14.

Fisheries Ecology in Rhode Island and Block Island Sounds

for the Rhode Island Ocean Special Area Management Plan 2010

by

Anna Malek, Monique LaFrance, Jeremy Collie, and John King

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Executive Summary

This study aimed to develop a base map of the fisheries resources in Rhode Island and Block Island Sounds and to investigate the relationship between the benthic environment and the demersal fish community. The demersal fish community was sampled at fifteen sites in conjunction with the NEAMAP survey on September 30th and October 2nd, 2009. Fish community metrics (abundance, biomass, diversity, evenness) and species-specific diet composition were determined for each station. These data were used to investigate spatial trends in the fisheries resources in Rhode Island and Block Island Sounds. Full coverage side-scan and bathymetric data were collected for 12 of the sites within Rhode Island and Block Island Sounds. A suite of benthic habitat parameters were derived from the acoustic datasets and used to evaluate the relationship between the benthic environment and the demersal fish community. 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. Similarly, the composition of the fish assemblage and fish diet depended on the geographic location and benthic habitat where the fish were caught. A distinct relationship between fish community and depth was also evident, with larger, more evenly distributed fish communities in deep water habitats and smaller, more diverse communities in shallow water habitats. Analysis of acoustically-derived benthic habitat parameters revealed a strong relationship between benthic habitat complexity and demersal fish community diversity, with more diverse fish communities occupying more complex habitats. Five acoustically-derived benthic habitat parameters were identified that significantly influence the species composition of the demersal fish assemblage (water depth and four measures of habitat heterogeneity). These benthic habitat parameters exhibited similar site-by-site patterns to the demersal fish assemblage, indicating that the demersal fish community is structured by the physical features of the benthic environment. 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 of Rhode Island and Block Island Sounds, 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 develop a base map of the fisheries resources in Rhode Island and Block Island Sounds and to investigate the relationship between the benthic environment and the demersal fish community. The demersal fish community was sampled at fifteen sites in conjunction with the NEAMAP survey on September 30th and October 2nd, 2009. Fish community metrics (abundance, biomass, diversity, evenness) and species-specific diet composition were determined for each station. These data were used to investigate spatial trends in the fisheries resources in Rhode Island and Block Island Sounds. Full coverage side-scan and bathymetric data were collected for 12 of the sites within Rhode Island and Block Island Sounds. A suite of benthic habitat parameters were derived from the acoustic datasets and used to evaluate the relationship between the benthic environment and the demersal fish community. 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. Similarly, the composition of the fish assemblage and fish diet depended on the geographic location and benthic habitat where the fish were caught. A distinct relationship between fish community and depth was also evident, with larger, more evenly distributed fish communities in deep water habitats and smaller, more diverse communities in shallow water habitats. Analysis of acoustically-derived benthic habitat parameters revealed a strong relationship between benthic habitat complexity and demersal fish community diversity, with more diverse fish communities occupying more complex habitats. Five acoustically-derived benthic habitat parameters were identified that significantly influence the species composition of the demersal fish assemblage (water depth and four measures of habitat heterogeneity). These benthic habitat parameters exhibited similar site-by-site patterns to the demersal fish assemblage, indicating that the demersal fish community is structured by the physical features of the benthic environment. 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 of Rhode Island and Block Island Sounds, we hope to guide the placement of offshore structures so as to preserve the ecological and economic value of the area.

1 Introduction

An ecosystem-based approach to marine management is essential to attain systemwide sustainability and to ensure the continued availability of marine resources that humans want and need (Pauly & Chuenpagdee 2007, McLeod et al. 2005). A core challenge of developing an ecosystem-based approach to management is the acquisition of knowledge concerning the distributions, population structure, interactions and trends of key species and communities. Such data are also essential to investigate changes in biological community structure (Collie et al. 2008) and shifts in the distributions of demersal species (Nye et al. 2009). Thus, without up-to-date, spatially explicit data, long-term sustainable resource use is not feasible.

Recent interest in offshore energy development combined with the ongoing need to assess the status of overfished groundfish species has focused the scientific community's attention on ecosystem-based spatial management planning in Rhode Island's offshore waters. Rhode Island Sound (RIS) and Block Island Sound (BIS) 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. RIS and BIS support a variety of commercial and recreational fishing activities, such as scallop dredging, otter trawling, long-lining and gill-netting. Until recently, RIS and BIS have been too far offshore for state surveys and too close to shore for federal surveys, resulting in a poor understanding of the distribution and dynamics of the fisheries resources in RIS and BIS.

The physical characteristics of marine benthic habitat have been shown to affect fish 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 the fish species assemblage on Hawaiian coral reefs. Unfortunately, very little is known about fish habitat use in temperate, transitional waters, such as RIS and BIS. While many of the fishing activities in RIS and BIS target specific areas having benthic habitat characteristics thought to yield the best harvest, the exact relationship between demersal fish and benthic habitat has yet to be defined (RI Ocean SAMP, Chapter 5). 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. Accordingly, this study aimed to develop a baseline for measuring the cumulative effects of offshore development projects and global climate change as well as to contribute a basic understanding of the fish-habitat relationship within RIS and BIS.

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 deeper survey sites were characterized by higher 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 was planned 1.) to develop a more comprehensive characterization of fish communities within RIS and BIS in order to measure the cumulative effects of offshore development and global climate change and 2.) to examine the relationship between fish communities and benthic habitat.

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 bottom trawled, twelve of which were acoustically surveyed. Study locations were chosen 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 Fish Community Dynamics

3.1.1. Fish Community Sampling

Bottom trawls were used to obtain habitat-specific fish and invertebrate species composition at fifteen sites in RIS and BIS (Figure 1). The demersal fish community was sampled in BIS on September 30th and in RIS on October 2nd, 2009. The sampling was performed in conjunction with the ongoing Northeast Monitoring and Assessment Program (NEAMAP), aboard the 90' FV *Darana R*, captained by James Ruhle (http://www.neamap.net/). Each tow was conducted with a 400 cm x 12 cm, three-bridle, four-seam bottom trawl, paired with a set of Thyboron, Type IV 66” trawl doors. The gear package was designed to maintain door spreads ranging from 32.0 m to 34.0 m, net wing spread between 13.0 m and 14.0 m, and headline heights in the range of 5.0 m to 5.5 m. The cod-end was made of 12 cm stretch mesh (knot to knot) with a 2.43 cm knotless nylon liner. All tows were 20 minutes in duration with a target tow speed of 3.1 knots, resulting in a tow distance of approximately 1.0 nautical mile.

The catch was processed at sea by a team of scientists from the Virginia Institute of Marine Science (VIMS) and the URI Graduate School of Oceanography. Once on board, the catch from each station was sorted by species and size class. Aggregate weights, counts and individual length measurements were recorded for all species collected.

A random sub-sample of 5 fish (per size class per target species per station) was selected for diet analysis following the protocol of Bowman et al. (2000). All fish stomachs were extracted immediately after capture and preserved in Normalin, a non-toxic preservative. In the laboratory, the contents of preserved stomachs were extracted and the total wet weight measured with an analytical balance. All recovered prey items were identified to the lowest possible taxon with the aid of stereomicroscopes. Most fish and invertebrate prey were grouped by family, in order to account for differences in digestive state and prey identification. Abundant prey items were grouped at lower taxonomic levels, while less abundant prey items were grouped at higher taxonomic levels. Scup, summer flounder, winter flounder, spiny dogfish, little skate and winter skate were present at 12 or more stations and were, therefore, selected for species-specific spatial analysis.

3.1.2. Univariate Analysis

For analyses of total catch data, abundance and biomass were summed over all species caught during bottom trawling for each of the 15 sites (Table 1). Hill’s N1 and N2 were used as indexes of diversity and evenness, respectively (Hill 1973). The average fish length at each station was calculated from individual length data and pooled over all species.

The classification of species-specific diet was based on the contribution of each prey group to the predator diet as the percent of total stomach content weight. The diet of each predator species was determined for all 15 sites. Pie charts, representing the site-specific diet composition of scup, summer flounder, winter flounder, spiny dogfish, little skate and winter skate were projected in Arcmap 9.3 for spatial analysis.

The shipping lane to the east of Block Island acted as the delineation between Block Island Sound and Rhode Island Sound for all spatial analyses (Figure 1). 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, whereas trawl sites located to the east of the shipping lane were considered to be in Rhode Island Sound (Table 2).

3.1.3. Multivariate Analysis

Species-specific fish abundance data from each of the 15 sites was fourth-root transformed to reduce the influence of highly abundant species. In the statistical software package, PRIMER 6.0, a Bray-Curtis similarity index was used to measure the similarity in fish community composition between sites. The Bray-Curtis measure is widely used and has properties that are desirable for ecological studies, such as complementarity, localization, and dependence on totals (Clark and Gorley 2006). A multi-dimensional scaling plot (MDS plot) was derived from the similarity matrix to ordinate the sites in two dimensions such that the relative distances apart of all points are in the same rank order as the dissimilarities of the study sites (Clarke and Gorley 2006). Accordingly, points that are close together represent sites that have very similar fish community composition and points that are far apart represent sites that have highly dissimilar fish community composition. The MDS plot was used to visualize between-site similarity in fish community composition and to investigate the factors that may contribute to the identified similarities.

The CLUSTER function in PRIMER 6.0 was used to divide the sites into groups based on the similarity of fish community composition. The CLUSTER analysis was carried out integrating the SIMPROF routine that determines statistically significant station clusters within an a-priori ungrouped set of stations (Clarke and Gorley 2006).

The fish abundance similarity matrix was subjected to the BVSTEP procedure in PRIMER 6.0. The BVSTEP analysis identifies a subset of species which collectively 'account' for the patterns in fish community composition within the full data set. Starting with a random subset of species, the BVSTEP procedure sequentially adds and subtracts species. The test statistic (rho) is the rank correlation between the similarity matrix for the subset of species and the similarity matrix for the full community. Though different subsets may give the same correlation (redundant species), by repeated runs, a set of species was identified that was consistently correlated with the full community. The test was permutated 999 times to assess the significance of the BVSTEP results. The purpose of this approach is to find the smallest possible subset of species which, in combination, describe most of the pattern in the full data set.

3.2 Acoustic Data

3.2.1. Collection

Acoustic data for 12 of the study sites within RIS and BIS were collected aboard the OSV Bold from August 24-29, 2009. An interferometric sonar system (C3D-LPM, Teledyne Benthos) was used to simultaneously collect swath bathymetric and side-scan sonar data. Survey speed was between 4 and 6 knots. During the surveys, raw data was continuously recorded in digital .OIC format with OIC GeoDas acquisition software (Ocean Imaging Consultants, Inc., Honolulu, HI) and monitored in real-time with a topside processor. A Hemisphere GPS (VS100 series) assured positional accuracy (< 0.6 m 95% confidence (DGPS)) of the data, corrected for vessel heading (< 0.30º rms at 0.5 m antenna separation), and vessel pitch and roll (< 1º rms at 0.5 m antenna separation).

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. The range of the bathymetry data is 10X the water depth, whereas the sidescan range is approximately 20X the water depth. Therefore, in order to achieve 100 % survey coverage, the line spacing is determined based on the 10X range of the bathymetry coverage.

3.2.2. Processing

The raw OIC files were processed into side-scan backscatter and bathymetry mosaics, both at 2 m pixel resolution, using OIC Cleansweep (version 3.4.25551, 64-bit) software. 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. Final maps of the side-scan backscatter and bathymetry for each station are given in Appendix I and II.

3.2.3. Deiving Benthic Habitat Parameters

A suite of benthic habitat parameters was derived from the acoustic data for each of the 12 stations (Table 3). Rugosity was used as a measure of benthic habitat complexity, with rugosity values near 1 representing flat, smooth terrain and higher values reflecting increasing rugosity. Rugosity was calculated from the bathymetry for each transect as the ratio of surface area to planar area (Hobson 1972). From the side-scan imagery, the number of bottom types and number of habitat interfaces along each fish trawl transect were determined. The minimum, maximum, mean and standard deviation of depth and backscatter were derived from the bathymetry and side-scan mosaics using the Block Statistics tool in the Spatial Analysis Toolbox in ArcInfo. These metrics were calculated at 2 m resolution within a 14 m wide buffer (the width of the fish tow net).

In addition, a map of benthic surface roughness, a measure of habitat complexity, was created for the entire RI Ocean SAMP study area (as seen in the RI Ocean SAMP Ecology Chapter (Chapter 2, Figure 2.26)) (Appendix III). This data layer is the standard deviation of the slope within a 1000 m radius calculated at 100 m pixel resolution (methods further discussed in LaFrance et al., 2010). The mean, minimum, maximum, and standard deviation of the surface roughness was calculated for all 15 fish trawl transects within a 500 m buffer (Table 3).

3.3. Benthic Habitat and Fish Community Integration

3.3.1. Univariate Analyses

Univariate regressions and graphical analysis were used to investigate the relationship between depth and fish community metrics (i.e. abundance, biomass, diversity and evenness). It was hypothesized that fish abundance and biomass would be positively correlated with depth ($r>>0$). NEAMAP tow depth and depth strata were both used in this analysis (Table 2). NEAMAP tow depth was measured at the start of each trawl, whereas NEAMAP depth stratum was determined for each trawl site based on pre-existing bathymetric maps. 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.

Relationships between acoustically-derived benthic habitat parameters and fish community metrics were also assessed with univariate regressions. It was hypothesized that fish diversity would be positively correlated with measures of bottom complexity (i.e. rugosity, number of bottom types, number of bottom type borders) (Salomon et al. 2010). Site-specific fish abundance, biomass, diversity and evenness were coupled with individual benthic habitat parameters for this analysis (Table 5).

3.3.2. Multivariate Analyses

In PRIMER 6.0, an analysis of similarity (ANOSIM) was performed on the Bray-Curtis similarity matrix of the species-specific fish abundance using location (RIS v. BIS) and depth strata as a factor. ANOSIM tests the null hypothesis that there are no differences between groups of samples (the fish abundance Bray-Curtis similarity matrix) when examined in the context of an a-priori factor (location, depth strata) (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).

A Draftsman plot, consisting of pairwise scatterplots, was created in PRIMER 6.0 to assess the correlation between the benthic habitat variables. Variables that were highly correlated ($r > 0.85$), and, therefore, redundant were eliminated from further analysis (see Table 1; variables marked with an asterisk were retained). The variables were then normalized to correct for differences in units, and a resemblance matrix was created based on the Euclidean distance metric. A multi-dimensional scaling plot (MDS plot) was derived from the benthic habitat parameter resemblance matrix to ordinate the sites in two dimensions. The MDS plot was used to visualize between-site similarity in benthic habitat and to compare the environmental patterns to that of the fish community.

The relationship between the non-correlated benthic habitat parameters and species-specific demersal fish community data for the 12 stations was examined in PRIMER 6.0 using the BIOENV procedure. The BIOENV procedure identifies a subset of benthic habitat parameters that best "explains" fish community 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 benthic habitat parameters and the fish community similarity matrix. A maximum of five variables was permitted in the output. The BIOENV procedure was permuted 999 times in order to evaluate the level of significance of the results.

