CHAPTER

3

Benthic Habitats

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Introduction

Benthic organisms are those that inhabit the ocean floor; from the Greek word benthos, meaning "depths of the sea." Living in soft substrates and feeding on plankton and organic debris, individual species are adapted to variations in light, depth, sediment size, temperature, and salinity. They are so well adapted to their environment that 15 entire phyla are exclusively marine (echinoderms, comb jellies, lampshells etc.) with no terrestrial counterparts (Norse 1993). Moreover, unlike the terrestrial world where three quarters of all diversity is contained in a single phylum (arthropods), the ocean contains almost the entire range of earth's body plans.

The seafloor habitats of the Northwest Atlantic reflect this immense diversity, containing over 2000 species in 13 phyla including:

- 662 species of arthropods (crabs, lobsters, shrimp, barnacles)
- 650 species of mollusks (clams, scallops, squid, limpets, sea slugs, snails)
- 547 species of annelids (sea worms)
- 195 species of echinoderms (sea stars, sea urchins, sea cucumbers, sand dollars)
- 141 species of bryozoans (crusts, bryozoans)
- 58 species of cnidarians (corals, anemones, jellyfish)
- 29 species of sipunculas (peanut worms)
- 21 species of chordates (sea squirts)
- 6 species of poriferans (sponges)
- 3 species of chaetognathans (arrow worms)
- 2 species of brachiopods (lamp shells)
- 1 species of nemerteans (ribbon worms)
- 1 species of ctenophores (comb jellies)

The distributions and life histories of benthic organisms are tied to their physical environment. Filter feeders, like sponges and mussels, strain suspended matter directly from the water column, and tend to dominate on shallow sandy bottoms. Deposit feeders, like terebellid worms, sift soil for detritus and may dominate in fine-grained mud. Mobile species such as sea stars, crabs, and snails scavenge in the habitats of their prey. It is these "habitats" that we aimed to identify, characterize, and map.

This chapter represents an initial effort to define and map marine benthic habitats using information on organism distributions combined with interpolated data on bathymetry, sediment grain size, and seafloor topography. The goal was to produce a regional map of broadly-defined, but distinct, seafloor habitats using a consistent and repeatable methodology. This work is ongoing and updated reports will be produced as the research matures. A team of scientists familiar with benthic classification served as a peer review team for this project and their comments have greatly improved this work. Comments on the methods and preliminary results were collected via meetings, individual and group phone calls, and in written edits. *Please note that critical steps of accuracy assessment, cross-validation using independent datasets, comparisons with demersal fish habitat, and final expert peer review are ongoing*

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Definition of Target Habitats

The goal of this work was to identify all of the benthic habitat types in the Northwest Atlantic and map their extent. We defined a benthic habitat as a group of organisms repeatedly found together within a specific environmental setting. For example, silt flats in shallow water typified by a specific suite of amphipods, clams, whelks and snails is one habitat, while steep canyons in deep water inhabited by hard corals is another. Conservation of these habitats is necessary to protect the full diversity of species that inhabit the seafloor, and to maintain the ecosystem functions of benthic communities.

Methods

To design a conservation plan for benthic diversity in the Northwest Atlantic, it is essential to have some understanding of the extent and location of various benthic habitats (e.g. a map). Fortunately, the challenge of mapping seafloor habitats has produced an extensive body of research (see Kostylev et al. 2001; Green et al. 2005; Auster 2006; World Wildlife Fund 2006; Todd and Greene 2008). In addition, comprehensive seafloor classification schemes have been proposed by many authors (see Dethier 1992; Brown 1993, European Environmental Agency 1999; Greene et al. 1999; Allee et al. 2000; Brown 2002; Conner et al 2004; Davies et al. 2004; Greene et al. 2005; Madden et al. 2009; Valentine et al. 2005; Kutcher 2006; and see reviews in National Estuarine Research Reserve System 2000 and Lund and Wilbur 2007).

Initially, we reviewed the literature on seafloor classification, and examined the variety of approaches already utilized in order to develop our methodology (Table 3-1). Many of the existing schemes base their classifications on physical factors such as bathymetry, sediment grain size, sediment texture, salinity, bottom temperature, and topographic features. This is logical as there is ample evidence that benthic distribution patterns are associated with many of these variables. For example, temperature is correlated with the community composition of benthic macroinvertebrates (Theroux and Wigley 1998); substrate type is correlated with community composition and abundance of both the invertebrates and demersal fish (Auster et al. 2001; Stevenson et al. 2004); habitat complexity is correlated with species composition, diversity, and richness (Etter and Grassle 1992; Kostylev et al. 2001; Serrano and Preciado 2007, reviews in Levin et al. 2001); and depth is correlated with abundance, richness, and community composition (Stevenson et al. 2004).

The approach presented here builds on existing schemes both explicitly and implicitly, and results can be readily compared to them. However, the goal of this assessment was to produce a map of broadly-defined benthic habitats in the Northwest Atlantic using readily available information. Therefore, a new classification system for benthic systems in general is not proposed here.

Table 3-1. A review of literature on seafloor classification and approaches utilized to develop our methodology.

Physical/Biological Variables	Ecological associations	Species	Data type/Comments	References
Temperature: annual temperature range	community composition	benthic macroinvertebrates		Theroux and Wigley 1998
Substrate type	species abundance	demersal fish and	benthic grabs; correlational analyses done separately for each group	Stevenson et al. 2004
	community composition	benthic macroinvertebrates		
	abundance	juvenile Atlantic cod	benthic grabs/submersible transects	Lough et al. 1989
	community composition	demersal fish	bottom trawls	Auster et al. 2001
		benthic macroinvertebrates	benthic grabs	Wigley and Theroux 1981
Habitat complexity	species abundance	demersal fish	video transects	Anderson and Yoklavich 2007
	community composition			
	species diversity	benthic macroinvertebrates	benthic grabs/photographs	Kostylev et al. 2001
			quadrat surveys; habitat complexity at fine scale – sediment heterogeneity	Serrano and Preciado 2007
			literature review	Levin et al. 2001
			benthic grabs	Etter and Grassle 1992
	juvenile survival rate	Atlantic cod	laboratory experiments	Lindholm et al. 1999
	species richness	demersal fish	visual surveys	Charton and Perez Ruzafa 1998
	total abundance			
Depth	organism density and community composition	benthic macroinvertebrates and demersal fish	benthic grabs; correlational analyses done separately for each group	Stevenson et al. 2004
Combination				
Depth + temperature	species assemblages	demersal fish	bottom trawl	Mahon et al. 1998
Depth + temperature + substrate (sediment) type	species abundance	Atlantic Cod; winter flounder; yellowtail flounder	bottom trawl; single species assessments	DeLong and Collie 2004
Depth (fixed) + substrate + bottom temperature + bottom salinity	benthic 'seascapes'	abiotic; no statistical correlational analyses performed with trawl data	abiotic; to 200 m only; Gulf of Maine, Georges Bank, Scotian shelf; depth was fixed at certain intervals	WWF/CLF 2006

Table 3-1 (continued). A review of literature on seafloor classification and approaches utilized to develop our methodology.

