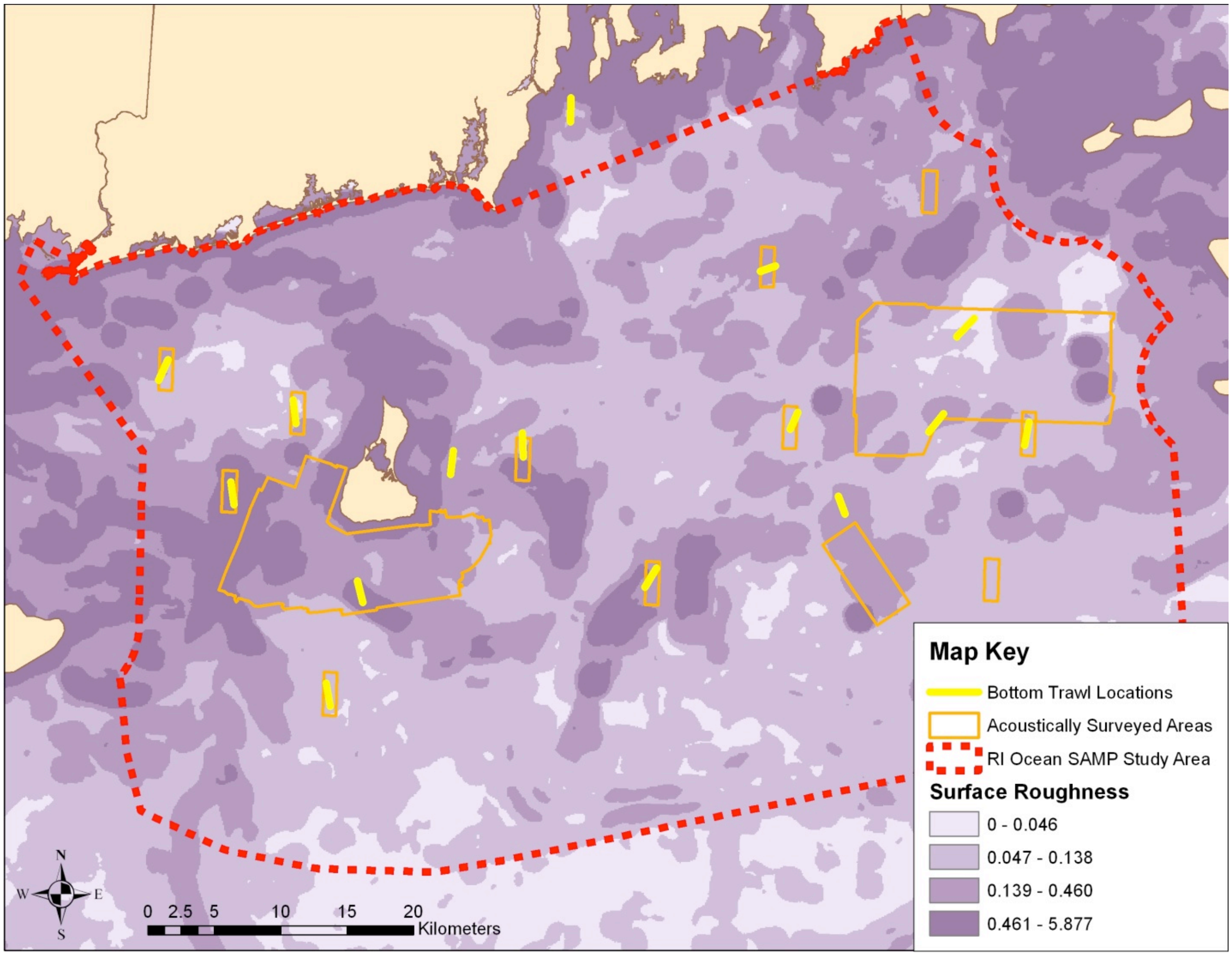

Figure 6. Aggregate fish abundance in Rhode Island Sound and Block Island Sound as measured by fifteen bottom trawls conducted in conjunction with the NEAMAP survey on September 30th and October 2nd, 2009 (http://www.neamap.net/). Green circles represent the total fish abundance at each site.