The benthic habitat parameters selected as important by the BIOENV were then entered into the LINKTREE procedure in PRIMER 6.0. The LINKTREE routine classifies the fish community data according to patterns in the selected benthic habitat parameters. LINKTREE groups the fish community samples by successive binary division using the benthic habitat parameters 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 fish community samples and quantitative thresholds of the benthic habitat parameters. An ANOSIM was performed on the LINKTREE classes to test the hypothesis that there are no significant ($p > 0.05$) differences in the fish assemblages among LINKTREE classes.

4 Results

4.1 Fish Community Dynamics

4.1.1. Univariate Analysis

Abundance, biomass, diversity and evenness of the fish community at all 15 sites are given in Table 4. Total fish abundance was highest at stations D, P and A (Figure 2; Station D = 99417, Station P = 96436, Station A = 91676) while total fish biomass was highest as stations J, P and I (Figure 3; Station J = 3652.39 kg, Station P = 2492.35 kg, Station I = 2435.33 kg). Total fish abundance was lowest at stations H, K, and U (Figure 2; Station H = 7953, Station K = 2857, Station U = 3315) while total fish biomass was lowest at stations B, H and O (Figure 3; Station B = 254.33 kg, Station H = 277.68 kg, Station O = 218.99 kg). Stations K and T had the most diverse fish communities (Hill's N1: Station K = 3.038, Station T = 3.079) and stations A, M and P exhibited the least fish diversity (Hill's N1: Station A = 1.390, Station M = 1.795, Station P = 1.800). With regard to evenness, stations A and M had the most evenly distributed fish communities (Hill's N2: Station A = 7.062, Station M = 3.726) and stations O, Q and T has the least evenly distributed fish community (Hill's N2: Station O = 1.645, Station Q = 1.658, Station

T = 1.695). Figure 2 and figure 3 show the relative abundance and biomass of the demersal fish community in the spatial context of RIS and BIS.

Graphical analysis of fish community data revealed apparent trends towards higher abundance and biomass in Rhode Island Sound as compared to Block Island Sound (Figure 4; Abundance: RIS = 24506, BIS = 50458; Biomass: RIS = 830.62 kg, BIS = 1481.62 kg). Overall species diversity, as defined by Hill's N1, was higher in Block Island Sound, whereas species evenness, as defined by Hill's N2, was higher in Rhode Island Sound (Figure 4; N1: RIS = 2.2, BIS = 2.7; N2: RIS = 3.2, BIS = 1.9).

The average length of the fish community at each of the 15 trawl sites is given in Table 4. The relative average lengths of the demersal fish community indicate that stations H,M and U had the largest average fish length (Figure 5; Station H = 147.76mm, Station M = 177.01mm, Station U = 203.47mm) and stations D, L and O had the smallest average fish length (Station D = 91.44mm, Station L = 78.51mm, Station O = 83.32mm). Graphical analysis of pooled fish length data showed a similar average fish length in RIS and BIS (Figure 4; RIS = 122.85mm ± 1.48, BIS = 124.43mm ± 1.02).

The diet composition of each of the predator species (i.e. scup, summer flounder, winter flounder, spiny dogfish, little skate, and winter skate) was unique and spatially variable (Figures 6-11). The diet composition of scup, winter flounder and little skates consisted primarily of amphipods, polychaetes and decapods, whereas the diets of summer flounder, spiny dogfish and winter skates were mainly squid and bony fishes. More specifically, scup diet (n=157) consisted primarily of amphipods (24.6%), polychaetes (8.66%) and various decapods (i.e. shimp and crabs, 6.39%); winter flounder diet (n=69) was mainly polychaetes (20.1%) and amphipods (32.9%); little skate diet (n=36) was mainly amphipods (31.6%) and small decapods (i.e. shimp and crabs, 29.2%); summer flounder diet (n=56) was mainly squid (36.88%) and bony fishes (39.6%); spiny dogfish diet (n=28) was mainly butterfish (36.7%), squid (28.33%) and other bony fishes (25.6%) and winter skate (n=27) diet consisted mostly of bony fishes (35.9%), amphipods (12.2%) and squid (11.38%).

Mapping of site-specific diet composition revealed a number of spatial patterns at both the species and community level (Figures 6-11). For example, a diet distinction between RIS and BIS was apparent in benthivorous species (scup, winter flounder, summer flounder, little skate), with plants consistently comprising a significant part of diet in Block Island Sound. Another pattern identified during spatial analysis of species-specific diet composition was the consistent prevalence of gammaraid and caprellid amphipods as prey items at sites J,D and H located near Block Island (Figures 6-11). Finally, squid were consistently present in the diet of all its main predators (spiny dogfish, winter skate and summer flounder) in Rhode Island and Block Island Sounds, suggesting that squid inhabit both the benthic and pelagic realm.

4.1.2. Multivariate Analysis

The MDS plot and CLUSTER analysis defined two groups of sites displaying significant between-site fish assemblage similarity as well as four sites that were unique (Figures 12 and 13). Group 1 included sites I,M and P (SIMPROF: π=1.021, p=0.335), Group 2 included sites A,L,D,O,Q,N,B and H (SIMPROF: π =0.971, p=0.184) and sites K,U,T and J were each considered unique.

The BVSTEP analysis identified 11 species (out of 47 total species) that account for most of the pattern in demersal fish and invertebrate community composition within the SAMP area (rho=0.953, p=0.01; refer to Table 1). The species important in shaping the demersal fish community are alewife, atlantic herring, black seabass, bluefish, butterfish, goosefish, quahog, round scad, silver hake and spiny dogfish. The species identified in the BIOENV procedure tended to be either the most abundant (i.e. alewife, butterfish, atlantic herring) or least abundant in RIS and BIS (i.e. quahog, goosefish, bluefish). However, not all species with high or low abundances were chosen, indicating that abundance is not the driving factor for the BIOENV procedure or in identifying community-shaping fish species.

4.2 Acoustic Data and Benthic Habitat Parameters

The benthic habitat parameters for all 12 stations are given in Table 3. Side-scan, bathymetry, and surface roughness of all 12 stations in RIS and BIS are shown in Appendices I, II and III, respectively.

Benthic surface roughness was higher in BIS than in RIS, suggesting that BIS contains more complex benthic habitats than RIS (Figure 14). The MDS plot shows two groups of sites with similar benthic habitat (I,M,P and B,D,H,L,O,Q) and three sites as individual outliers (J,K,U) (Figure 15).

4.3. Benthic Habitat and Fish Community Integration

4.3.1. Univariate Analyses

Integration of site-specific fish community data and depth measurements revealed a strong trend in depth, whereby sites at deeper depths were characterized by the highest fish abundance and biomass (Figure 16 & 17). Inverse trends in diversity and evenness were also evident, with decreasing diversity and increasing evenness with depth. There was no apparent trend in average fish length in relation to depth (Figures 16 & 17). Therefore, overall, survey sites at deeper depth were characterized by the highest abundance and biomass, while survey sites at shallower depths were characterized by higher species diversity, suggesting that in RIS and BIS, fish communities residing in deeper water are larger and less diverse than fish communities residing in shallower water (Figure 16 & 17).

Regressions between benthic habitat parameters and fish community metrics revealed a remarkably strong inverse relationship between the number of bottom types and fish abundance (R^2 = 0.711, $p<0.001$; Table 5). There was also a significant inverse relationship between fish abundance and the number of bottom-type borders (R^2 = 0.359, p=0.039) as well as a significant proportional relationship between fish abundance and mean depth (R^2 = 0.337, p=0.048; Table 5). Fish species diversity, on the other hand, exhibited a significant proportional relationship with the number of bottom-type borders (R^2 = 0.417, p = 0.023) and a significant inverse relationship with mean depth (R^2 = 0.371, p = 0.036; Table 5). The remaining fish-habitat relationships were not significant ($R^2 < 0.2$, $p > 0.05$). These results suggest that deeper habitats support more abundant, less diverse fish communities and more heterogeneous habitats support less abundant, more diverse fish communities. However, none of the individual benthic habitat parameters displayed a significant relationship with all of the fish community metrics, suggesting that a combination of acoustically-derived benthic habitat parameters collectively defines the relationship between the environment and the fish community.

4.3.2. Multivariate Analyses

ANOSIM analyses and MDS visualization indicate that Block Island Sound and Rhode Island Sound support different communities of demersal fish (Figure 18, R=0.113, p=0.1). ANOSIM analyses also indicate that depth strata significantly influences the species composition of demersal fish communities within Rhode Island and Block Island Sounds (Figure 19, R=0.332, p=0.011).

The BIOENV procedure identified five benthic habitat parameters as being most influential to the fish community composition (rho=0.495, p=0.118). These parameters were mean depth, number of bottom types, number of boundaries crossed, standard deviation of bottom roughness and rugosity (10m resolution).

The LINKTREE analysis divided the 12 study sites into four groups based on thresholds of the mean water depth or the number of bottom types (Figure 20). Group 1 included sites J, K and U. Group 2 included sites I, M and P. Group 3 included site D only. Group 4 included sites B,H,L,O and Q. These LINKTREE groups are remarkably similar to the CLUSTER groups, suggesting a strong link between the physical features of the benthos and the demersal fish community (Figure 12 & 15). Evidence of this relationship is apparent in the projection of the LINKTREE groups on the fish assemblage MDS plot (Figure 12). Furthermore, ANOSIM analyses of the fish community data with respect to the LINKTREE classes indicate that there are significant differences in the demersal fish assemblage between LINKTREE classes (R=0.715, p=0.001).

5 Discussion

Fish Community

The demersal fish community of Rhode Island's transitional seas is spatially variable in abundance, biomass and species assemblage (Figures 2, 3 and 12). The pattern towards higher fish abundance and biomass in Rhode Island Sound (refer to figure 4) 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), which, if the typical bottom-up ecological model is followed, would lead to increased fish abundance in RIS (Hunter & Price 1992, McQueen et al. 1989). Ongoing studies concerning primary production and fish community in RIS and BIS, may serve to further elucidate this relationship.

As a biological 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). Evidence of this trend is seen in the inverse relationships of diversity and evenness with depth and benthic surface roughness (Figure 17 & Table 5). The trends toward greater evenness and higher abundance in Rhode Island Sound suggest that larger fish communities tend to have a more even species distribution while smaller fish communities tend to be more diverse. In RIS and BIS, large fish communities are often dominated by schooling species (dogfish, scup, butterfish). These species exploit both benthic and pelagic niches and, therefore, reduce the diversity of the fish community (Scharf et al. 2000).

Schooling behavior of certain fish species in RIS and BIS may also influence spatial patterns in the demersal fish community. It has been shown that large aggregations of prey attract schools of predators, which, in turn, shape the fish community through top-down control (Zamon 2003, McQueen et al. 1989). Evidence of this phenomenon in RIS and BIS is apparent in the diet analysis and spatial distribution of the spiny dogfish, *Squalus acanthias,* and loligo squid (Figure 9, Gerry 2008). Spiny dogfish are opportunistic feeders and are known to exhibit schooling behavior, therefore, dominating the assemblage and size of the fish community when they are present (see Figure 9, sites H,M and U). In RIS and BIS, spiny dogfish, along with winter skates and summer flounder are key predators of loligo squid, a common schooling species. The results from this study suggest that squid inhabit the entire water column in RIS and BIS and, therefore, attract exclusive bottom feeders (e.g. summer flounder, winter skates) as well as semi-pelagic feeders (e.g. spiny dogfish). Thus, the predator-prey interactions and schooling behaviors of dogfish and squid play an important role in the fisheries ecosystem dynamics in RIS and BIS.

Scup, *Stenotomus chrysops*, are similar to dogfish in their schooling patterns (Bigelow & Schroeder 2002). Scup, however, are smaller and more benthivorous in their feeding regime and, therefore, school in areas with aggregations of small benthic prey, such as amphipod tube mats (Bigelow & Schroeder 2002). In this study, the diet of scup and other benthivorous species were dominated by gammarid and caprellid amphipods at sites J, D and H (Figures 6-11). This trend indicates that these areas, all surrounding Block Island, exhibit unique benthic habitat features favorable for epifaunal and infaunal amphipods. Accordingly, these areas surrounding Block Island may be an important foraging ground for demersal fish, as amphipods are a key prey items for many species (Garrison & Link 2000). It is important to protect such unique benthic habitats and the food resources they provide so as to sustain vulnerable groundfish species and maintain overall ecosystem balance.

The results of the BVSTEP procedure suggest that alewife, atlantic herring, black seabass, bluefish, butterfish, goosefish, quahog, round scad, silver hake and spiny dogfish collectively account for most of the patterns in fish community composition within RIS and BIS. This list accounts for both bottom-up and top-down trophic cascades by including top predators (i.e. spiny dogfish and bluefish) as well as planktivores (i.e. alewife, atlantic herring, round scad, quahogs) (Hunter & Price 1992). Bottom-up trophic cascades are based on the theory that increased primary production leads to increased abundances in plants and animals higher in the food chain (McQueen et al. 1989). Thus, planktivores would be the first fishes to respond to changes in primary production. Conversely, top-down trophic cascades are based on the theory that top predators structure the ecological community via predation, such that an increase in predator populations (i.e. bluefish and dogfish) leads to a decrease in prey abundance (i.e. herring, scad, butterfish) and a subsequent increase in zooplankton communities (Carpenter et al. 1985). When attempting to predict the effects of development and exploitation on the demersal fish assemblage of the SAMP area, it is essential to consider the interactions of these community-shaping species.

Environmental Effects on the Fish Community

The fisheries ecosystem of RIS and BIS is composed of many environmental factors, including geographical location, water depth, benthic surface roughness and benthic habitat heterogeneity. 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.

In Rhode Island and Block Island Sounds, deeper habitats tend to support many of the most abundant demersal fish species and shallower habitats tend to support a more diverse and less abundant community of fish (Figure 16 & 17). While the preference of demersal fish for specific depth ranges has been observed in a variety of ecosystems, this strong system-wide pattern is novel to RIS and BIS (Persohn et al. 2009; Sonntag et al. 2009). According to this study, when aiming to protect fish community diversity in RIS and BIS, focus should be on shallow water habitats; whereas when aiming to preserve total fish biomass, focus should be on deep water habitats.

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 species diversity increase (Salomon et al. 2010). The presumed relationship is that the more heterogeneous the habitat, the more species it can support because more niches are available (Eriksson et al. 2006, Levin et al. 2001, Guegan & Oberdorff 2000). This pattern appears to hold true in Rhode Island's offshore waters, where the more complex bottom terrain of Block Island Sound (i.e. more habitat diversity) supports more diverse fish communities than the less complex bottom terrain of Rhode Island Sound (Figure 4 & 14). Accordingly, areas with high bottom roughness tend to correspond with prime fishing areas for several species targeted by commercial and recreational fisheries in RIS and BIS (RI Ocean SAMP, Chapter 5).