<table>
<tr><th>Physical/Biological Variables</th><th>Ecological associations</th><th>Species</th><th>Data type/Comments</th><th>References</th></tr>
<tr><td colspan="5">Principal Component Analysis</td></tr>
<tr><td>PC1: SST, thermal gradients, stratification, chlorophyll</td><td rowspan="6">species abundance and richness</td><td rowspan="6">pelagic (nekton) and benthic</td><td rowspan="6">bottom trawl; research survey trawls; bongo nets (for nekton); principal components combine physical and biological variables</td><td rowspan="6">Fogarty and Keith 2007</td></tr>
<tr><td>PC2: depth, primary production, chlorophyll, zooplankton, biomass, benthic biomass</td></tr>
<tr><td>PC3: substrate type, nekton species richness</td></tr>
<tr><td>PC4: nekton biomass</td></tr>
<tr><td>PC5: benthic biomass</td></tr>
<tr><td>PC6: nekton species richnes</td></tr>
</table>

Biological Factors: Benthic Organisms

The map of benthic habitats presented here is based on the distribution and abundance of benthic organisms in the Northwest Atlantic. The knowledge of these species and their distributions comes largely from seafloor grab samples described below. In the analysis of this data, groups of species with shared distribution patterns were identified, then thresholds in the physical factors were identified that correlated with those patterns. Specifically, three basic steps were followed: 1) quantitative analysis of the grab samples to identify distinct and reoccurring assemblages of benthic organisms, 2) recursive partitioning to relate the species assemblages to physical factors (bathymetry, sediment types, and seabed topographic forms), and 3) mapping the habitats based on the statistical relationships between the organism groups and the distribution of the physical factors. Although organism distributions were used to identify meaningful thresholds and cutoffs in the physical variables, the final habitat maps are composed solely of combinations of enduring physical factors and are thus closely related to the maps and classification schemes proposed by others.

This study was made possible by access to over forty years of benthic sampling data by the National Marine Fisheries Service's (NMFS) Northeast Fisheries Science Center (NEFSC). The NEFSC conducted a quantitative survey of macrobenthic invertebrate fauna from the mid 1950s to the early 1990s across the region (Figure 3-1, Table 3-2). Each year, samples of the seafloor were systematically taken during 25+ individual cruises by five or more research vessels using benthic grab samplers designed to collect 0.1 to 0.6m² of benthic sediments. In total, over 22,000 samples were collected. Organisms collected in each sample were sorted and identified to species, genus, or family, and information on the sediment sizes, depth, and other associated features were recorded for each sample. A thorough discussion of the sampling methodology, gear types, history, and an analysis of the benthic dataset, including the distribution and ecology of the organisms, can be found in the publications of Wigley and Theroux (1981 and 1998). Recently, new video and remote sensing technologies have arisen to directly assess the seafloor and supplement the sample data (Kostylev et al. 2001). In future iterations of the assessment, we hope to integrate data collected using these new methods.

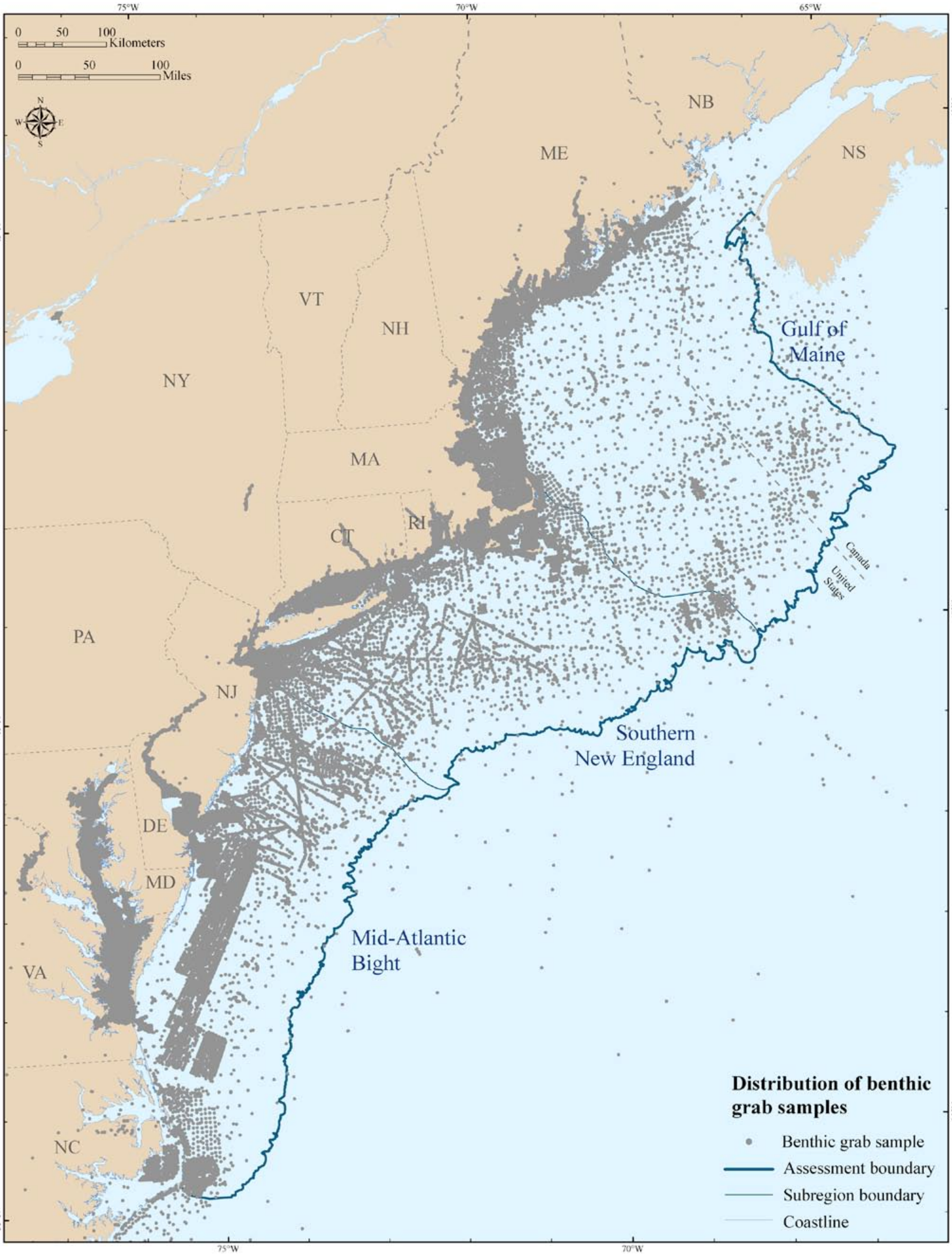


Figure 3-1. Distribution of the 11,132 benthic grab samples.