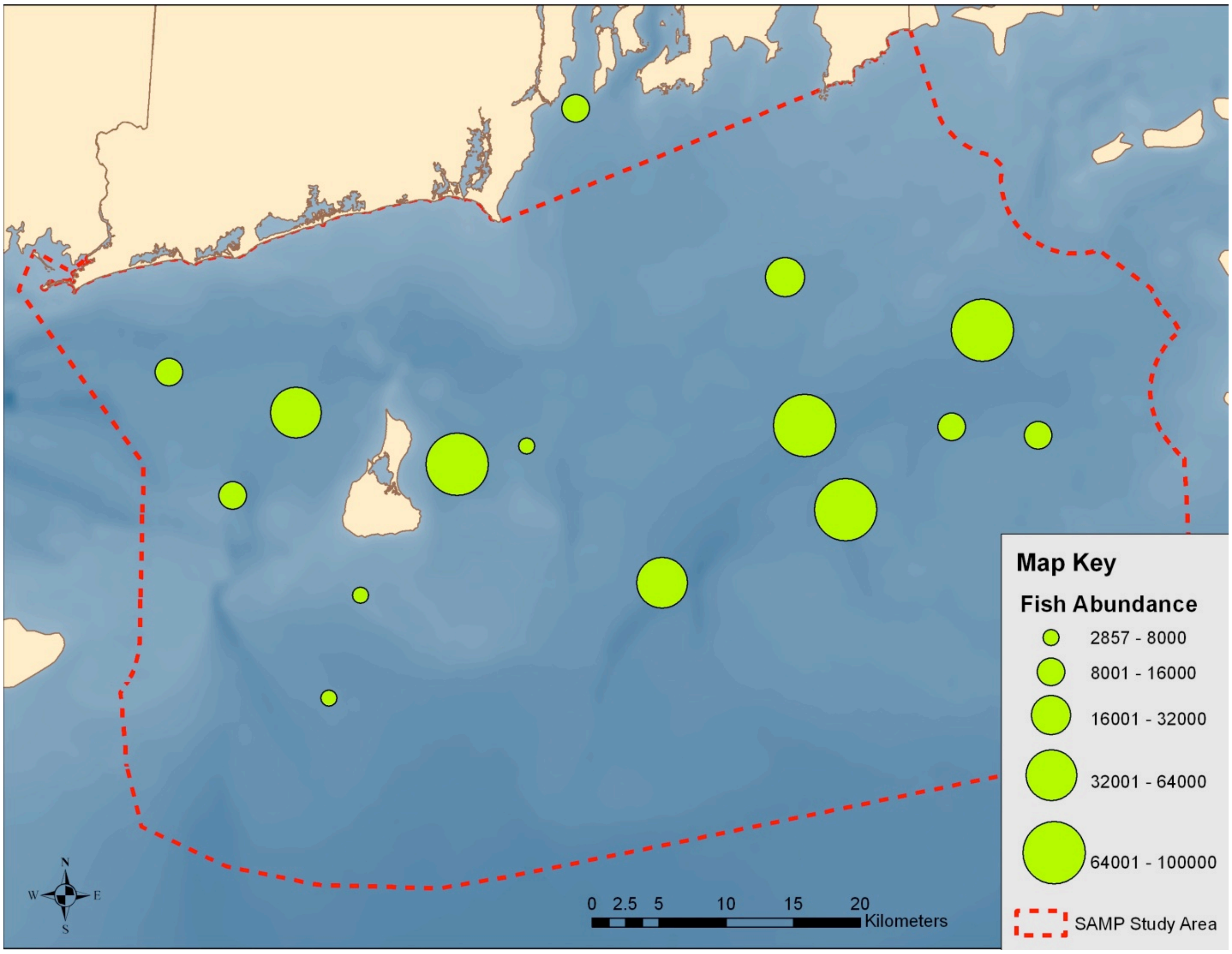

Figure 7. Aggregate fish biomass in Rhode Island Sound and Block Island Sound as measured by fifteen bottom trawls conducted in conjunction with the NEAMAP survey on September 30th and October 2nd, 2009 (http://www.neamap.net/). Blue circles represent the total fish biomass at each site.