By nature, the benthos is an intricate system, characterized by a collection of unique environmental parameters. Relationships between such benthic habitat parameters and fish communities has been well documented in coral reefs and seagrass beds, but this research is novel to temperate, offshore water environments (Ault & Johnson 1998; Christensen et al. 2003; Eriksson et al. 2006). This study identified five specific benthic habitat parameters which are, collectively, influential in the composition of demersal fish assemblages in RIS and BIS (BIOENV: rho=0.495, p=0.118). Four out of the five environmental parameters identified in the BIOENV procedure are indicators of habitat heterogeneity (number of bottom types, number of bottom type boundaries crossed, standard deviation of the slope and rugosity), supporting the theory that benthic habitat heterogeneity plays an important role in shaping the demersal fish community in temperate marine ecosystems such as RIS and BIS. It is important to note, however, that none of the individual benthic habitat parameters displayed a significant relationship with all of the fish community characteristics (i.e. abundance, biomass, diversity, assemblage). Thus, the relationship between demersal fish community and benthic habitat is not defined by one distinctive parameter, but rather a combination of environmental features.

Similarity between the benthic habitat parameter MDS and demersal fish assemblage MDS as well as patterns in LINKTREE and CLUSTER groups further suggest that the fish community in RIS and BIS is shaped by the physical environment (Figure 12 & 15). Groups of sites, such as I,M,P and B,H,L,Q, are similarly laid out in both the environmental and fish community MDS plots (Figure 12 & 15). These sites are also grouped together in both the CLUSTER and LINKTREE analysis. Since the physical benthic environment is static and the demersal fish community is mobile, the fish community must be shaped by the environment and not vice versa. One ecological mechanism that may account for this habitat-fish association is the interaction of predators and prey (Stein 1977). If the predator-prey interaction within the fish community is strong, then the prey act as the link to the environment, seeking out the most hospitable environment, whereas the predators simply follow the prey (Powers et al. 1985). If there is no predator-prey interaction, then the fish community as a whole is linked to specific physical features of the benthic environment.

Future Work

As mentioned previously, the BIOENV shows that environmental variables explain a large portion of the pattern in demersal fish community composition. The rest of the variability in the biology may be explained by other environmental parameters that were not measured in this study, such as currents and sediment grain size. Further research on benthic habitat features that may influence demersal fish assemblage is needed to gain a better understanding of the functional relationship between the environment and the fish community in RIS and BIS. Furthermore, understanding the influence of benthic habitat features on the demersal fish community is essential in developing strategies for rebuilding fish stocks important to Southern New England. Thus, future work will aim to assess additional benthic habitat parameters, using underwater video and advanced acoustic analysis.

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 operative relationship between benthic habitat and the demersal fish community in Block Island and Rhode Island sound, a greater variety of bottom types must be mapped and sampled, as 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). Accordingly, future work will focus on using beam trawls to collect fish community data in cobble, moraine and other hard-bottom habitats .

6 Conclusions

Our understanding of demersal fish community dynamics and the relationship to benthic habitat in Rhode Island and Block Island Sounds will help to guide the placement of offshore structures so as to preserve the ecological and economic value of the area. Based on 15 bottom trawls and 12 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.

- Average fish length is similar in Rhode Island Sound and Block Island Sound, but is spatially variable at a finer (site-by-site) scale.
- The composition of the fish assemblage and fish diet depends on the habitat where the fish were caught.
- 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.
- Benthic habitat complexity is greater in Block Island Sound than Rhode Island Sound.
- Mean water depth in combination with four measures of benthic habitat heterogeneity (number of bottom types within each site, number of bottom type boundaries crossed by the trawl trackline, standard deviation of benthic surface roughness and rugosity), were found to be the environmental variables most influencing the species composition of the demersal fish community within Rhode Island and Block Island Sounds.
- The demersal fish community of Rhode Island and Block Island Sounds is shaped by a variety of physical environmental variables, not all of which have been accounted for in this study.

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Figures

Figure 1. RI Ocean SAMP study area and location of acoustic survey and bottom trawls sites. The pink dashed line represents the boundaries of the SAMP area. Light blue lines represent the boundaries of acoustically surveyed sites and thick red lines represent bottom trawl track-lines. The black dashed line designates the separation between Rhode Island Sound and Block Island Sound.

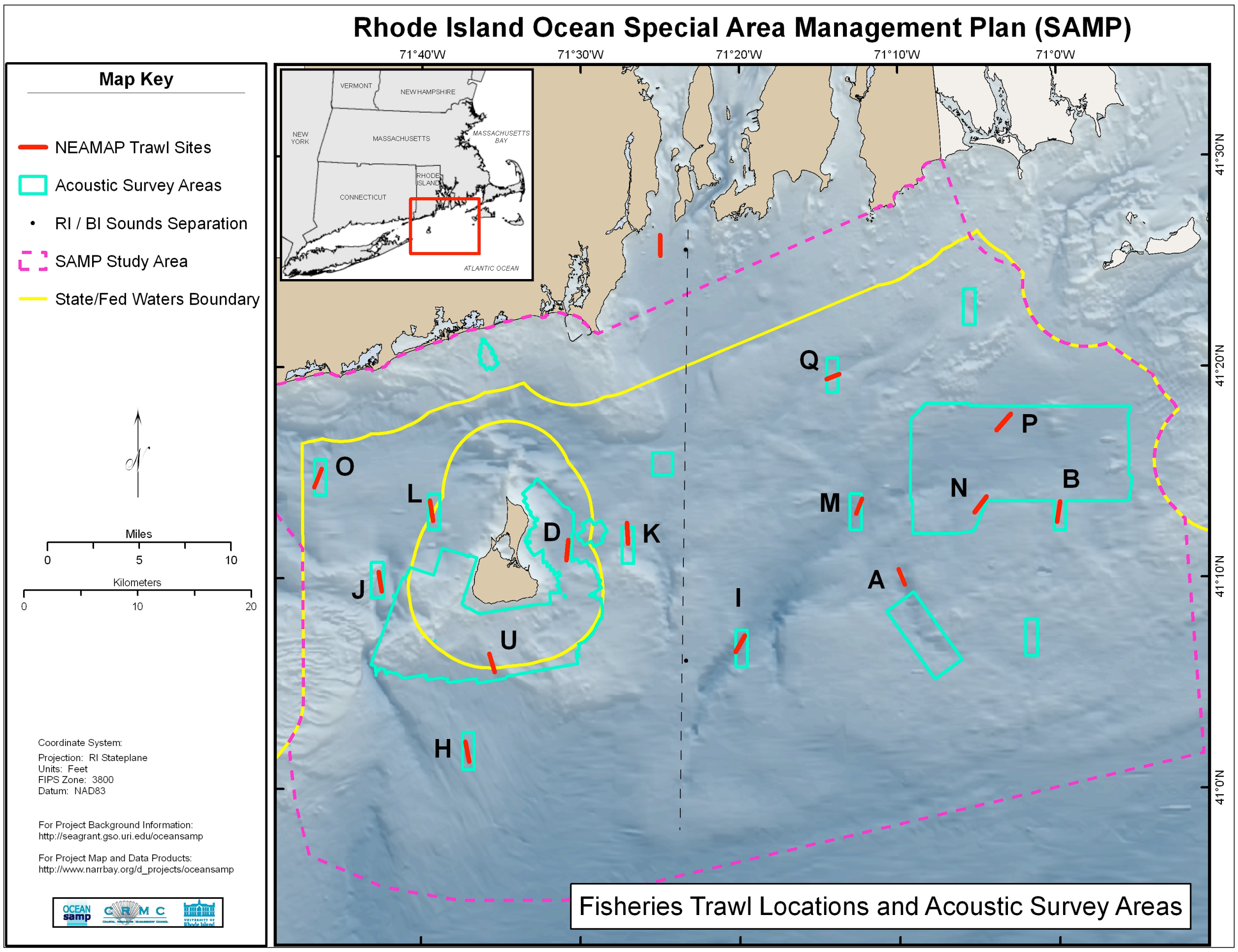


Figure 2. Aggregate fish abundance in Rhode Island Sound and Block Island Sound as measured by fifteen bottom trawls conducted in conjunction with the NEAMAP survey on September 30th and October 2nd, 2009 (http://www.neamap.net/). Green circles represent the total fish abundance at each site.

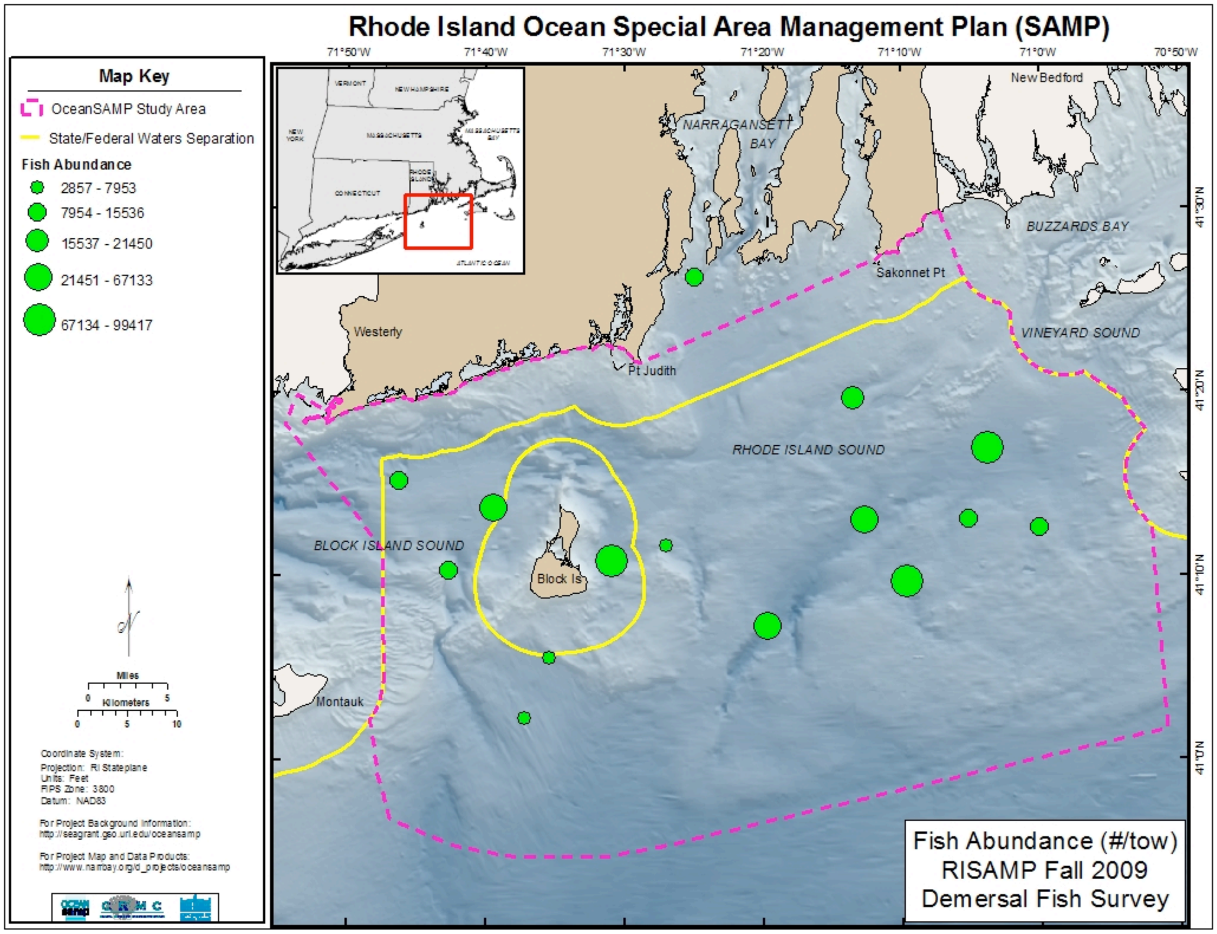


Figure 3. Aggregate fish biomass in Rhode Island Sound and Block Island Sound as measured by fifteen bottom trawls conducted in conjunction with the NEAMAP survey on September 30th and October 2nd, 2009 (http://www.neamap.net/). Blue circles represent the total fish biomass at each site.

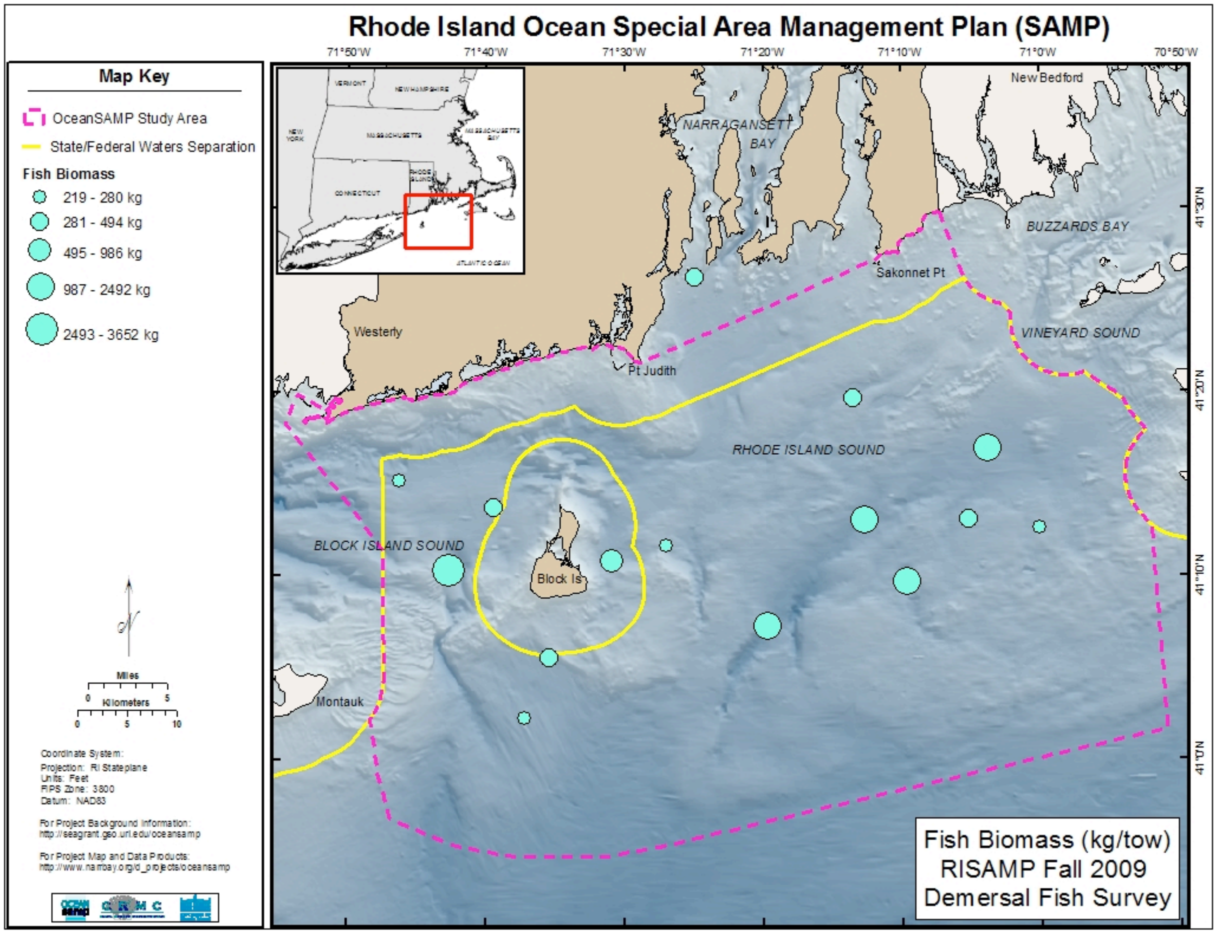


Figure 4. Comparison of total fish abundance, biomass, diversity, evenness and mean fish length between Rhode Island Sound and Block Island Sound. Hill's N1 and N2 were used as indices of diversity and evenness, respectively.