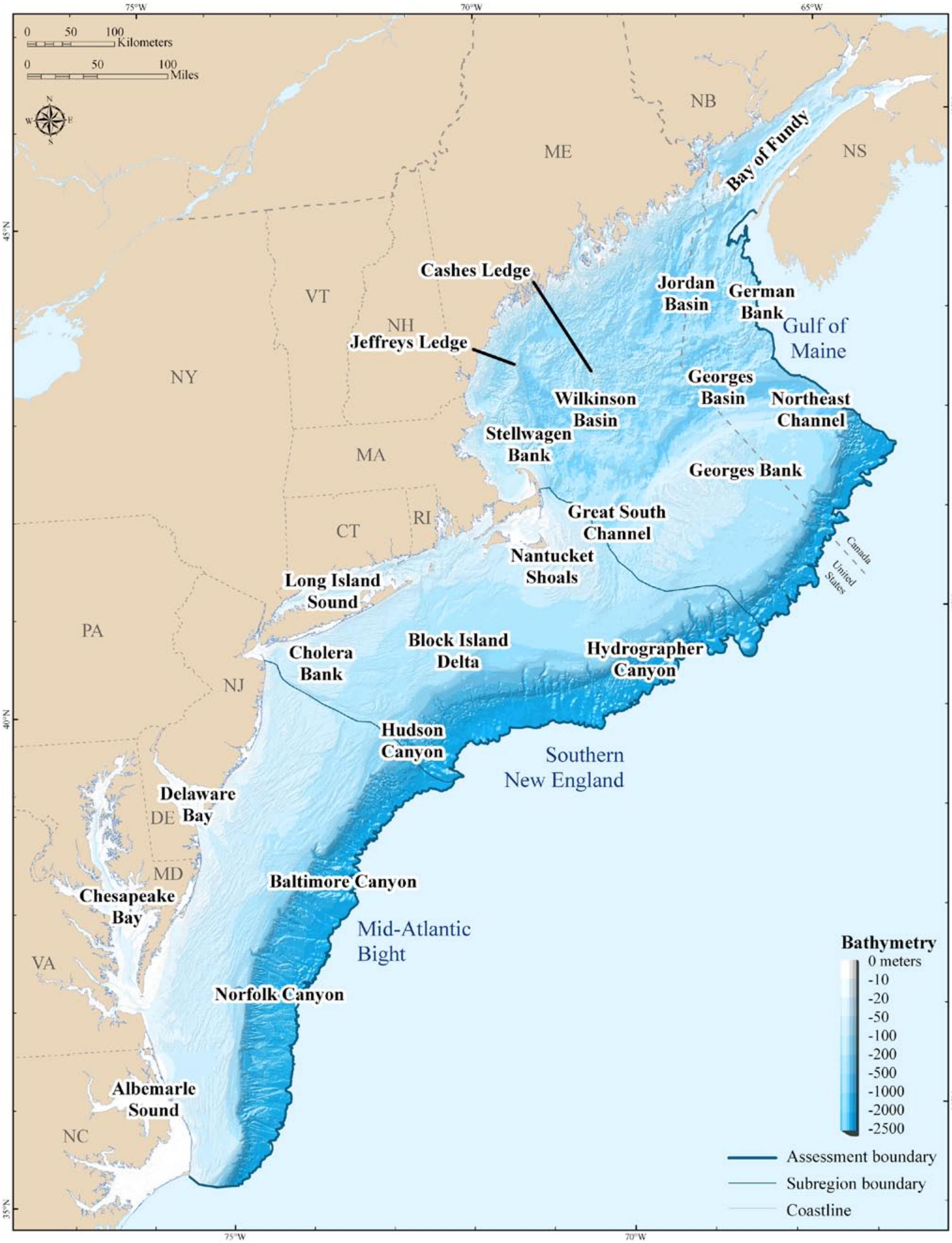


Figure 3-2. Geography of the region showing the three subregions.

Table 3-2. Distribution of the benthic grab samples by decade and subregion.

Decade	Gulf of Maine	Southern New England	Mid-Atlantic	Outside of region	Grand Total
Pre-1950	38	33	2	1	74
1950s	2,150	660	61	164	3,035
1960s	4,146	2,693	857	669	8,365
1970s	188	3,770	1,166	4	5,128
1980s	637	3,681	1,535	1	5,854
1990s			25		25
Total	7,159	10,837	3,646	839	22,481

Classification Methods

Classification analysis began with the entire 22,481 seafloor samples taken between 1881 and 1992. However, only about half of the samples contained information on the full composition or the sample identified to species, and it is that subset of 11,132 samples that is used in this analysis. Initially, two separate classifications were created - one based on genera and one based on species as a way of including more samples in the analysis. However, because the species level classification showed a stronger relationship with the physical factors, this level of taxonomy was used. Organisms in the samples that were identified only to family or order were omitted from the dataset, as were fish, plants, egg masses, and organic debris.

Separate classifications were created for each of the three subregions: the Gulf of Maine, Southern New England, and the Mid-Atlantic Bight (Figure 3-2). For each, samples with similar species composition and abundance were grouped together using hierarchical cluster analysis (PCORD, McCune and Grace 2002). This technique starts with pairwise contrasts of every sample combination then aggregates the pairs most similar in species composition into a cluster. Next, it repeats the pairwise contrasts, treating the clusters as if they were single samples, and joins the next most similar sample to the existing clusters. The process is repeated until all samples are assigned to one of the many clusters. For our analysis, the Sorenson similarity index and the flexible beta linkage technique with Beta set at 25 was used as the basis for measuring similarity (McCune and Grace 2002). After grouping the samples, indicator species analysis was used to identify those species that were faithful and exclusive to each organism group (Dufrene and Legrande 1997). Lastly, Monte Carlo tests of significance were run for each species relative to the organism groups to identify diagnostic species for each group using the criterion of a p-value less than or equal to 0.10 (90% probability). The number of sets of clusters (testing 10 to 40) was determined by seeing which amount gave the lowest average p-value. The test concluded that 20-22 organism groups for each subregion yielded the lowest p-value.

Physical Factors: Bathymetry, Substrate and Seabed Forms

To understand how the benthic invertebrate community distributions related to the distribution of physical factors, a spatially comprehensive data layer for each factor of interest was developed. Four aspects of seafloor structure were used: bathymetry, sediment grain size, topographic forms, and habitat complexity. These factors were chosen as they are both correlated with the distribution and abundance of benthic organisms (Table 3-1) and are relatively stable over time and space. Variables that fluctuate markedly over time were purposely avoided, such as temperature and salinity. Data on each physical factor were compiled from separate sources and the techniques used to create a comprehensive map are discussed below.