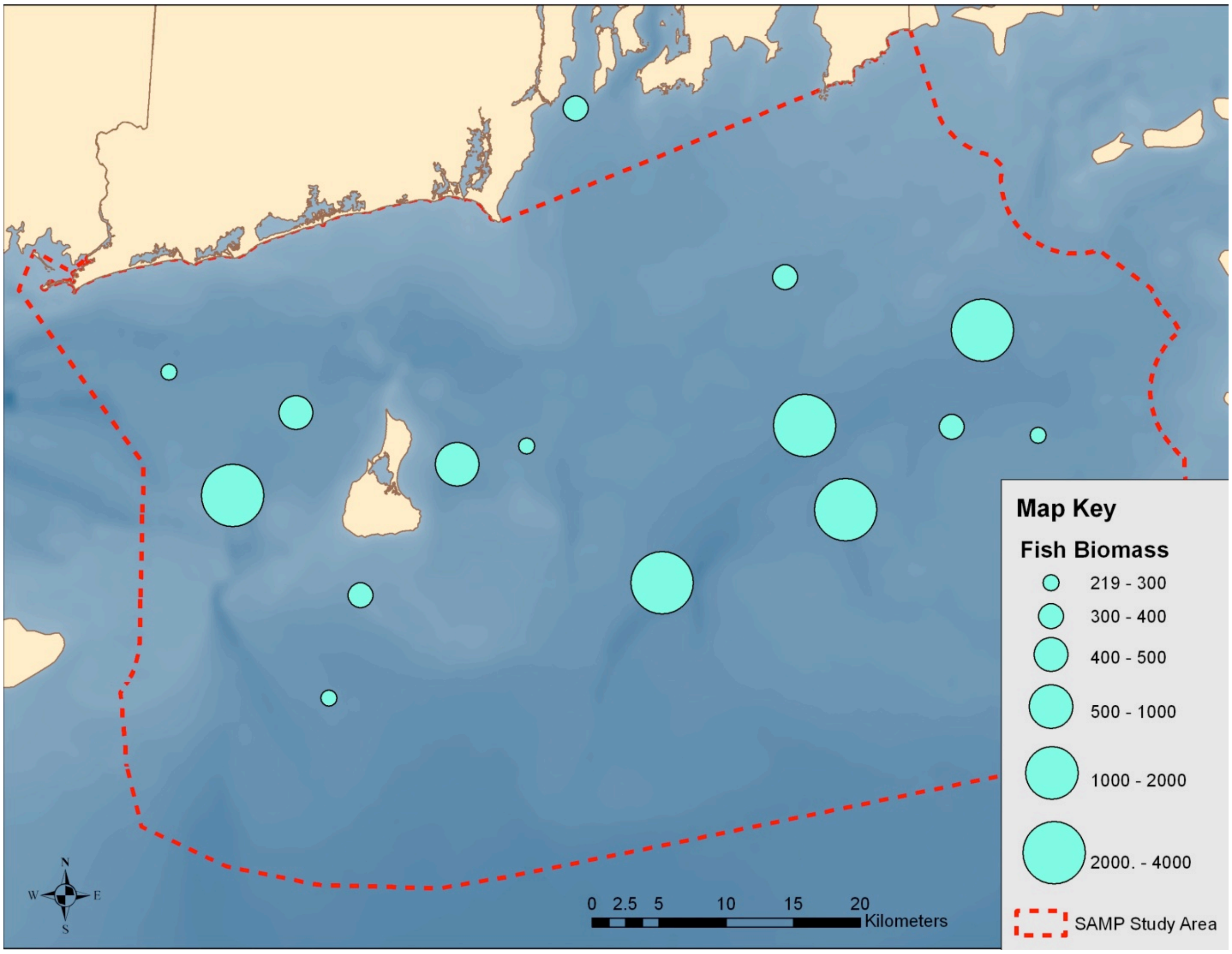

Figure 8. Comparison of total fish abundance, biomass, diversity and evenness between Rhode Island Sound and Block Island Sound. Hill's N1 and N2 were used as indices of diversity and evenness, respectively.

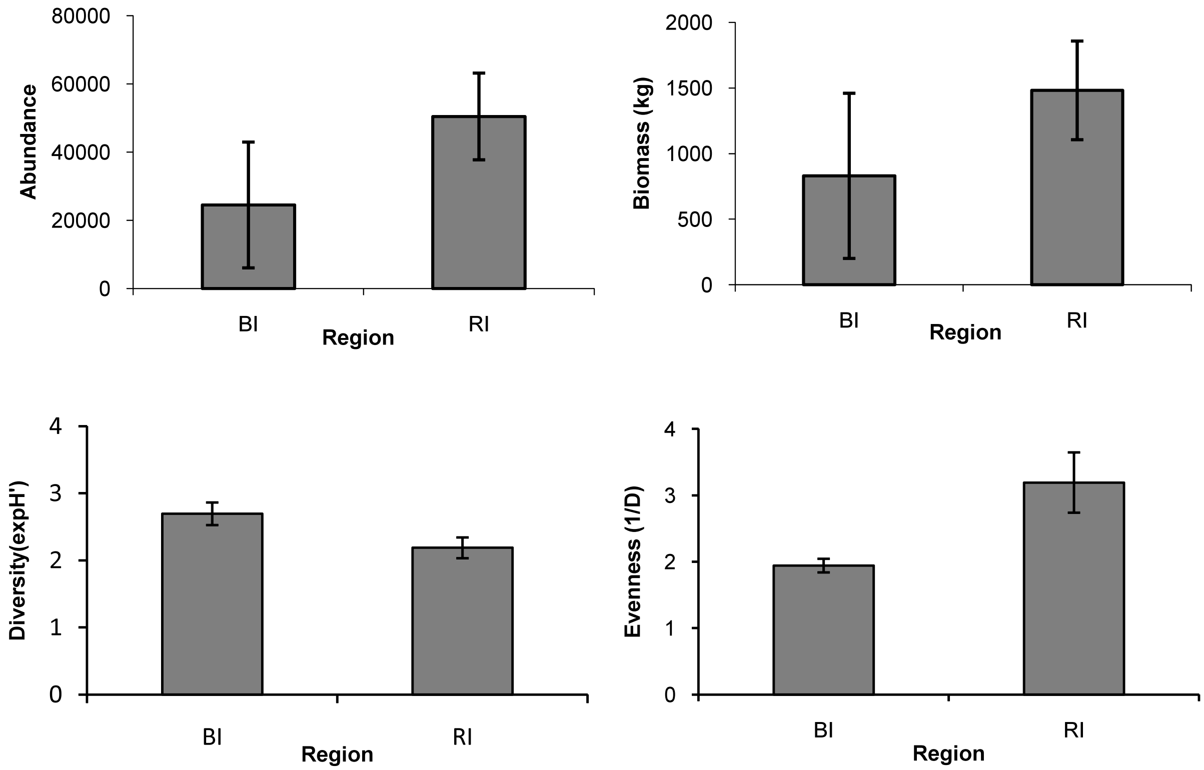

Figure 9. Comparison of total fish abundance, biomass, diversity and evenness between NEAMAP depth strata. The depth strata were defined as follows: Stratum 1: 20-40ft, Stratum 2 : 40- 60ft, Stratum 3: 60-90ft, Stratum 4 : 90-120ft, Stratum 5: >120ft.