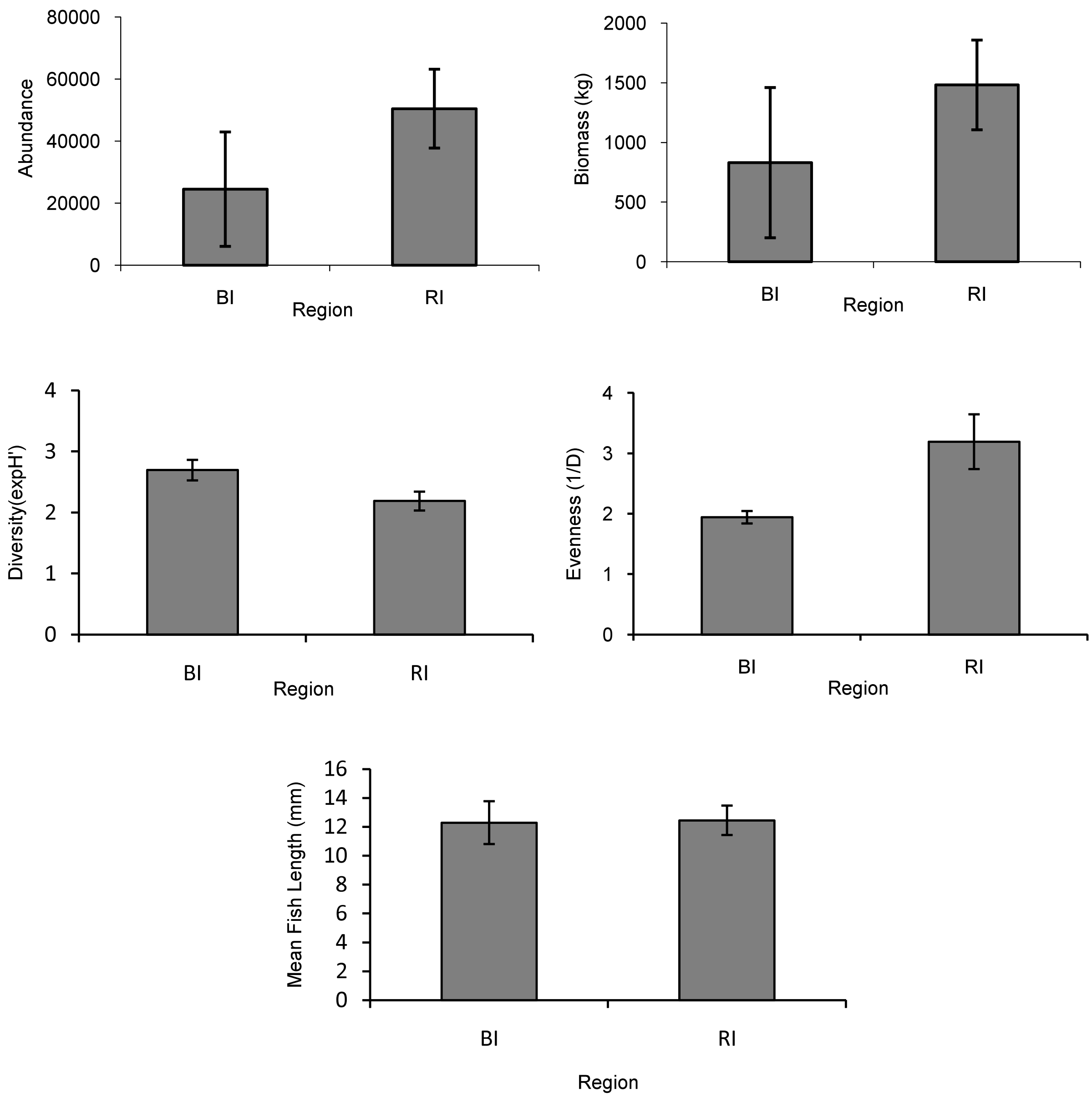


Figure 5. Aggregate mean fish length (mm) in Rhode Island Sound and Block Island Sound as measured by fifteen bottom trawls conducted in conjunction with the NEAMAP survey on September 30th and October 2nd, 2009 (http://www.neamap.net/). Red circles represent the mean fish length at each site.

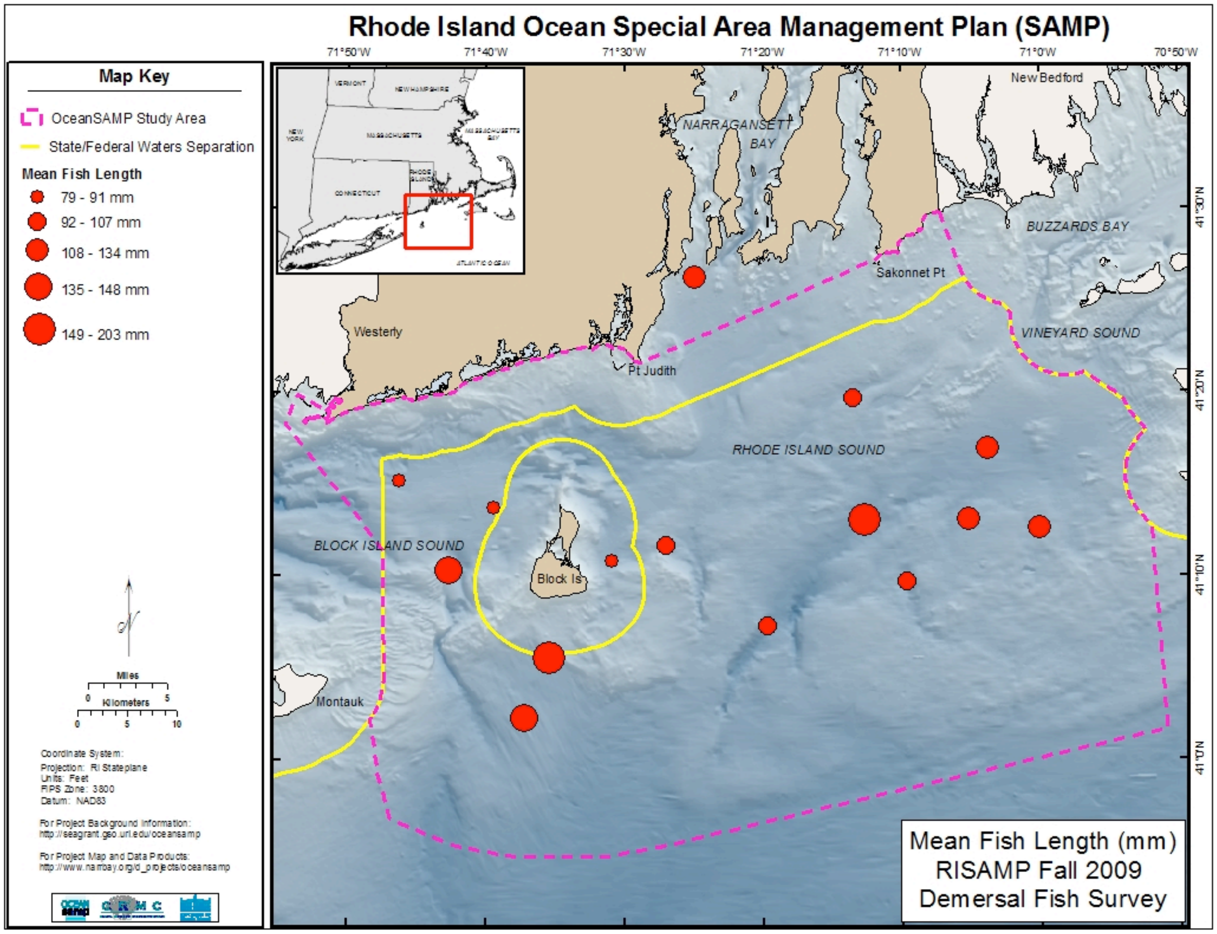


Figure 6. Site-specific scup (*Stenotomus chrysops*) diet composition in Rhode Island Sound and Block Island Sound. All stomach samples were collected in conjunction with the NEAMAP survey on September 30th and October 2nd, 2009 (http://www.neamap.net/). Each pie chart represents the diet composition of scup at one study site, with proportions derived from prey abundance measurements.

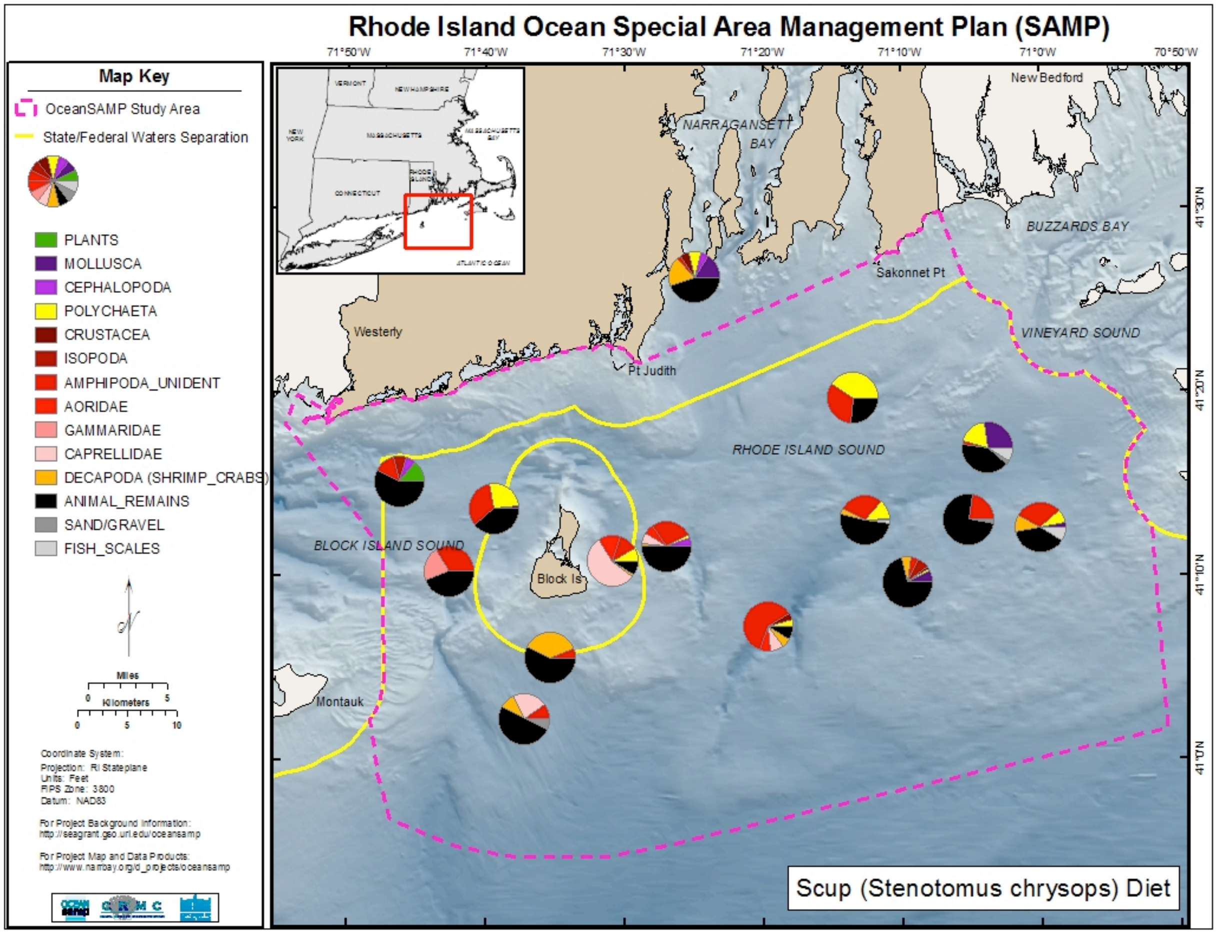


Figure 7. Site-specific summer flounder (*Paralichthys dentatus*) diet composition in Rhode Island Sound and Block Island Sound. All stomach samples were collected in conjunction with the NEAMAP survey on September 30th and October 2nd, 2009 (http://www.neamap.net/). Each pie chart represents the diet composition of summer flounder at one study site, with proportions derived from prey abundance measurements.

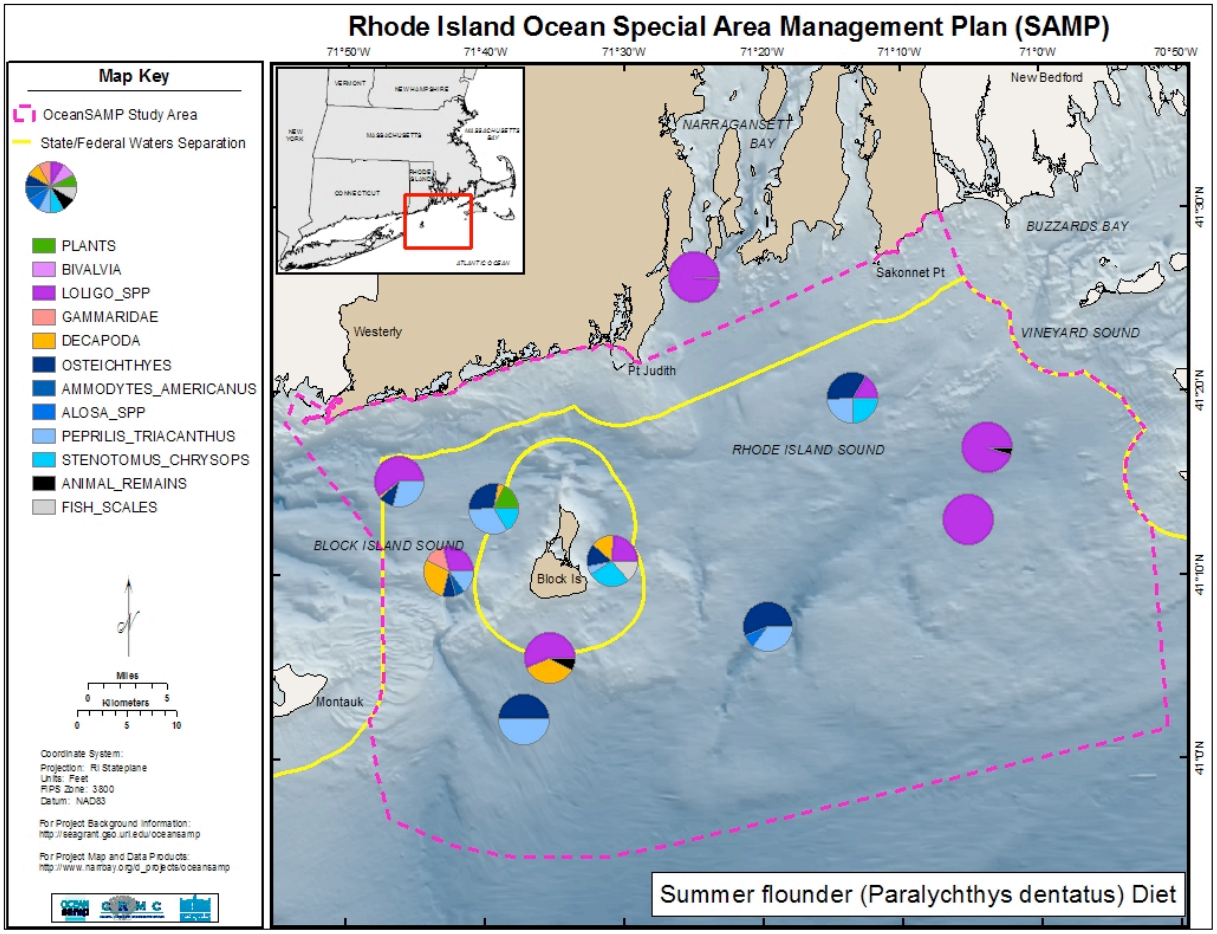


Figure 8. Site-specific winter flounder (*Pseudopleuronectes americanus*) diet composition in Rhode Island Sound and Block Island Sound. All stomach samples were collected in conjunction with the NEAMAP survey on September 30th and October 2nd, 2009 (http://www.neamap.net/). Each pie chart represents the diet composition of winter flounder at one study site, with proportions derived from prey abundance measurements.