Bathymetry

A comprehensive bathymetry grid was created to characterize depths across the region, to uncover organisms' depth preferences, and to create seabed topographic forms (Figure 3). The primary dataset used for mapping bathymetry was National Geographic Data Center's Coastal Relief Model (CRM). The CRM is a "gridded" bathymetric surface (similar to an architect's site model) generated from soundings of the Continental Shelf and slope. The soundings are from hydrographic surveys completed between 1851 and 1965, from survey data acquired digitally on National Ocean Service (NOS) survey vessels since 1965, and are stored in the NOS Hydrographic Database. The CRM was prepared in a GIS format with the value for each 82m cell representing the depth of that cell. In some areas, however (particularly east of the Hudson Canyon), the dataset showed distinct artifacts of interpolation, with the resulting surface stretched into a taut plane marked with peaks and valleys at survey locations where actual depths were taken. In these places, data was augmented with insets from NOS Bathymetric and Fishing Maps (BFM). The BFM contours were drawn by hand, by cartographers interpreting topography from soundings, and provide a more credible topography in some of the problematic sections of the CRM. It should be noted that a considerable data gap exists off the coast of North Carolina and is reflected as an area of "no data" in subsequent analyses that rely on bathymetry (e.g., seabed forms, ecological marine units, benthic habitats).

The Canadian portion of the region, including the Bay of Fundy, was covered by United States Geological Survey's (USGS) Gulf of Maine 15' Bathymetry (Roworth and Signell 1998). Because the spatial resolution of this layer (~350 meter cell size) is coarser than the CRM (~82 m cell size), it was used only to fill in areas north of the Hague line and in a section of eastern Georges Bank. A fringe from the CRM was removed where data had been inferred up to 9 km beyond actual soundings.

Seafloor Substrates: Soft Sediments and Hard Bottoms
Substrate data for the entire United States portion of the region was obtained from usSEABED, an innovative system that brings assorted numeric and descriptive sediment data together in a unified database (Reid et al. 2005). The information includes textural, geophysical, and compositional characteristic of points collected from the seafloor, and is spatially explicit. The data coverage extends seaward across the Continental Shelf and slope, and combines more than 150 different data sources containing over 200,000 data points for the Atlantic seaboard. A unique feature of the database is its use of data mining and processing software to extend the coverage of information in areas where data coverage is more descriptive than quantitative (details in Reid et al. 2005).

Initially, two standard sediment classification schemes were experimented with - Shepard (1954) and Folk (1954) - that classify sediment types by their principal component (e.g. sand) and secondary components (e.g. muddy sand). Ultimately, the average grain size of each sample was used, which was recorded for almost every data point. To create a map of soft sediments for the region, points were removed from the dataset that were coded as hard bottoms ("0" in ave. grain size, and "solid" in the texture field). Then, interpolations were generated from the remaining sediment points that ranged from 0.001 mm clays to 9 mm gravels in average size (Table 3-3).

Interpolating this dataset - estimating the average grain size for areas between the sample points - was problematic because there was very little spatial autocorrelation in the average grain size of each point (Gearey's C = 0.034, $p<0.01$). In other words, nearby points were not necessarily more likely to have a similar grain size. Moreover, the density of data differed greatly across the region: sample points were considerably sparser in deep water areas. To account for this, a Voronoi map was generated to display spatial patterns and attribute benthic grab sample points with sediment information from the closest usSEABED point. A Voronoi analysis creates a cell around each data point such that all space within the cell is closer to the central point than to any other data point (Figure 3-4 and

Figure 3-3. Bathymetry map of the region derived from various sources.

Table 3-3. Grain size and sediment class names (Wentworth 1922).

Grain Size (mm)		Class	Grain Size (mm)		Class
0	0.001	Fine clay	0.25	0.5	Medium sand
0.001	0.002	Medium clay	0.5	1	Coarse sand
0.002	0.004	Coarse clay	1	2	Very coarse sand
0.004	0.008	Very fine silt	2	4	Very fine pebbles (granules)
0.008	0.016	Fine silt	4	8	Fine pebbles
0.016	0.031	Medium silt	8	16	Medium pebbles
0.031	0.063	Coarse silt	16	32	Coarse pebbles
0.063	0.125	Very fine sand	32	86	Very coarse pebbles to cobbles
0.125	0.25	Fine sand			

3-5). Next, the explanatory power of the closest sediment point in differentiating among the organism groups was tested using the partitioning methods described below. This allowed comparison of the various interpolation techniques by contrasting the results with the results of the closest point attributes and measuring the improvement, or lack of improvement, in explanatory power. In addition, the correlation between each interpolation method and the raw Voronoi output was determined, assuming that results that were highly uncorrelated with the Voronoi map were probably distorting the data.

After considerable experimentation, the following interpolation parameters were used: ordinary kriging, spherical semivariogram, variable search radius type using three points with no maximum distance, and output cell size of 500 meters. This method had the strongest correlation with the Voronoi map, and had the highest explanatory power for differentiating the organism groups. Moreover, kriging provides consistent results across areas that have been sparsely and densely sampled. Visually, the kriging interpolation resembled the Voronoi map, but with smoother surfaces and more realistic looking shapes (Figure 3-6).

A separate dataset of hard bottom locations was created from the points coded as "solid" in the usSeabed dataset. The dataset was supplemented by adding points coded as "solid" from the NMFS bottom trawl survey (see Chapter 5 for description of this database). Thus, the final sediment map consisted of the interpolated soft sediment points overlaid with the hard bottom locations (Figure 3-7).

Soft sediment diversity was mapped at a 10 km scale by superimposing a 10 km unit around each map cell and calculating the number of grain size classes within the unit's area. Each cell was scored with the results creating a visually seamless surface (Figure 3-8). Ideally, mapping sediment diversity helps identify *ecotonal benthic areas,* the transition area between two different habitats, where which demersal fish are known to favor (Kaufman, personal communication). However, these results were sensitive to the huge variations in data density across the region and were not used in the predictive models.

Seabed Topographic Forms

This region is characterized by a complexity of banks, basins, ledges, shoals, trenches, and channels in the north, shoals and deltas to the south, and deep canyons along the