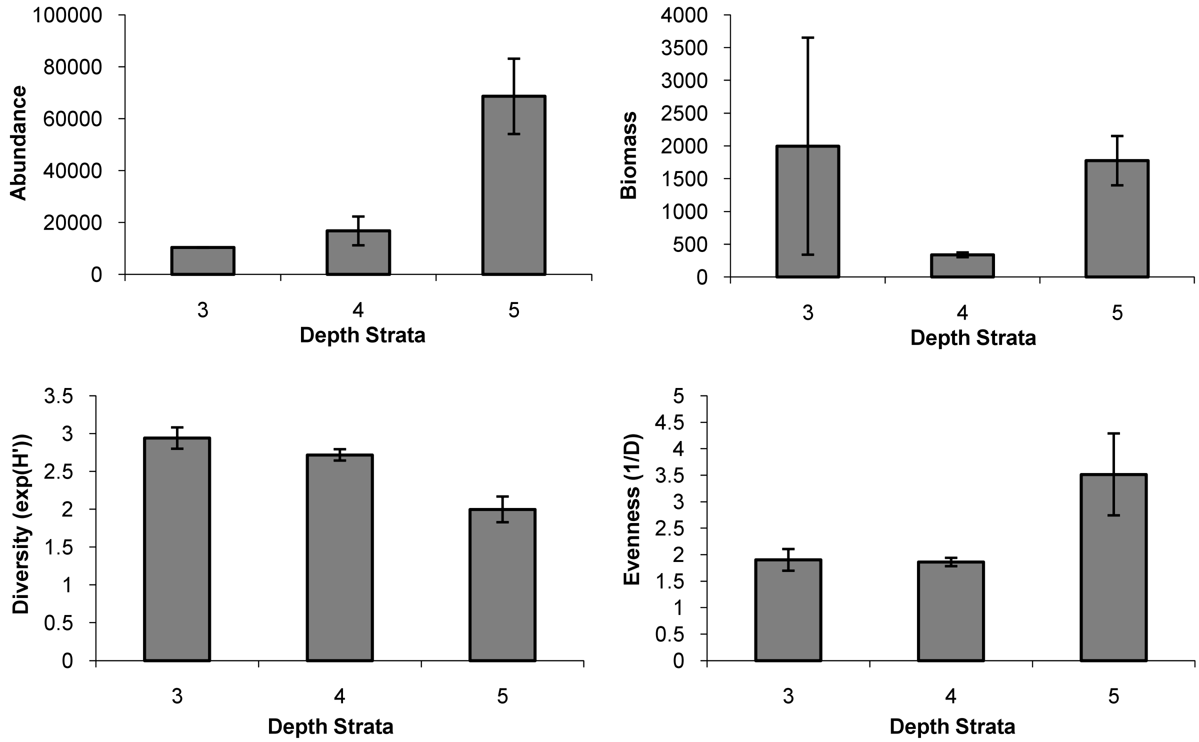

Figure 10. Univariate regressions between tow depth and fish abundance, biomass, diversity and evenness. Regression statistics are given in the upper right corner of each graph.

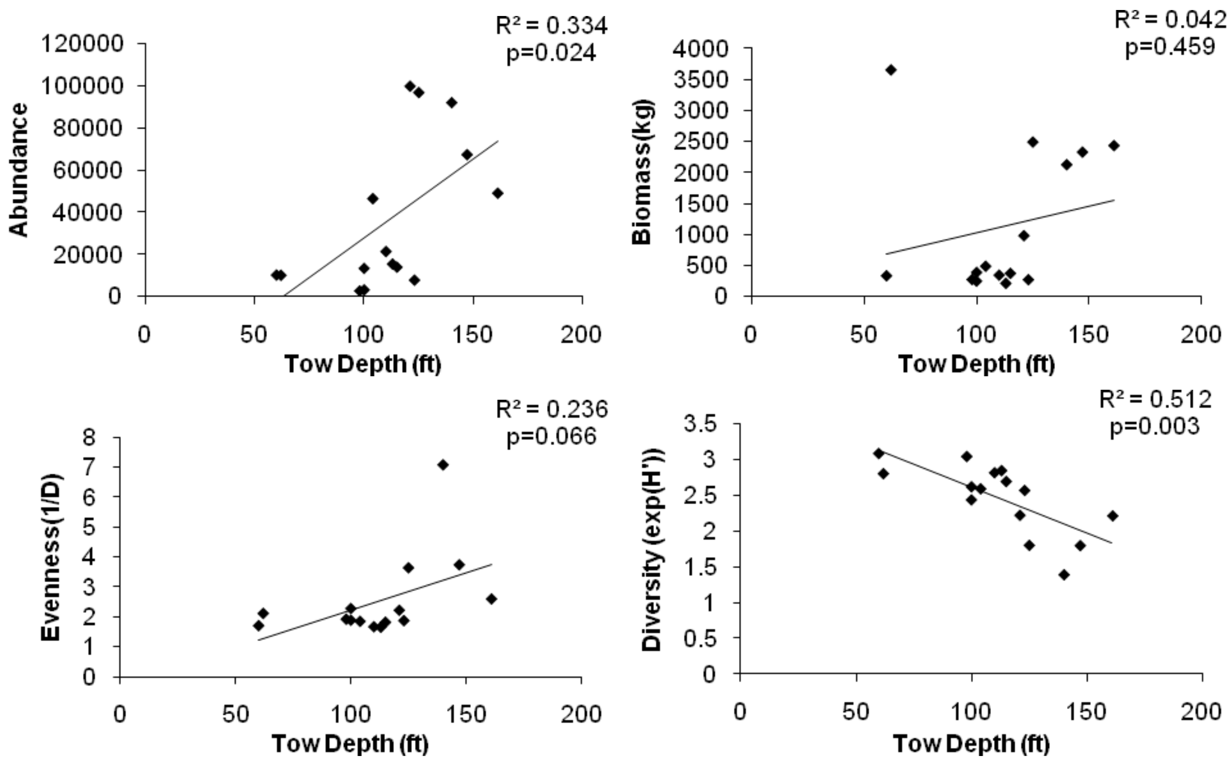

Figure 11. Ordination of the abundances of fish and invertebrate species sampled with demersal bottom trawls within Block Island and Rhode Island Sound. This nonmetric multidimensional scaling plot (MDS) depicts the pattern in demersal fish and invertebrate species composition, with similar species compositions close together. Each point represents one site.