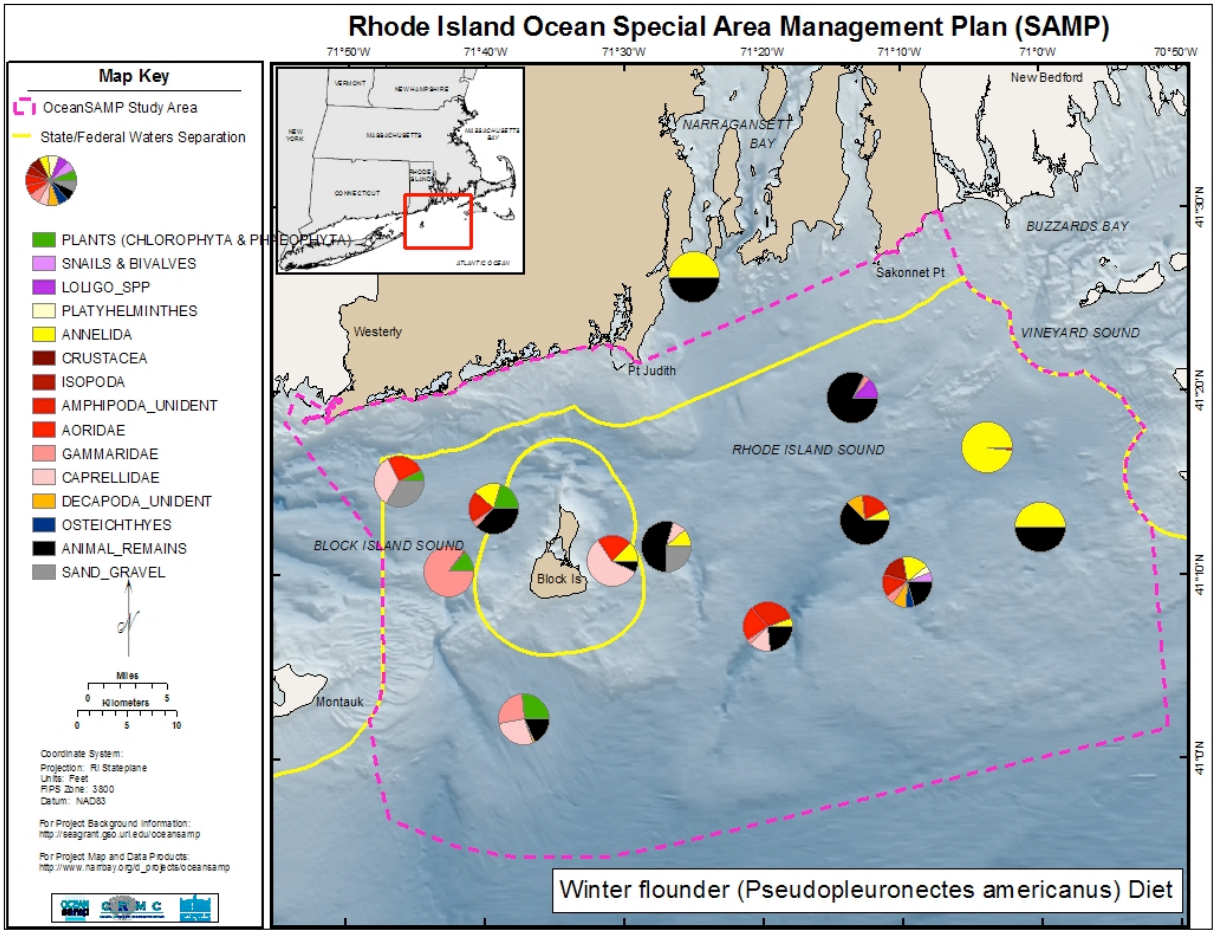


Figure 9. Site-specific spiny dogfish (*Squalus acanthius*) diet composition in Rhode Island Sound and Block Island Sound. All stomach samples were collected in conjunction with the NEAMAP survey on September 30th and October 2nd, 2009 (http://www.neamap.net/). Each pie chart represents the diet composition of spiny dogfish at one study site, with proportions derived from prey abundance measurements.

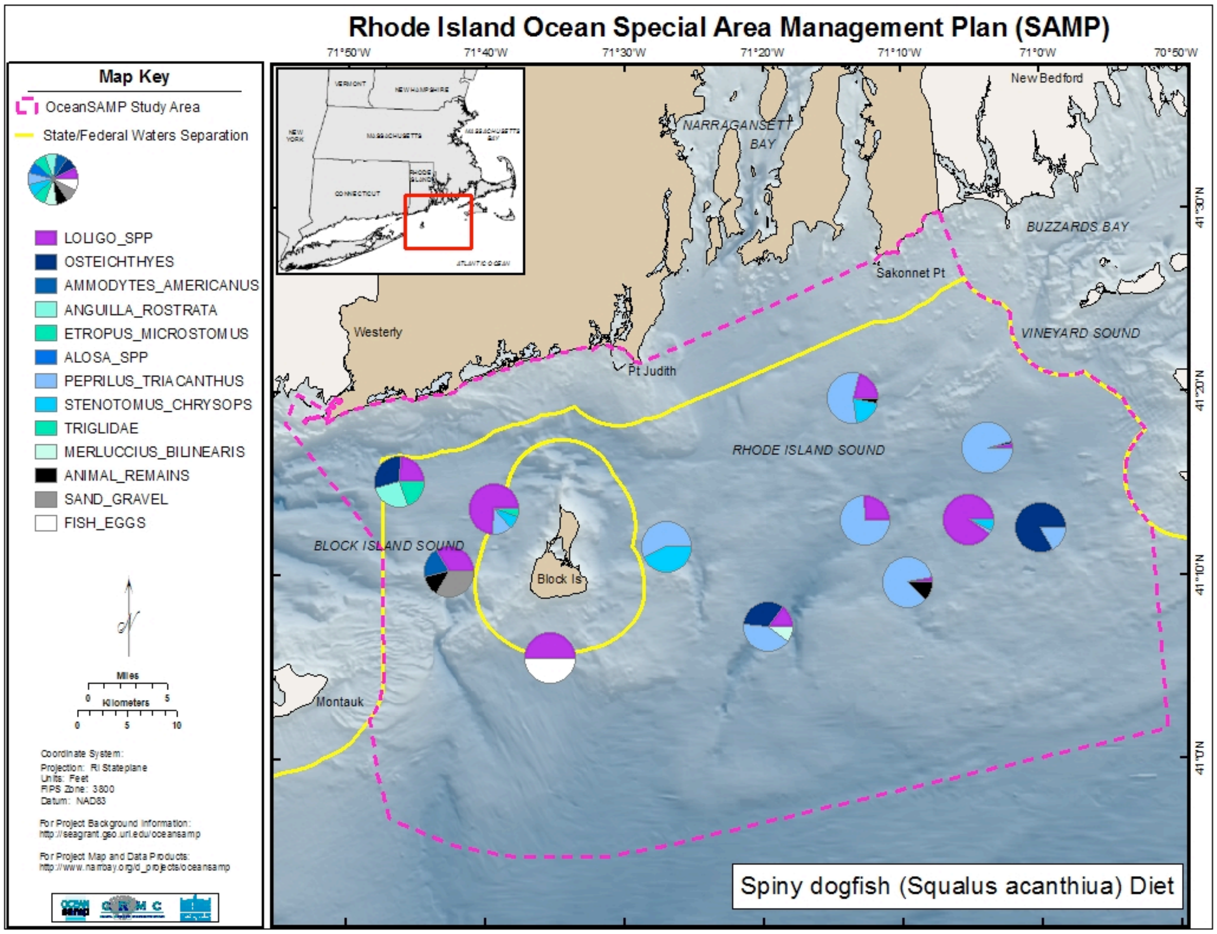


Figure 10. Site-specific little skate (*Leucoraja erinacea*) diet composition in Rhode Island Sound and Block Island Sound. All stomach samples were collected in conjunction with the NEAMAP survey on September 30th and October 2nd, 2009 (http://www.neamap.net/). Each pie chart represents the diet composition of little skate at one study site, with proportions derived from prey abundance measurements.

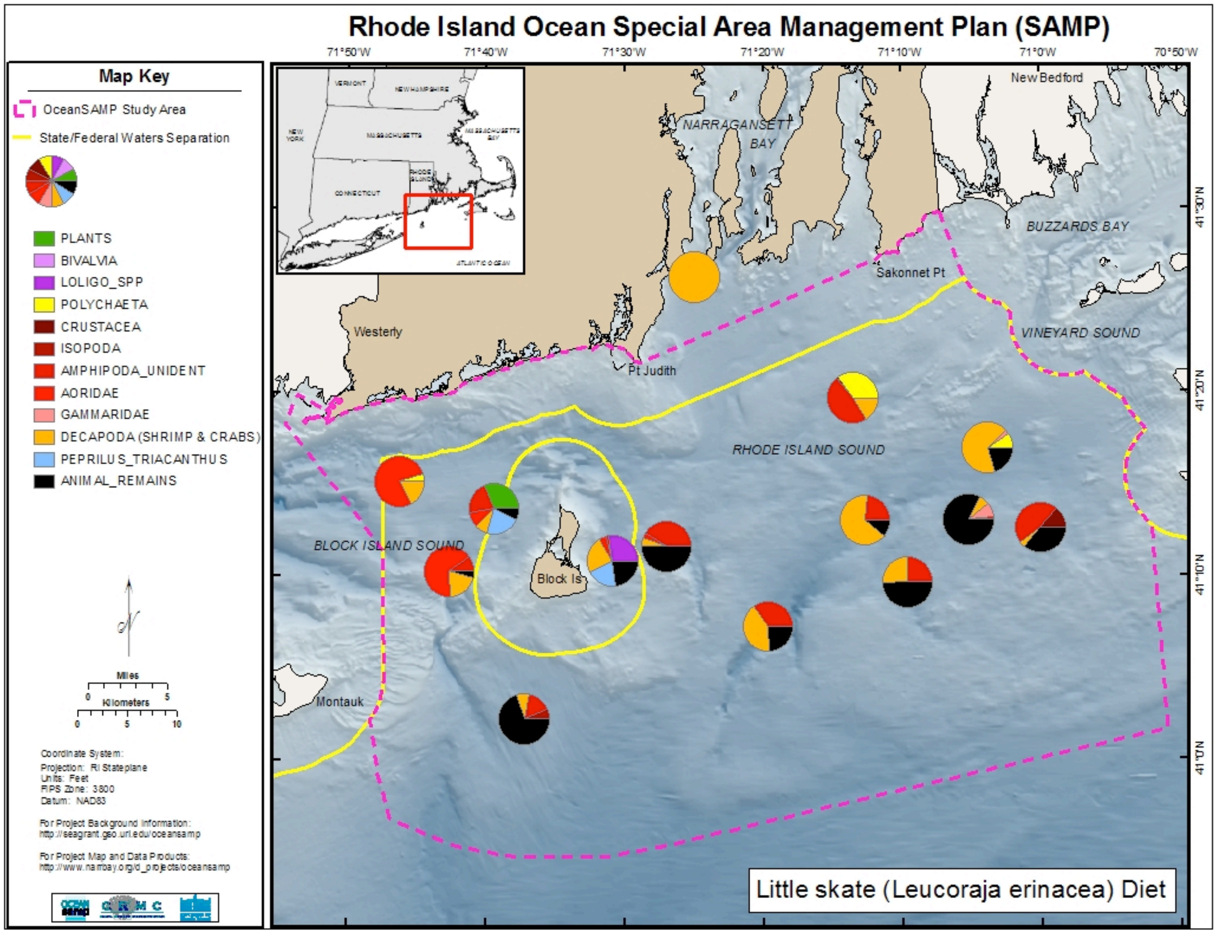


Figure 11. Site-specific winter skate (*Leucoraja ocellata*) diet composition in Rhode Island Sound and Block Island Sound. All stomach samples were collected in conjunction with the NEAMAP survey on September 30th and October 2nd, 2009 (http://www.neamap.net/). Each pie chart represents the diet composition of winter skate at one study site, with proportions derived from prey abundance measurements.