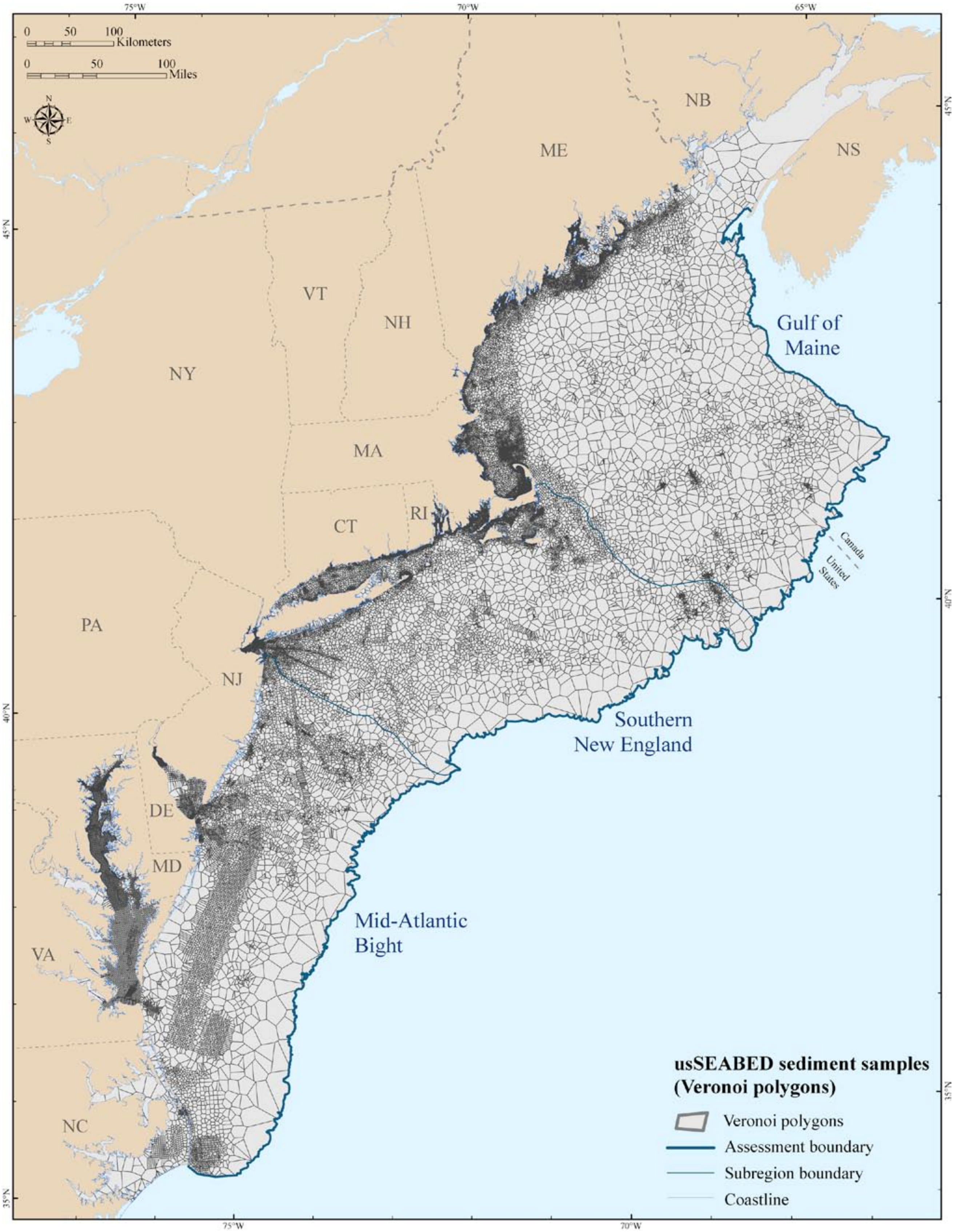


Figure 3-4. Voronoi map of the usSEABED database, showing the distance between samples.

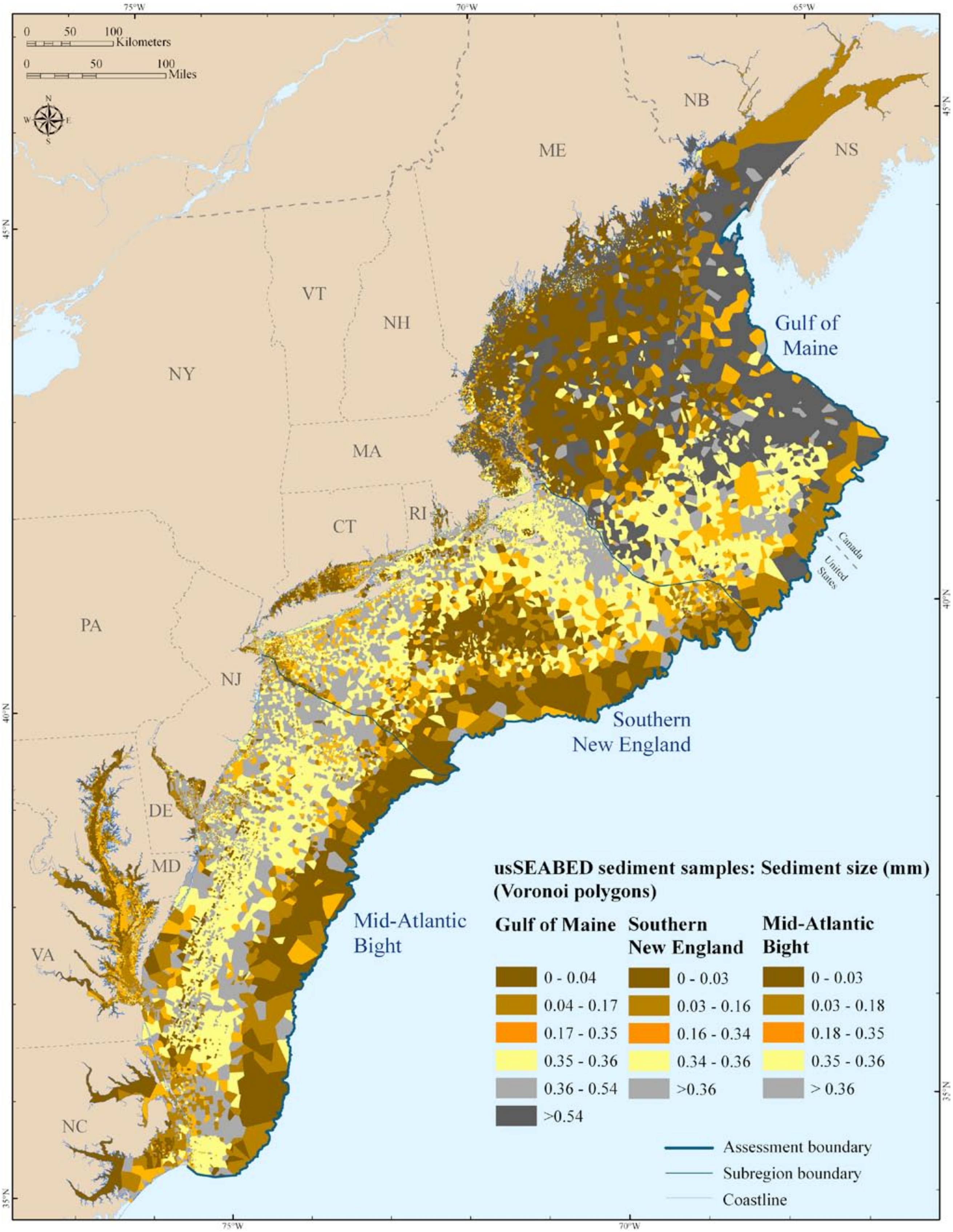


Figure 3-5. Voronoi map of the usSEABED database, showing sediment grain size.