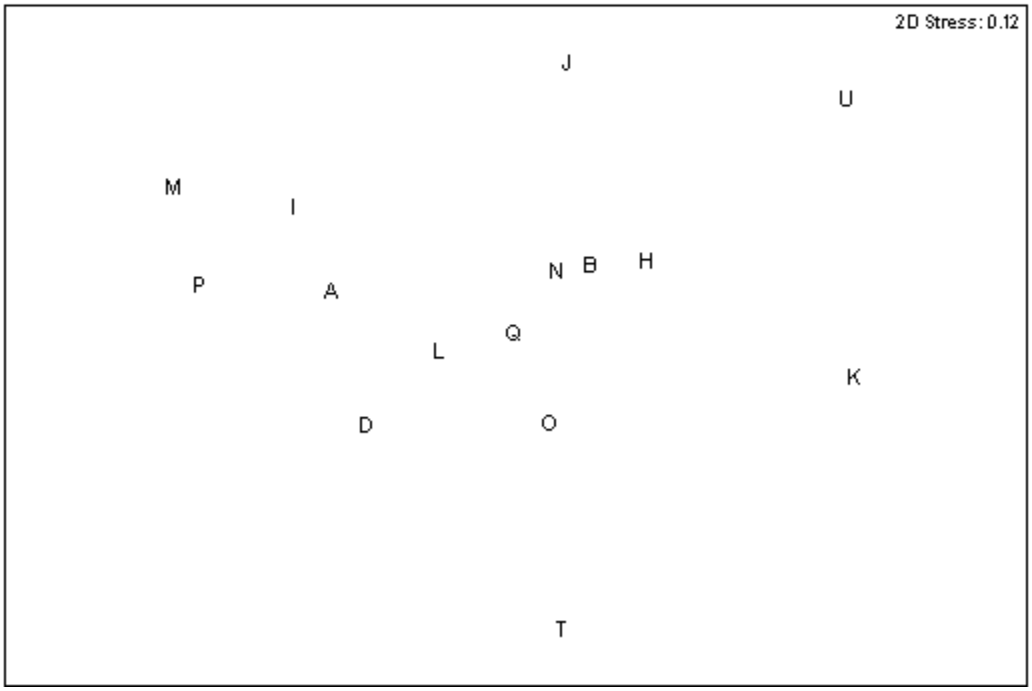

Figure 12. Multidimensional scaling plot (MDS) depicting the pattern in demersal fish and invertebrate species composition in Rhode Island Sound and Block Island Sound. Each point represents one site. Green triangles represent sites in depth stratum 5 (>120 ft), inverted blue triangles represent sites in depth stratum 4 (90-120ft) and light blue squares represent sites in depth stratum 3 (60-90ft). ANOSIM analysis indicates that depth strata has a significant effect on the composition of the demersal fish assemblage (R=0.337, p=0.011).