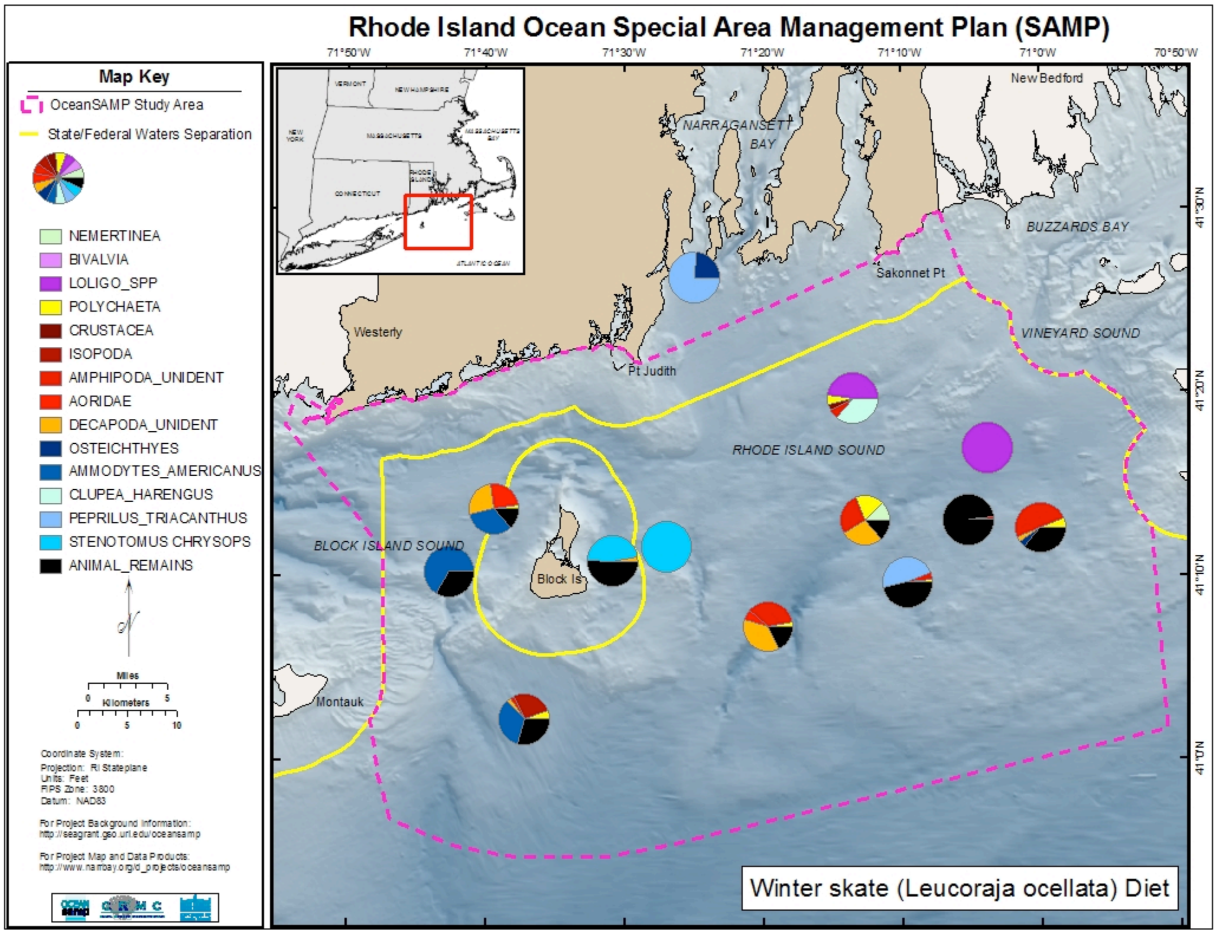


Figure 12. Ordination of the abundances of fish and invertebrate species sampled with bottom trawls in Block Island and Rhode Island Sound. This nonmetric multidimensional scaling plot (MDS) depicts the pattern in demersal fish and invertebrate species composition, with similar species compositions close together. Each letter represents one site (refer to Figure 1 for site locations). Similarity circles represent the CLUSTER groupings of sites with similar demersal fish community composition. Symbols represent LINKTREE groups of sites with similar benthic habitat parameters.

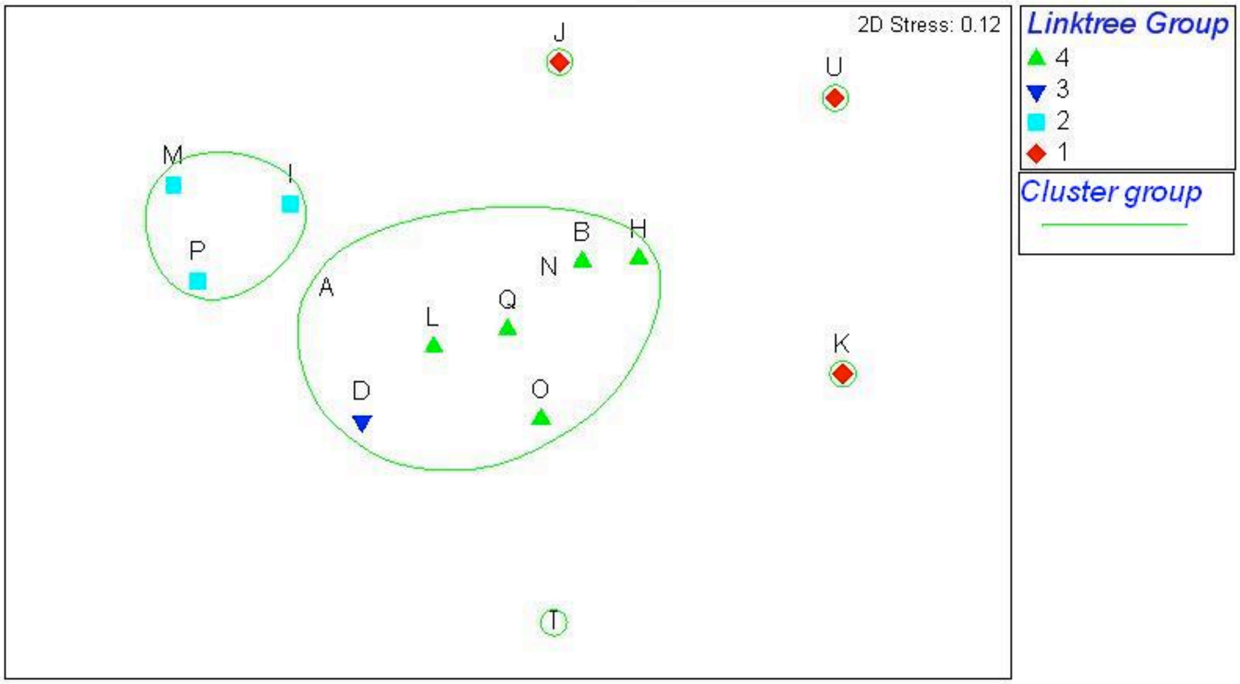


Figure 13. CLUSTER analysis groupings based on site-by-site similarity and dissimilarity of demersal fish community composition. Cluster groups are defined by the last solid black branching point, such that group 1 includes sites I,M and P (SIMPROF: π=1.021, p=0.335), Group 2 includes sites A,L,D,O,Q,N,B and H (SIMPROF: π =0.971, p=0.184) and sites K,U,T and J are each considered unique.

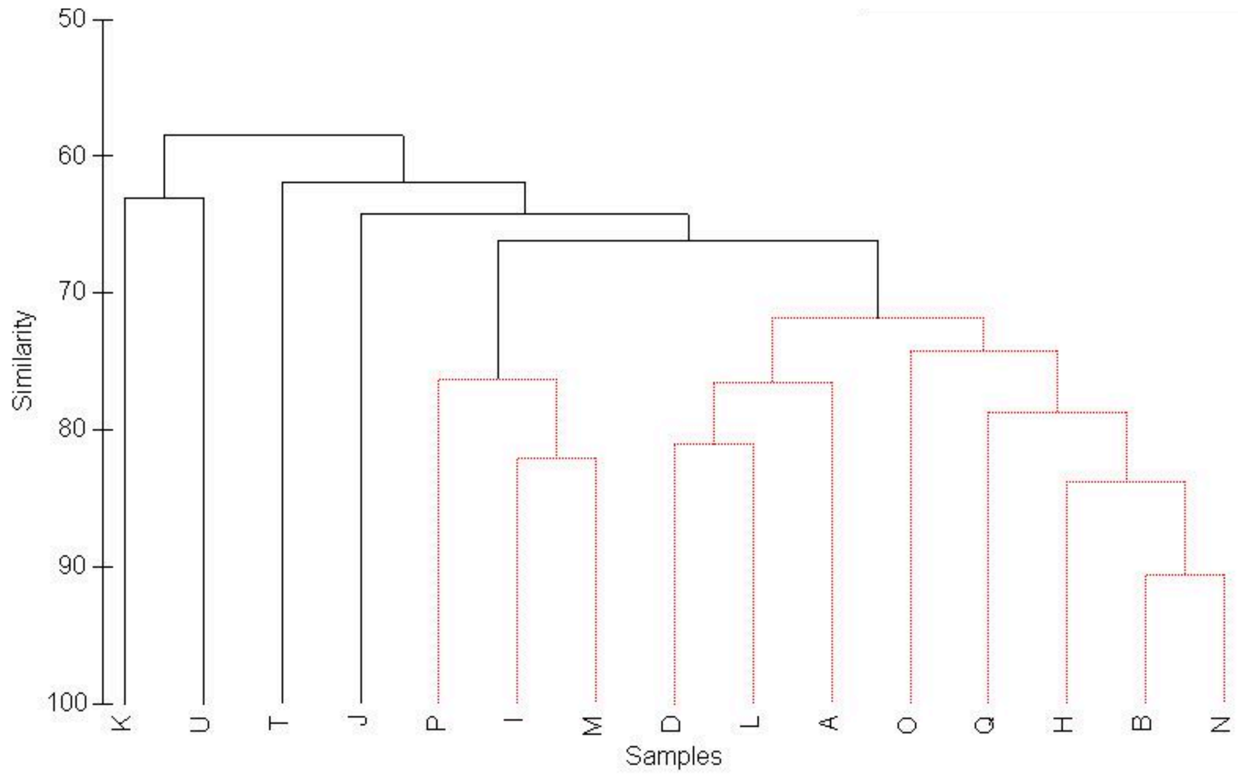


Figure 14. Comparison of benthic surface roughness between Block Island Sound and Rhode Island Sound. Mean benthic surface roughness data was calculated for each site in ArcMap. See Appendix I for more information.

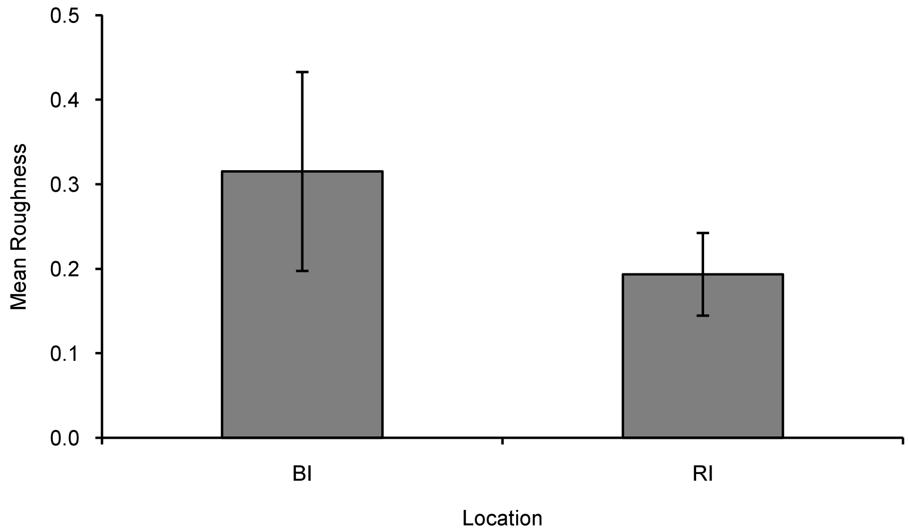


Figure 15. Ordination of benthic habitat structure derived from side-scan backscatter, bathymetry, rugosity and benthic surface roughness of Block Island and Rhode Island Sound. This nonmetric multidimensional scaling plot (MDS) depicts the pattern in benthic habitat structure, with similar benthic habitat structures close together. Each letter represents one site (refer to Figure 1 for site locations). Symbols represent LINKTREE groups of sites with similar benthic habitat parameters. Similarity circles represent the CLUSTER groupings of sites with similar demersal fish community composition.

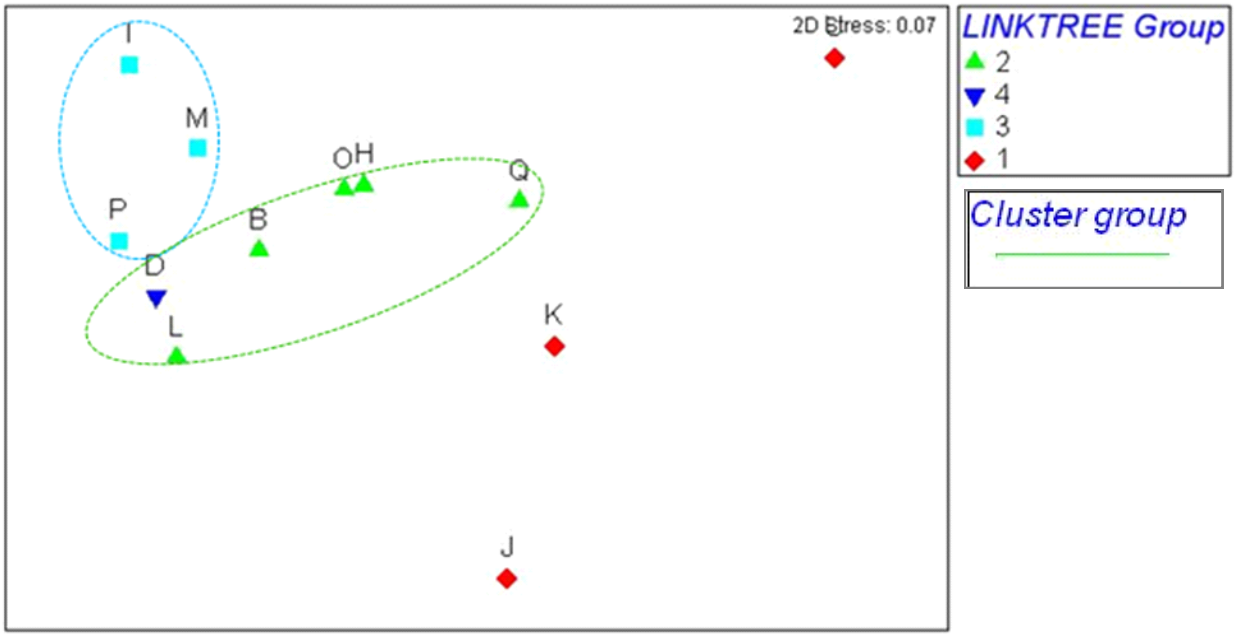


Figure 16. Comparison of total fish abundance, biomass, diversity, evenness and mean fish length between NEAMAP depth strata. The depth stratum were defined as follows: Strata 1: 20-40ft, Strata 2 : 40- 60ft, Strata 3: 60- 90ft, Strata 4 : 90-120ft, Strata 5: >120ft.