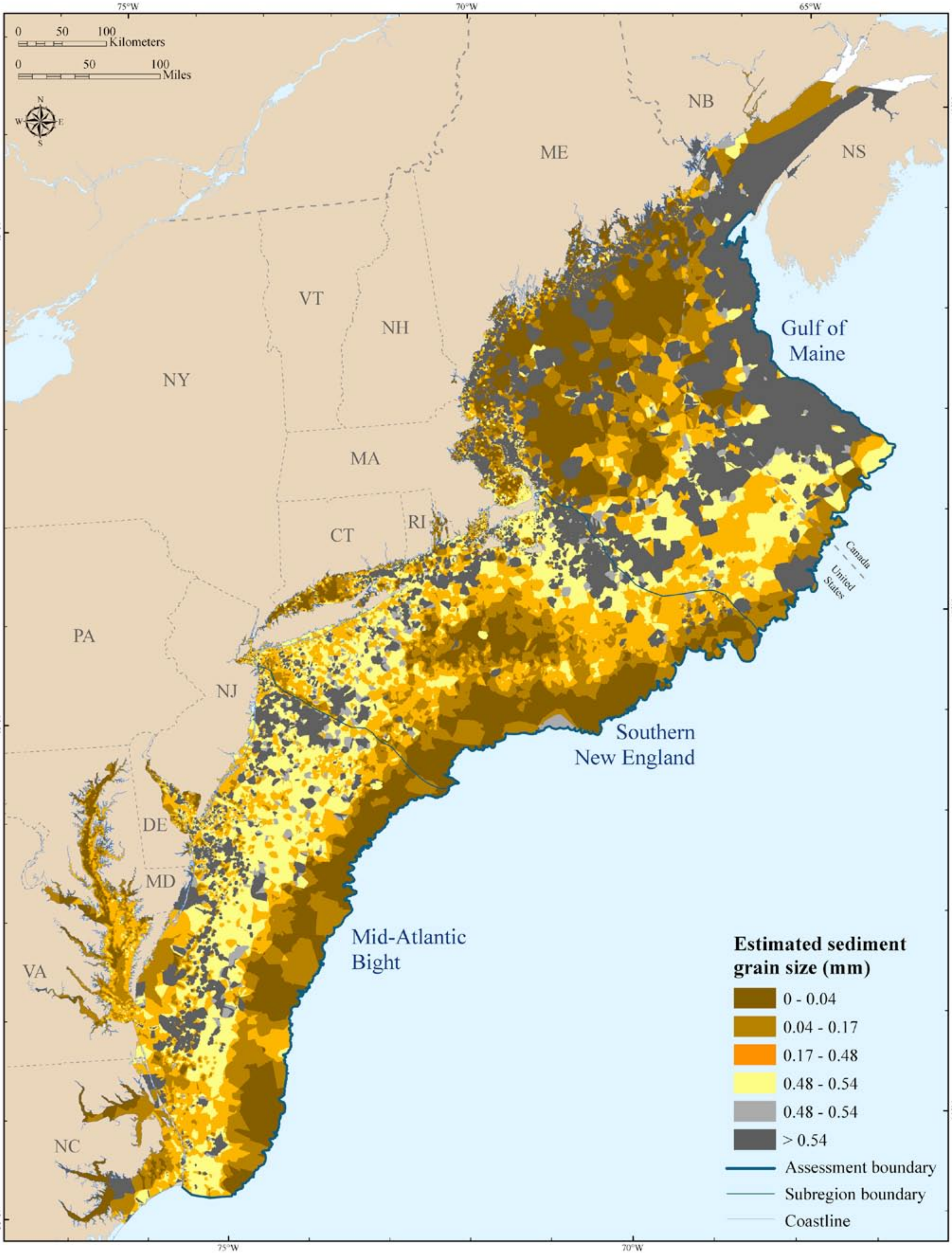


Figure 3-6. Interpolated map of soft sediments.

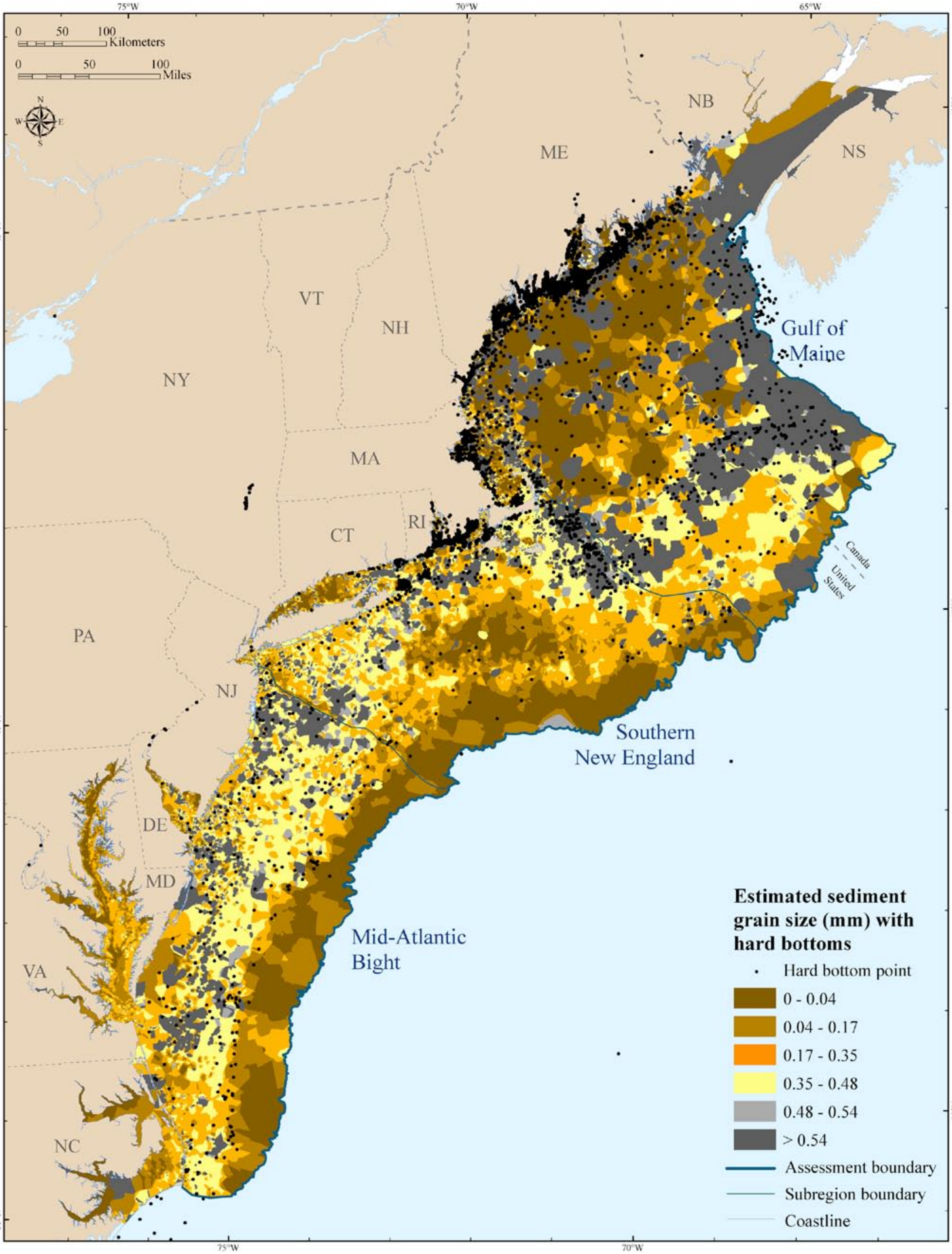


Figure 3-7. Hard bottom points overlaid on the soft sediment interpolation.