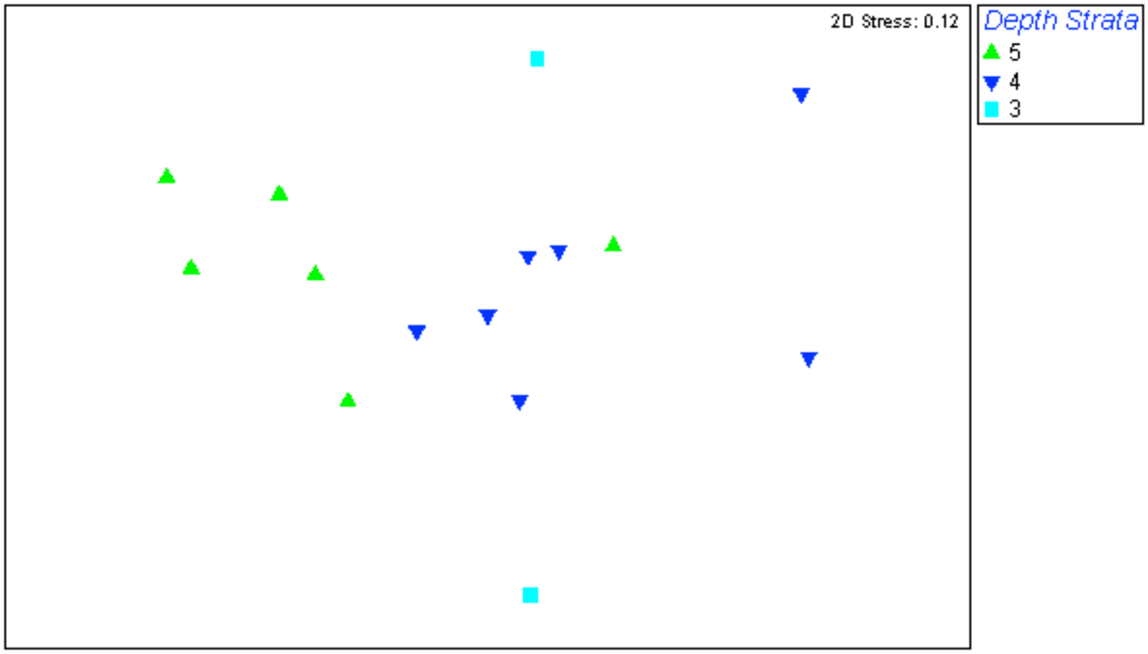

Figure 13. Multidimensional scaling plot (MDS) depicting the pattern in demersal fish and invertebrate species composition in Rhode Island Sound and Block Island Sound. Each point represents one sampling site. Green triangles represent sites in Rhode Island Sound (east of the shipping lane). Inverted blue triangles represent site in Blocked Island Sound (west of the shipping lane). ANOSIM analysis indicates that location (RIS v. BIS) has an effect on the composition of the demersal fish assemblage (R = 0.113, p= 0.10).

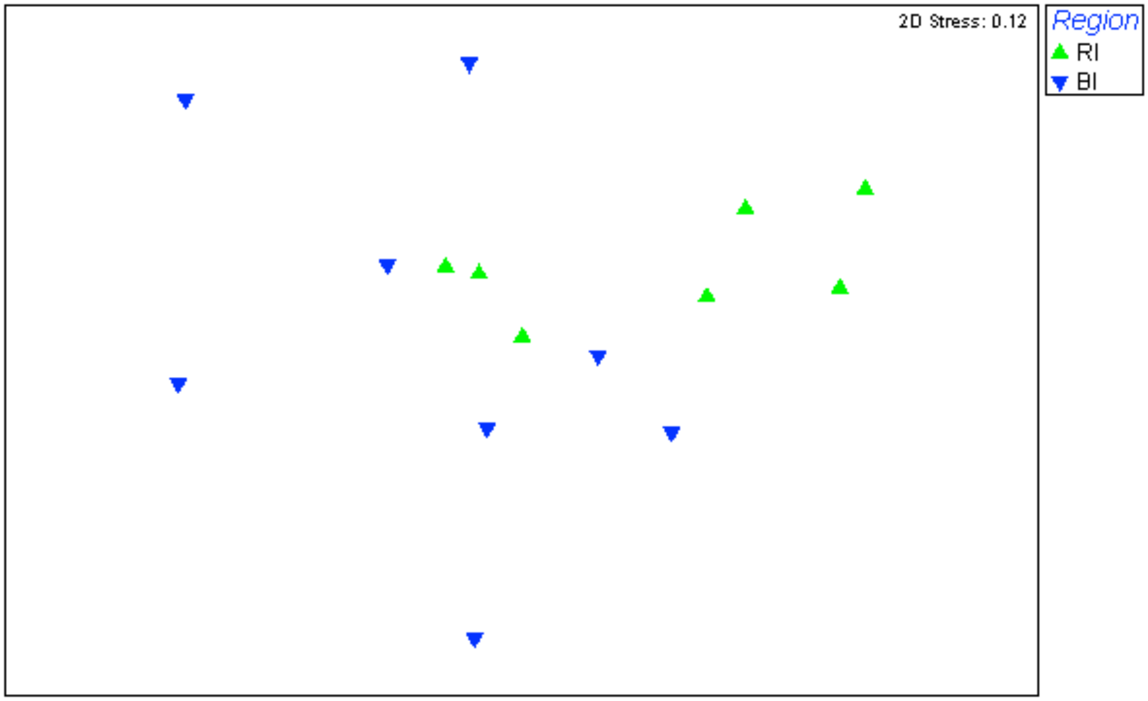

Figure 14. Comparison of benthic surface roughness between Block Island Sound and Rhode Island Sound. Mean benthic surface roughness data was calculated for each site in ArcMap. See Appendix I for more information.