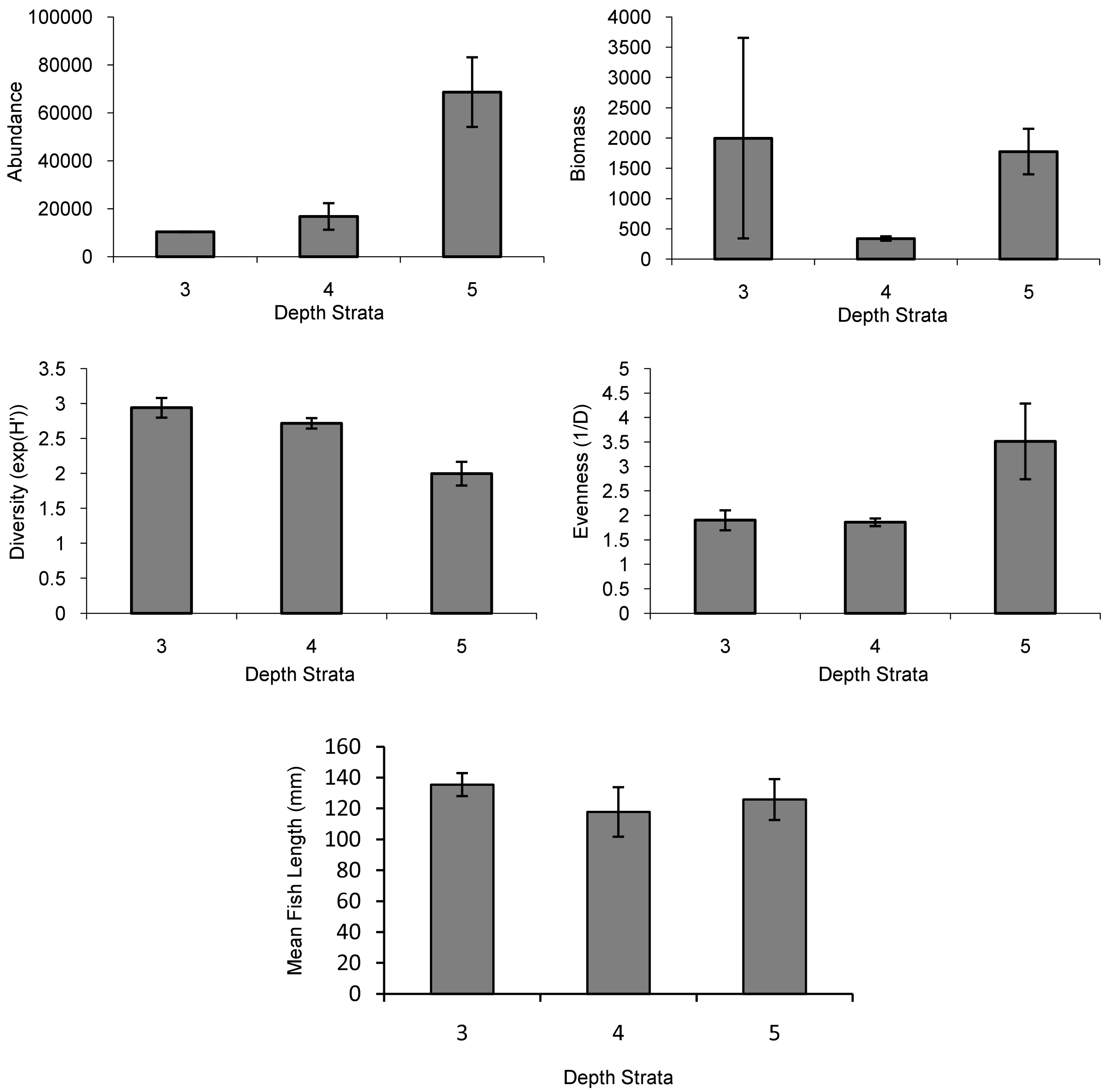


Figure 17. Univariate regressions between tow depth and fish abundance, biomass, diversity , evenness and mean fish length. Regression statistics are given in the upper right corner of each graph.

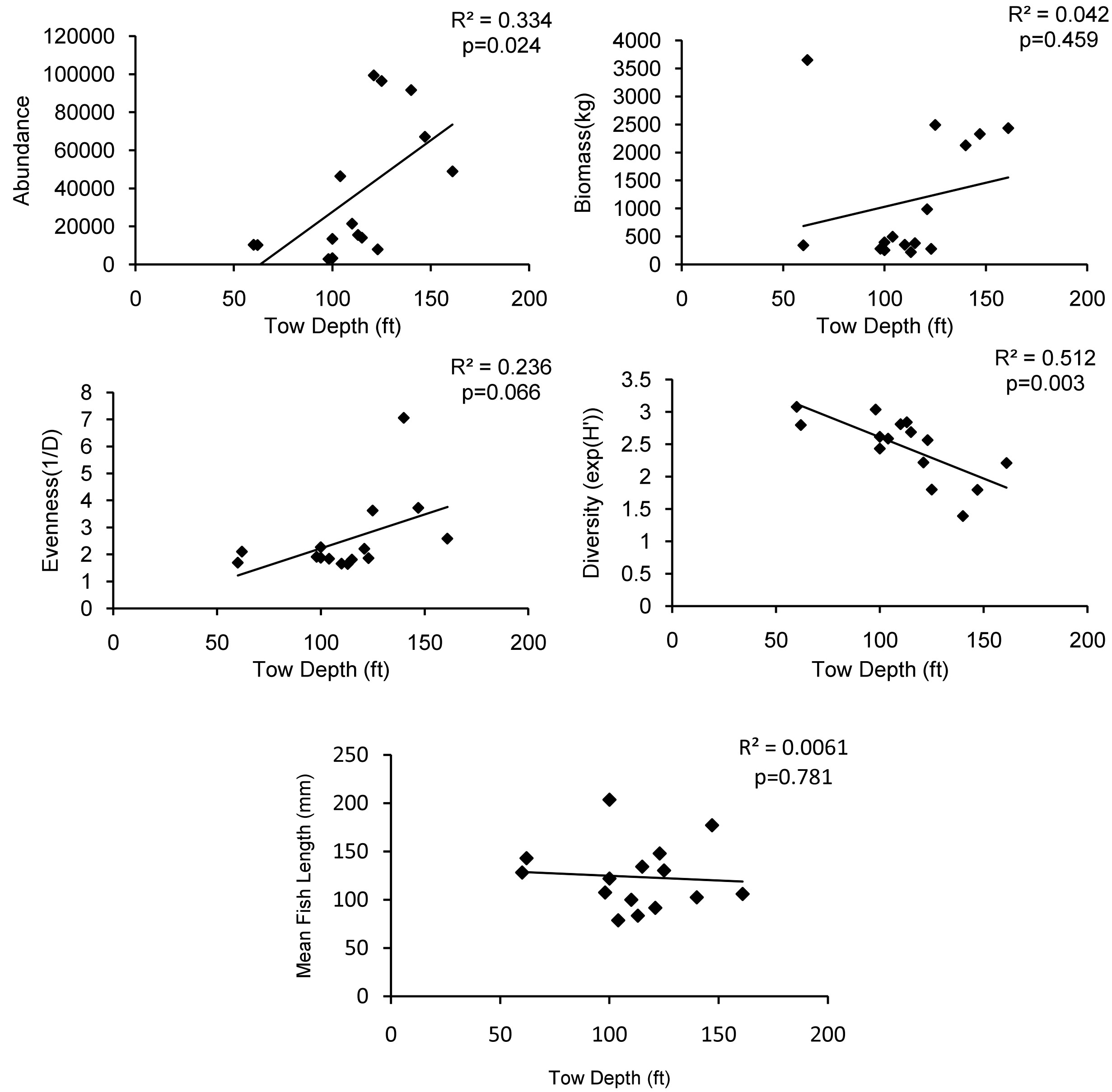


Figure 18. Multidimensional scaling plot (MDS) depicting the pattern in demersal fish and invertebrate species composition in Rhode Island Sound and Block Island Sound. Each point represents one sampling site. Green triangles represent sites in Rhode Island Sound (east of the shipping lane). Inverted blue triangles represent sites in Block 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).

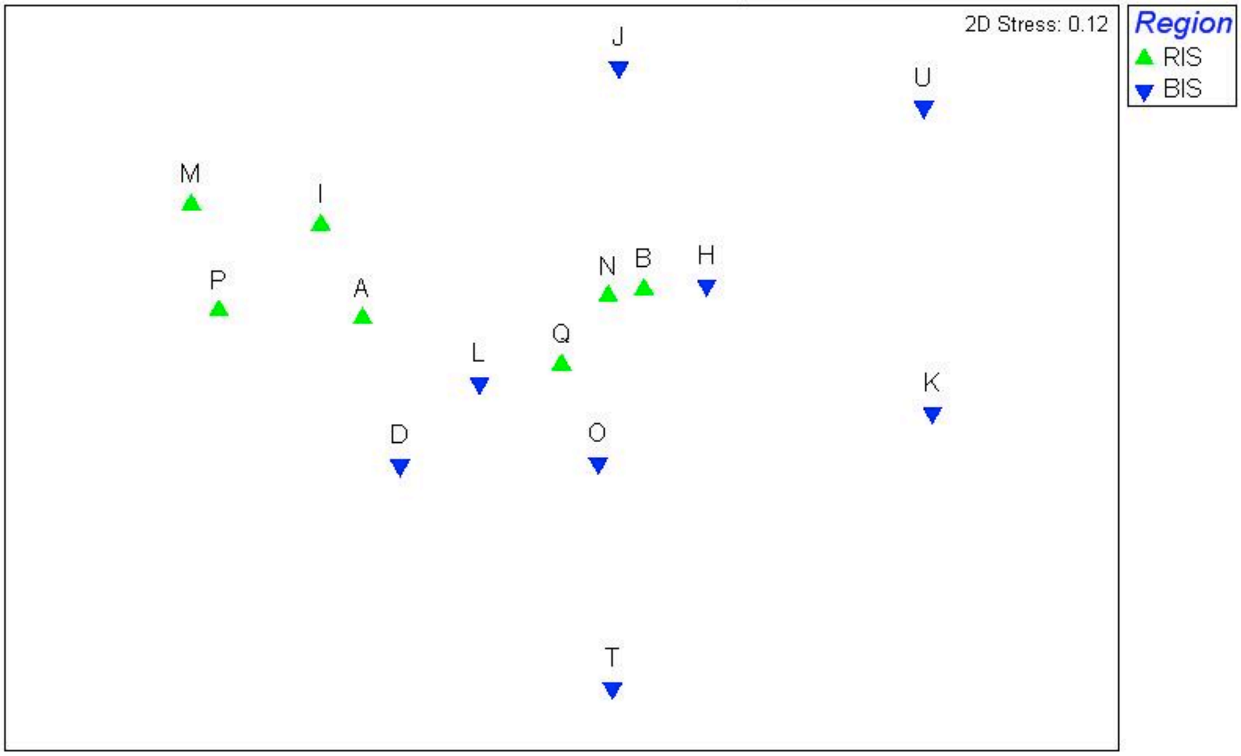


Figure 19. Multidimensional scaling plot (MDS) depicting the pattern in demersal fish and invertebrate species composition in Rhode Island Sound and Block Island Sound. Each point represents one site. Green triangles represent sites in depth stratum 5 (>120 ft), inverted blue triangles represent sites 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).

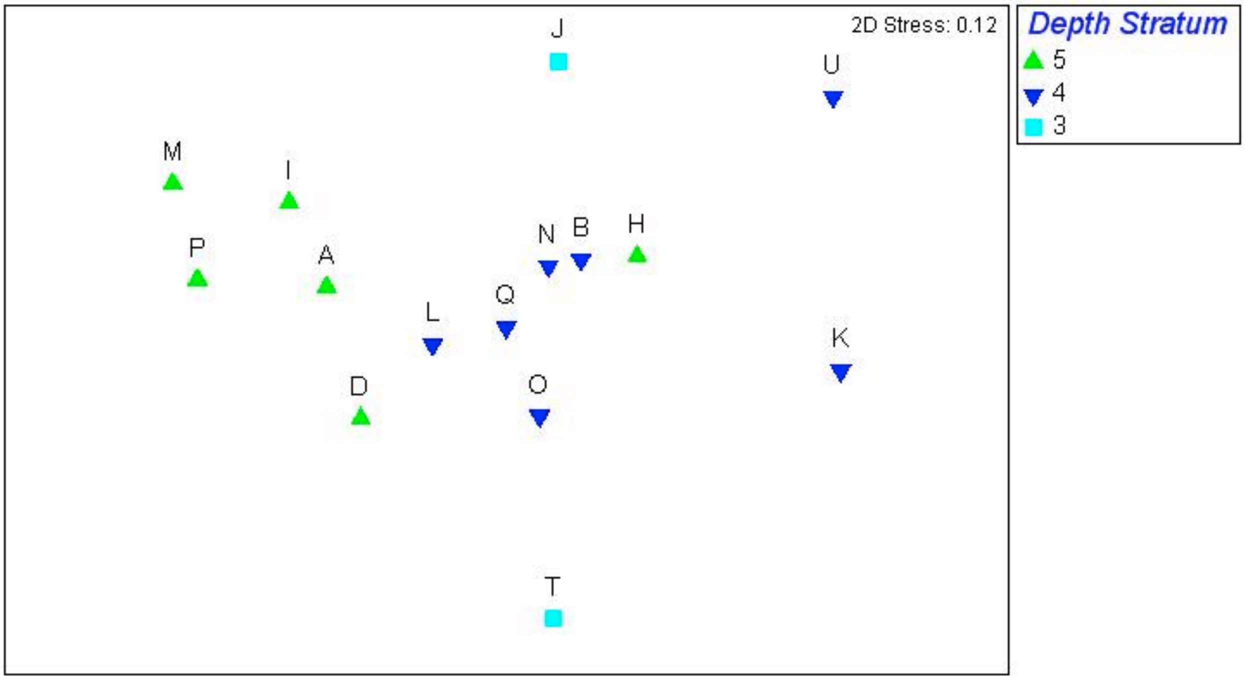
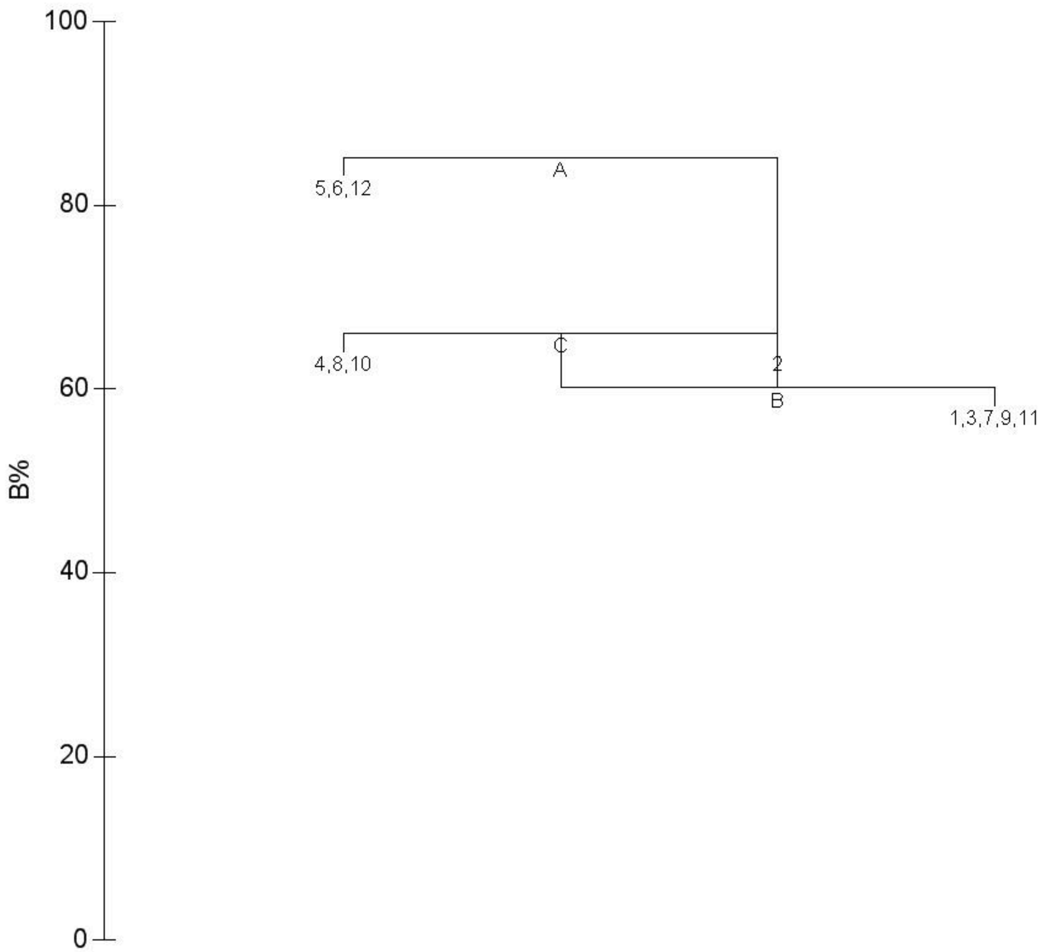


Figure 20. LINKTREE output based on site-by-site similarity and dissimilarity of benthic habitat variables. The linkage tree identified 4 groups based on the quantitative threshold of one of the benthic habitat parameters. Group 1 included sites J, K and U, indicated by 5,6 and12 on the linkage tree. Group 2 included sites I, M and P, indicated by 4,8 and 10 on the linkage tree. Group 3 included site D only, indicated by 2 on the linkage tree. Group 4 included sites B,H,L,O and Q, indicated by 1,3,7,9 and 11 on the linkage tree. The threshold for each split is listed below.