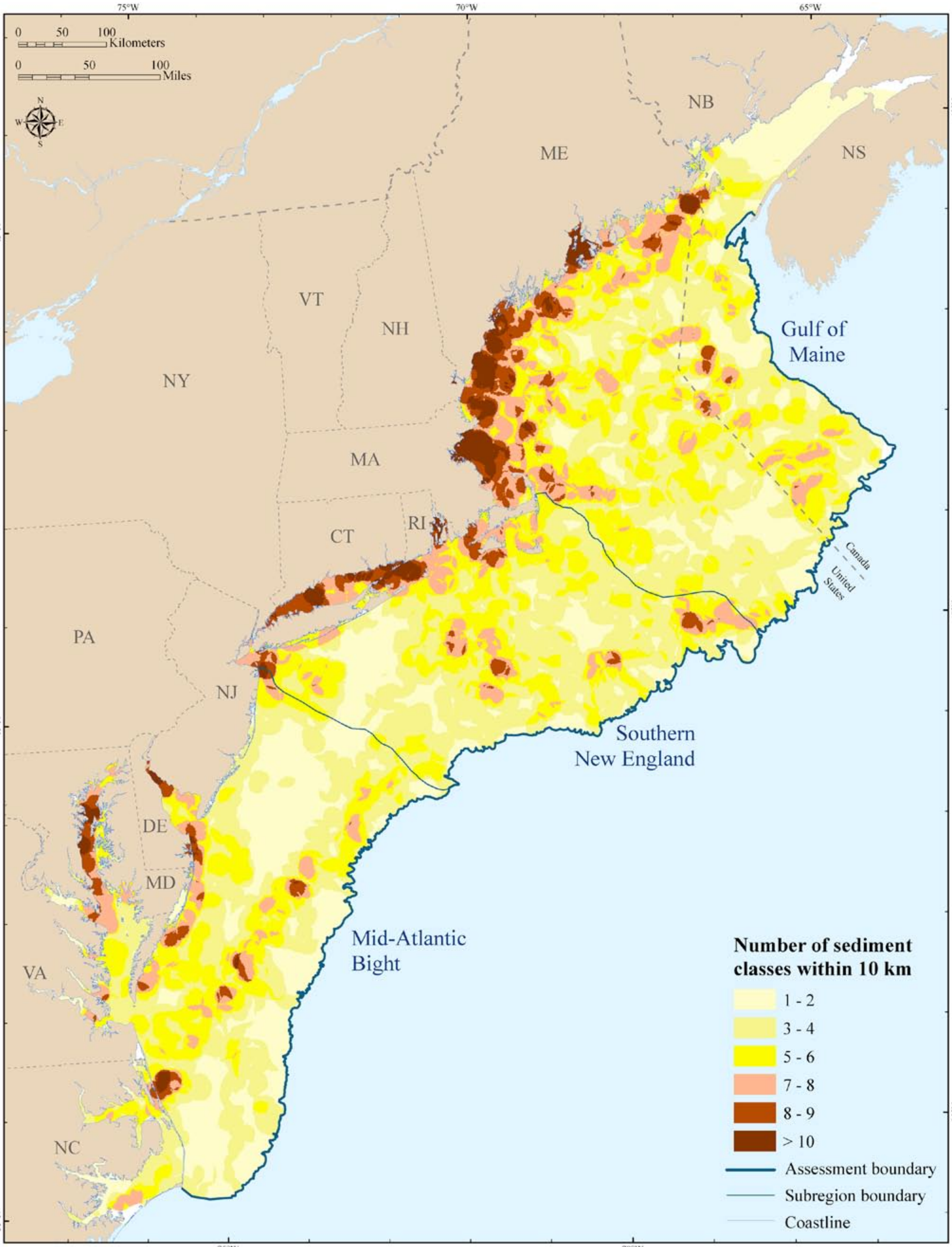


Figure 3-8. Map of sediment diversity using a 10 k focal window.

Continental Shelf (Figure 3-2). These features have a large influence on oceanic processes, and on the distribution of benthic habitats. With this in mind, the seabed form data layer was developed to characterize seafloor topography in a systematic and categorical way, relevant to the scale of benthic habitats. The units that emerge from this analysis, from high flats to depressions, represent depositional and erosional environments that typically differ in fluvial processes, sediments, and organism composition (Wigley and Theroux 1981).

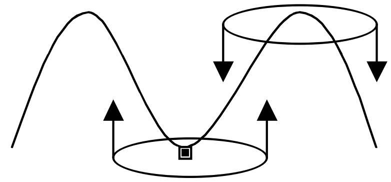
Seabed topographic forms were created from relative position and degree of slope of each seafloor cell. Seabed position (or topographic position) describes the topography of the area surrounding a particular 82 m cell. Calculations were based on the methods of Fels and Zobel (1995) that evaluate the elevation differences between any cell and the surrounding cells within a specified distance. For example, if the model cell is, on average, higher than the surrounding cells, then it is considered to be closer to the ridge top (a more positive seabed position value). Conversely, if the model cell is, on average, lower than the surrounding cells then it is considered closer to the slope bottom (a more negative seabed position value).

The relative position value is the mean of the distance-weighted elevation differences between a given point and all other model points within a specified search radius. The search radius was set at 100 cells after examining the effects of various radii. Position was grouped into six classes that were later simplified to three classes:

1) Very low	Low
2) Low	Low
3) Lower mid	Mid
4) Upper mid	Mid
5) High	High
6) Very high	High

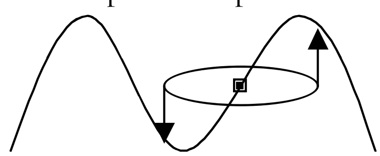
The following diagrams illustrate the seabed position index values along slopes:

Ridge: seabed position = positive value

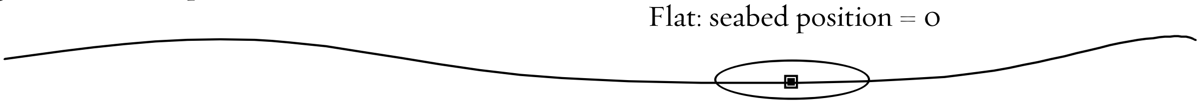


Slope Bottom: seabed position = negative value

Sideslope: seabed position = 0



Flat: seabed position = 0



The second element of the seabed forms, degree of slope, was used to differentiate between steep canyons and flat depressions. Slope was calculated as the difference in elevation between two neighboring raster cells, expressed in degrees. After examining the distribution of slopes across the region, slopes were grouped according to the following thresholds:

1) 0° - 0.015°	Level flat
2) 0.015° - 0.05°	Flat
3) 0.05° - 0.8°	Gentle slope
4) 0.8° - 8.0°	Slope
6) >8.0°	Steep slope (includes canyons)

The cutoffs might be misleading if interpreted too literally, For example, there are very few locations on the Continental Shelf with slopes in the category >8° and most of these correspond to canyon walls reported as 35-45° slope by divers. The discrepancies are due to the cell size (82 m) of the analysis unit that averages slope over a larger area.