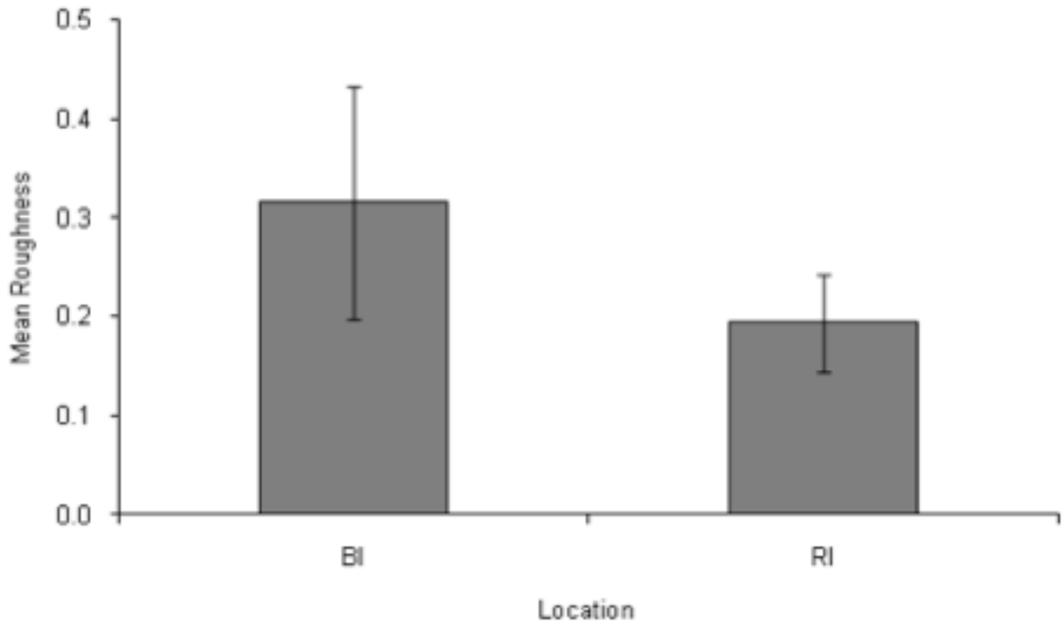

Table 1. Abiotic variables calculated from side-scan, bathymetry and roughness data. Rugosity was calculated from bathymetry data with the Benthic Terrain Modeler Toolbox in ArcMap. A Drafstman plot was used to identify highly correlated variables which were subsequently removed from analysis. Variables marked with an asterisk were uncorrelated and were used in final analyses.

Source	Resolution	Variable
Side-scan (Backscatter)	2m	Min*
		Max
		Mean*
		Standard Deviation*
	25m	Min
		Max
		Mean
		Standard Deviation
	50m	Min
		Max
		Mean
		Standard Deviation
	N/A	Number of Bottom Types*
		Number of Benthic Interfaces*
Bathymetry (Depth)	2m	Min
		Max
		Mean*
		Standard Deviation*
	25m	Min
		Max
		Mean
		Standard Deviation
	50m	Min
		Max
		Mean
		Standard Deviation
	25m	Rugosity*
Roughness (Damon, 2010)	100m	Min
		Max
		Range
		Mean*
		Standard Deviation*

Table 2. Mean abundance and biomass of the fish and invertebrate species caught during bottom trawl sampling in Rhode Island and Block Island Sounds on September 30th and October 2nd, 2009. All species listed below were included in calculations of total abundance, biomass, diversity and evenness as well as multivariate ordination of fish community composition. Species marked with an asterisk account for most of the pattern in the demersal fish assemblage within Block Island Sound and Rhode Island Sound (BVSTEP: rho=0.953).

Common Name	Scientific Name	Abundance	Biomass
Alewife*	*Alosa pseudoharengus*	183.7	11.4
American eel	*Anguilla rostrata*	1.2	0.2
American lobster	*Homarus americanus*	6.8	2.0
American shad	*Alosa sapidissima*	27.5	2.2
Atlantic herring*	*Clupea harengus*	188.0	2.9
Atlantic moonfish	*Selene setapinnis*	3.5	0.0
Atlantic torpedo	*Torpedo nobiliana*	1.0	20.9
Barndoor skate	*Dipturus laevis*	1.0	1.8
Black seabass*	*Centropristis striata*	2.0	2.2
Blueback herring	*Alosa aestivalis*	18.0	0.8
Bluefish*	*Pomatomus saltatrix*	4.8	3.3
Bluespotted cornetfish	*Fistularia tabacaria*	1.5	0.0
Butterfish*	*Peprilus triacanthus*	26104.3	371.5
Clearnose skate	*Raja eglanteria*	1.0	2.7
Crevalle jack	*Caranx hippos*	2.0	0.1
Cunner	*Tautogolabrus adspersus*	1.0	1.2
Fourspot flounder	*Paralichthys oblongus*	7.6	1.7
Goosefish*	*Lophius americanus*	2.5	6.8
Gulf Stream flounder	*Citharichthys arctif rons*	13.7	0.3
Horseshoe crab	*Limulus polyphemus*	1.0	2.5
Jonah crab	*Cancer borealis*	3.6	0.8
Little skate	*Leucoraja erinacea*	123.7	75.1
Longfin squid	*Loligo peali*	6258.9	86.3
Longhorn sculpin	*Myoxocephalus octodecemspinosus*	1.0	0.2
Northern searobin	*Prionotus carolinus*	1.0	0.1
Quahog*	*Mercenaria mercenaria*	3.0	0.7
Red hake	*Urophycis chuss*	12.5	1.6
Rock crab	*Cancer irroratus*	2.0	0.4
Rough scad	*Trachurus lathami*	5.9	0.2
Round herring	*Etrumeus sadina*	4.8	0.1
Round scad*	*Decapterus punctatus*	40.7	1.2
Scup	*Stenotomus chrysops*	3674.4	136.2
Sea raven	*Hemitripterus americanus*	10.0	5.4
Sea scallop*	*Placopecten magellanicus*	23.0	2.1
Silver hake*	*Merluccius bilinearis*	57.1	3.5
Smooth dogfish	*Mustelus canis*	1.7	5.4
Spider crab	*Libinia emarginata*	5.0	0.1
Spiny dogfish*	*Squalus acanthias*	161.6	442.1
Spot	*Leiostomus xanthurus*	1.0	0.1
Spotted hake	*Urophycis regius*	1.5	0.2
Striped bass	*Morone saxatilis*	2.0	8.6
Striped searobin	*Prionotus evolans*	2.3	1.1
Summer flounder	*Paralichthys dentatus*	8.1	14.6
Weakfish	*Cynoscion regalis*	7.5	0.6
Windowpane	*Scophthalmus aquosus*	3.5	0.8
Winter flounder	*Pseudopleuronectes americanus*	52.8	15.3
Winter skate	*Leucoraja ocellata*	13.2	25.6