Linktree Thresholds		
Split		
A	Mean depth	< 31.7 (>26.2)
B	Mean depth	>42.2 (<45.3)
C	Standard deviation of benthic surface roughness	<0.023 (>0.010)
C	Rugosity	<1.003 (>1.001)

Tables

Table 1. 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 demersal fish assemblage within Block Island Sound and Rhode Island Sound (BVSTEP: rho=0.953, p=0.01).

Common Name	Scientific Name	Abundance	Biomass
Alewife*	*Alosa pseudoharengus*	183.7	11.4
American eel	*Anguilla rostrata*	1.0	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 arctifrons*	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 2. Depth strata, tow depth and region of all 15 sampling sites in Rhode Island and Block Island Sounds. Depth strata 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).

Station	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 3. Benthic habitat parameters calculated from side-scan, bathymetry and roughness data. The rugosity of each transect was calculated as the ratio of surface area to planar area, with rugosity values near 1 representing flat, smooth terrain and higher values reflecting increasing rugosity. 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. Variables marked with a double asterisk (**) resulted in the highest rank correlation between the fish community and the benthic habitat parameters (BIOENV: rho=0.495, p=0.118).

Source	Resolution	Variable	B	D	H	I	J	K	L	M	O	P	Q	U
Side-scan (Backscatter)	2m	Min*	15	6	74	16	33	64	20	36	2	32	56	17
		Max*	226	205	232	255	204	221	69	160	160	87	255	166
		Mean*	116.97	111.27	152.17	77.56	115.51	142.59	42.713	97.279	34.45	49.234	95.992	71.017
		Standard Deviation*	27.937	21.791	17.475	14.152	27.612	21.928	5.575	17.186	18.91	6.415	22.814	22.685
	N/A	Number of Bottom Types**	2	1	3	2	3	3	1	2	3	1	3	4
		Number of Benthic Interfaces**	2	0	4	1	2	9	0	1	2	0	9	3
Bathymetry (Depth)	2m	Min												
		Max												
		Mean**	38.105	42.299	38.95	52.424	28.943	31.606	33.989	46.033	36.126	39.295	34.408	26.224
		Standard Deviation*	0.414	0.557	0.628	0.396	3.841	0.706	0.416	0.441	1.22	1.793	0.527	3.338
		Rugosity*	1.0020	1.0195	1.0034	1.0072	1.0073	1.0070	1.0011	1.0041	1.0010	1.0126	1.0043	1.0161
	10m	Rugosity**	1.0001	1.0005	1.0002	1.0003	1.0003	1.0002	1.0000	1.0001	1.0001	1.0001	1.0003	1.0013
Roughness (Damon, 2010)	100m	Min												
		Max												
		Range												
		Mean*	0.0845	0.2168	0.0901	0.4186	1.0428	0.1468	0.0718	0.1142	0.1551	0.0474	0.2212	0.5694
		Standard Deviation**	0.0218	0.0653	0.0088	0.0231	0.1945	0.1001	0.0369	0.0102	0.0168	0.0197	0.0267	0.0403

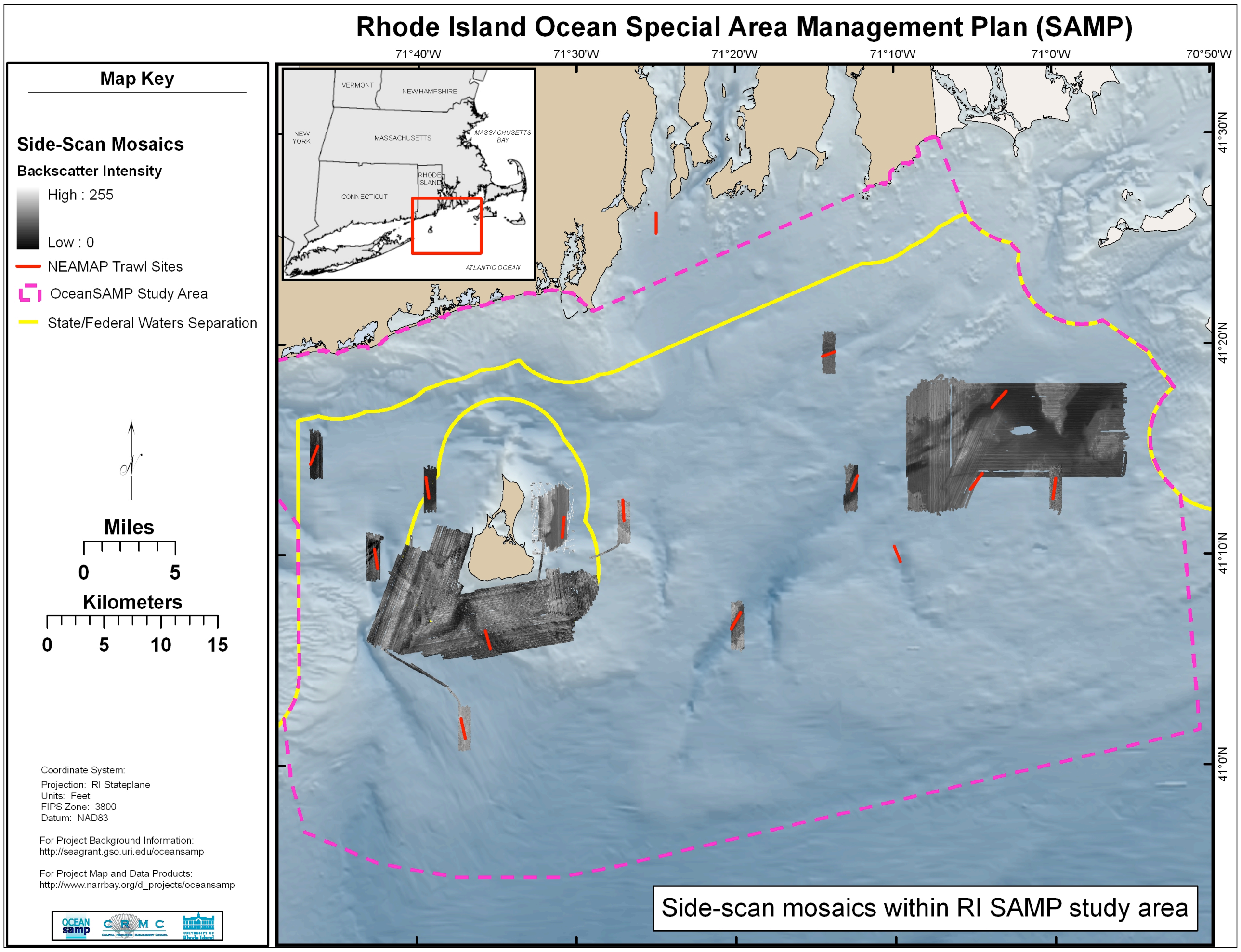
Table 4 . Total abundance, biomass, diversity, evenness and mean fish length of the fish community at 15 sites within Rhode Island Sound and Block Island Sound as measured by bottom trawls conducted in conjunction with the NEAMAP survey on September 30th and October 2nd, 2009. Hill's N1 (exp(H')) and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

Site	Abundance	Biomass (kg)	Diversity	Evenness	Mean Fish Length (mm)
A	91676	2127.97	1.390	7.062	102.33
B	13485	254.33	2.616	1.877	121.81
D	99417	985.73	2.219	2.210	91.44
H	7953	277.68	2.565	1.862	147.76
I	48949	2435.33	2.21	2.586	105.85
J	10232	3652.39	2.798	2.104	142.88
K	2857	280.10	3.038	1.912	107.35
L	46383	494.45	2.588	1.840	78.51
M	67133	2330.53	1.795	3.726	177.02
N	14078	379.55	2.689	1.810	134.09
O	15536	218.99	2.841	1.645	83.32
P	96436	2492.35	1.800	3.627	130.16
Q	21450	351.26	2.811	1.658	99.79
T	10359	341.23	3.079	1.695	128.04
U	3315	394.35	2.433	2.267	203.47

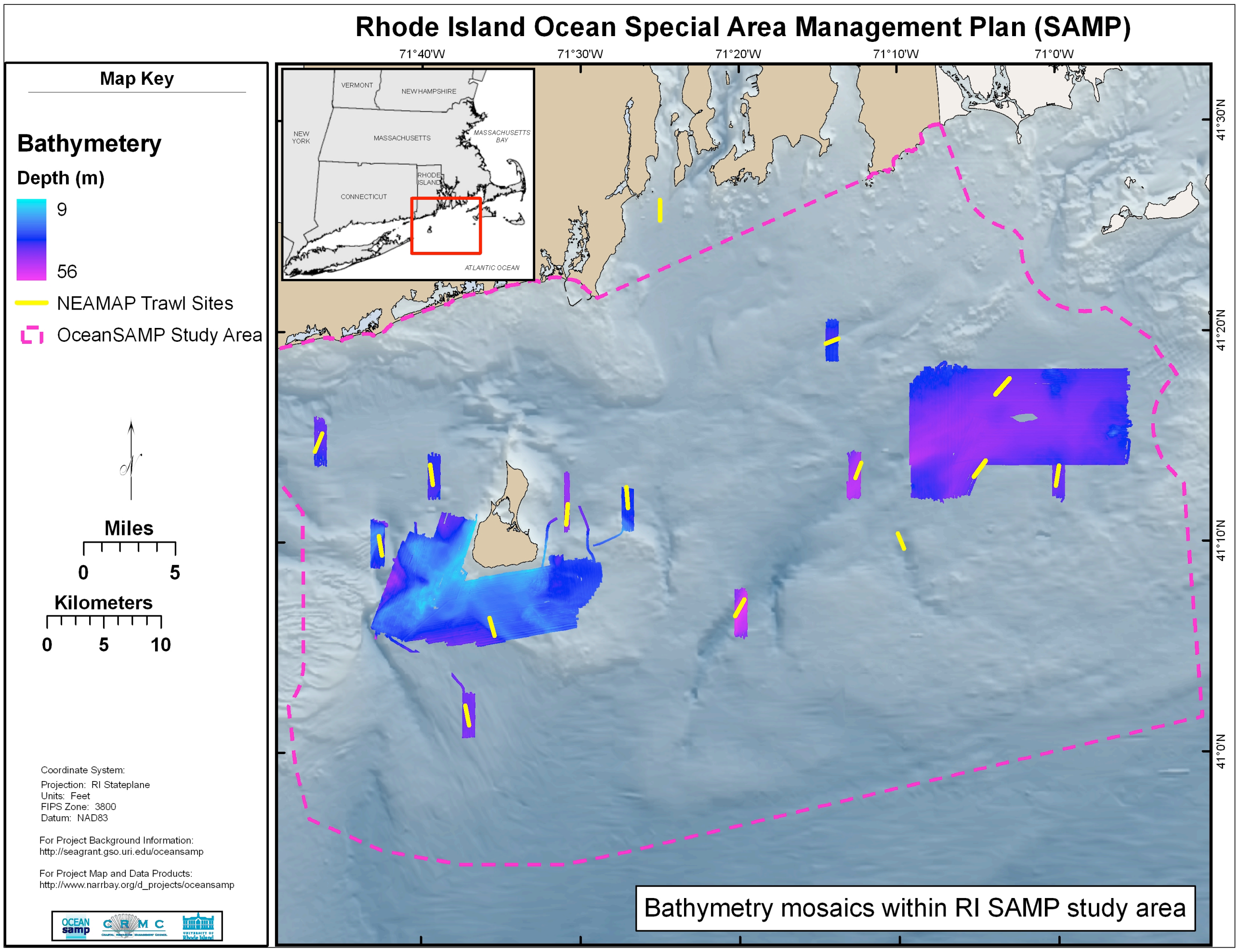
Table 5. Results of univariate regressions between acoustically-derived benthic habitat parameters and fish community metrics. Significant relationships are marked with an asterisk (p<0.05).

X variable	Y variable	R^2	p	Relationship	
# Bottom Types	Abundance	0.711	<0.001	Negative	*
# Bottom Types	Biomass	0.057	0.453	Negative	
# Bottom Types	Diversity	0.308	0.061	Positive	
# Bottom Types	Evenness	0.161	0.197	Negative	
# Borders	Abundance	0.359	0.039	Negative	*
# Borders	Biomass	0.184	0.165	Positive	
# Borders	Diversity	0.417	0.023	Positive	*
# Borders	Evenness	0.206	0.138	Negative	
STD Roughness	Abundance	0.055	0.463	Negative	
STD Roughness	Biomass	0.207	0.137	Positive	
STD Roughness	Diversity	0.171	0.182	Positive	
STD Roughness	Evenness	0.039	0.538	Negative	
Rugosity	Abundance	0.039	0.533	Negative	
Rugosity	Biomass	0.012	0.737	Negative	
Rugosity	Diversity	0.0007	0.935	None	
Rugosity	Evenness	0.003	0.872	None	
Mean Depth	Abundance	0.337	0.048	Positive	*
Mean Depth	Biomass	0.081	0.371	Positive	
Mean Depth	Diversity	0.371	0.036	Negative	*
Mean Depth	Evenness	0.216	0.128	Positive	

Appendix I. Side-scan backscatter of acoustically surveyed sites. 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. The RI Ocean SAMP area is outlined by a dashed pink line. Bottom trawl tracklines are represented by solid red lines.



Appendix II. Bathymetry of acoustically surveyed sites. Light blue represents shallower water and dark pink represents deeper water. The RI Ocean SAMP area is outlined by a dashed pink line. Bottom trawl tracklines are represented by solid yellow lines.



Appendix III. 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 pink line. The solid black lines represent the boundaries of acoustically surveyed sites. Bottom trawl tracklines are represented by solid yellow lines.