Table 3. Depth strata, tow depth and region of all 15 sampling sites in Rhode Island and Block Island Sounds. Depth stratum was determined for each trawl site based on pre-existing bathymetric maps, while tow depth was measured at the start of each trawl. Depth strata were defined as follows: Stratum 1: 20-40ft, Stratum 2 : 40- 60ft, Stratum 3: 60- 90ft, Stratum 4 : 90-120ft, Stratum 5: >120ft. Region was classified as follows: Rhode Island Sound (RIS): East of the shipping lane, Block Island Sound: West of the shipping lane (Figure 1).

Site	Depth Strata	Tow Depth (ft)	Region
A	5	140	RIS
B	4	100	RIS
D	5	121	BIS
H	5	123	BIS
I	5	161	RIS
J	3	62	BIS
K	4	98	BIS
L	4	104	BIS
M	5	147	RIS
N	4	115	RIS
O	4	113	BIS
P	5	125	RIS
Q	4	110	RIS
T	3	60	BIS
U	4	100	BIS

Table 4. Total abundance, biomass, diversity and evenness of the fish community at 15 sites within Rhode Island Sound and Block Island Sound as measured by bottom trawls conducted in conjunction with the NEAMAP survey on September 30th and October 2nd, 2009. Hill's N1 (exp(H')) and Hill's N2 (1/D) were used as indices for diversity and evenness, respectively.

Site	Abundance	Biomass (kg)	Diversity	Evenness
A	91676	2127.971	1.390	7.062
B	13485	254.334	2.616	1.877
D	99417	985.733	2.219	2.210
H	7953	277.689	2.565	1.862
I	48949	2435.333	2.210	2.586
J	10232	3652.395	2.798	2.104
K	2857	280.103	3.038	1.912
L	46383	494.456	2.588	1.840
M	67133	2330.536	1.795	3.726
N	14078	379.556	2.689	1.810
O	15536	218.995	2.841	1.645
P	96436	2492.355	1.800	3.627
Q	21450	351.260	2.811	1.658
T	10359	341.235	3.079	1.695
U	3315	394.357	2.433	2.267

Table 5. Results of univariate regressions between acoustically-derived abiotic variables and fish community metrics. Significant relationships are marked with an asterisk.

X variable	Y variable	R^2	p	Relationship
# BT	Diversity	0.691	0.081*	+
# BT	Abundance	0.836	0.030*	-
# BT	Biomass	0.406	0.247	-
# BT	Evenness	0.809	0.038*	-
STDev Depth	Abundance	0.433	0.228	-
STDev Depth	Biomass	0.033	0.770	+
STDev Depth	Diversity	0.184	0.471	+
STDev Depth	Evenness	0.081	0.642	-

Appendix I. Acoustically-determined abiotic benthic habitat variables for sites I, J, P Q and U. All analyses were carried out in ArcMap.

			Station				
Source	**Resolution**	**Variable**	**I**	**J**	**P**	**Q**	**U**
Side-scan (Backscatter)	2m	Min	38	36	32	73	17
		Max	255	191	87	184	166
		Mean*	111.848	115.569	49.234	123.405	71.017
		Standard Deviation*	37.669	27.703	6.415	17.552	22.685
	25m	Min	62.091	31.098	41.882	73.346	26.663
		Max	255	255	121.905	255	136.266
		Mean	121.038	114.436	50.789	126.477	74.117
		Standard Deviation	30.932	24.545	5.675	21.477	20.651
	50m	Min	66.529	34.732	43.534	78.16	33.987
		Max	255	255	84.626	255	113.643
		Mean	121.249	114.546	50.785	127.668	73.965
		Standard Deviation	24.503	22.795	4.725	22.148	17.57
	N/A	Number of Bottom Types*	2	3	1	4	4
		Number of Benthic Interfaces*	1	2	0	9	3
Bathymetry (Depth)	2m	Min	51.248	20.345	37.678	32.042	17.584
		Max	53.617	34.951	40.492	36.584	36.863
		Mean*	52.424	28.943	39.34	34.734	26.269
		Standard Deviation*	0.396	3.841	0.686	0.46	3.415
	25m	Min	47.064	20.589	37.256	28.513	19.982
		Max	53.744	34.686	40.893	36.446	36.771
		Mean	52.052	28.673	39.299	34.515	26.627
		Standard Deviation	1.088	4.42	0.781	0.887	3.919
	50m	Min	47.901	20.68	37.574	27.946	21.587
		Max	53.615	34.676	40.814	36.246	36.02
		Mean	52.046	28.673	39.299	34.509	26.618
		Standard Deviation	1.079	4.413	0.777	0.88	3.906
	N/A	Rugosity	1.00002	1.00011	1	1.00002	1.00008
Roughness (Damon, 2010)	100m	Min	0.363	0.547	0.024	0.176	0.387
		Max	0.460	1.367	0.082	0.258	0.612
		Range	0.098	0.820	0.059	0.082	0.225
		Mean*	0.419	1.043	0.047	0.221	0.569
		Standard Deviation*	0.023	0.194	0.020	0.027	0.040