Table 3-4. Seabed forms showing position and slope combinations. For example, code 11 = Very low + Level flat = Low flat.

		Slope				
		Level flat	Flat	Gentle slope	Slope	Steep slope
Position	Very low	depression	depression	low slope	low slope	steep
	Low	depression	depression	low slope	low slope	steep
	Lower mid	mid flat	mid flat	sideslope	sideslope	steep
	Upper mid	mid flat	mid flat	sideslope	sideslope	steep
	High	high flat	high flat	high slope	high slope	steep
	Very high	high flat	high flat	high slope	high slope	steep

Slope and relative position were combined to create 30 possible seabed forms ranging from high flat banks to low level bottoms to steep canyons. Initially, all 30 types were used in the analysis of organism relationships, but results suggested that they could be simplified while maintaining, or improving, their explanatory power. Therefore, the analysis was simplified into the following six categories: 1) depression, 2) mid flat, 3) high flat, 4) low slope, 5) high slope,6) sideslope, and 7) steep (Table 3-4).

Small errors in the bathymetry grid were bypassed by identifying very small-scale variations in depth. Generalization tools were used to clean up small scale variations in the dataset. This eliminated thousands of "dimples" present in the CRM bathymetry without having to edit the original grid.

Each individual cell was assigned to a unique seabed form and often groups of forms cluster to define a larger scale topographic unit such as Jeffreys Ledge or Georges Bank (Figure 3-9). Depressions and mid position flats represent the broad plains common in Southern New England, steep areas identify the canyons of the continental slope, and highest position sideslopes occur on the cusp of the shelf-slope break.

Habitat Complexity: Standard Deviation of the Slope

In addition to the categorical analysis of topography for the seabed forms, habitat complexity was assessed using the standard deviation of slope. Using the bathymetry grid, "floating window" analyses of the standard deviation of the slope were conducted within a 500 m, 1 km, and 10 km search radii. To calculate the standard deviation of the slope, the slope for each cell was calculated using the GIS slope command (3 x 3 cell neighborhood). Next, the range was divided into ten equal interval classes and the mean and standard deviation of the cells within each search radius were calculated (Figure 3-10). The search radius matters because the importance of any given spatial feature depends on its size relative to the species of interest. The 1 km analysis had the greatest explanatory power for differentiating between the benthic organism groups.

Linking the Organisms to Physical Factors

Recursive partitioning (JMP software package) was used to uncover relationships between benthic communities and the physical environment. Recursive partitioning is a statistical method that creates decision trees to classify members of a common population (the classification types) based on a set of dependent variables (the physical

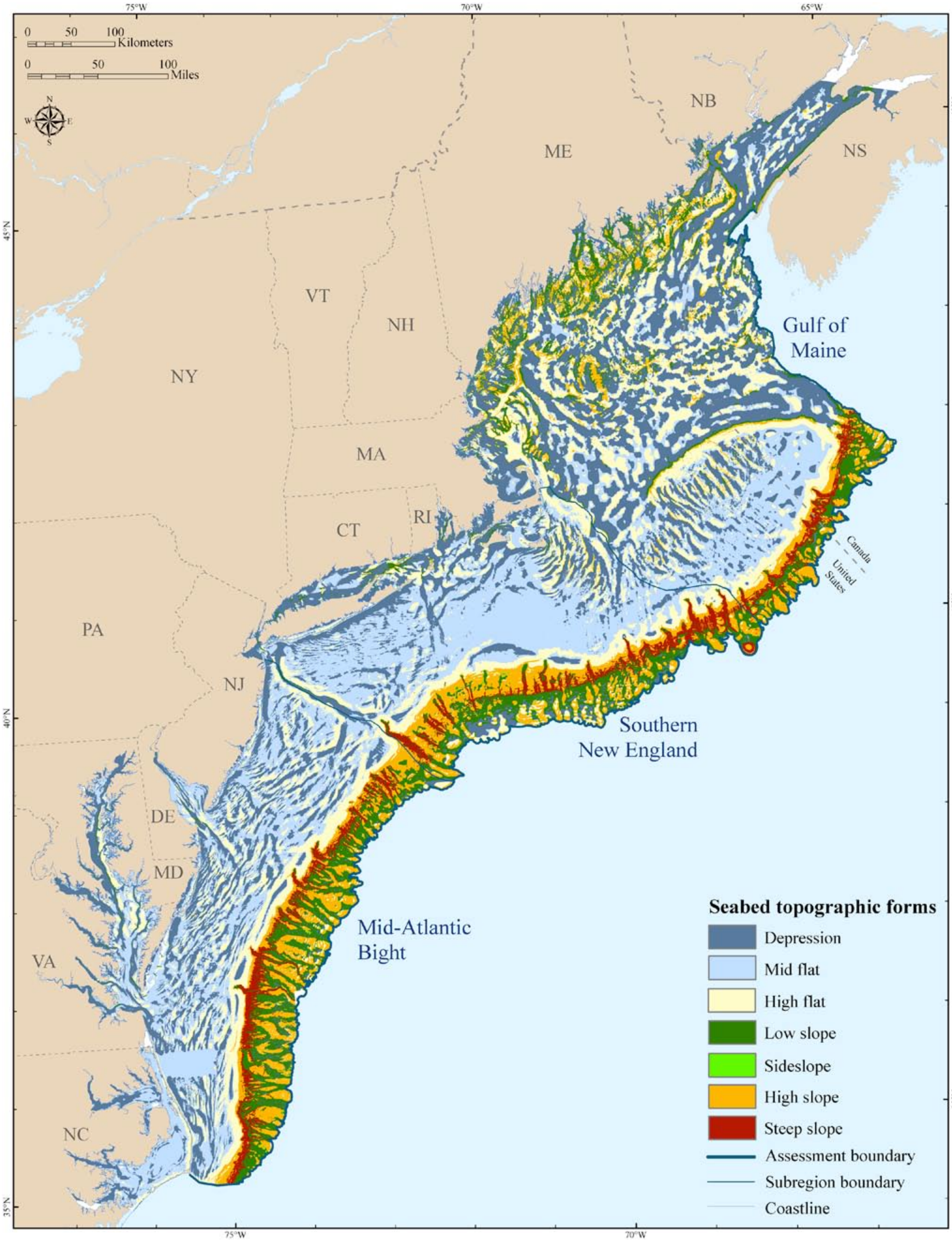


Figure 3-9. Map of the seabed topographic forms.

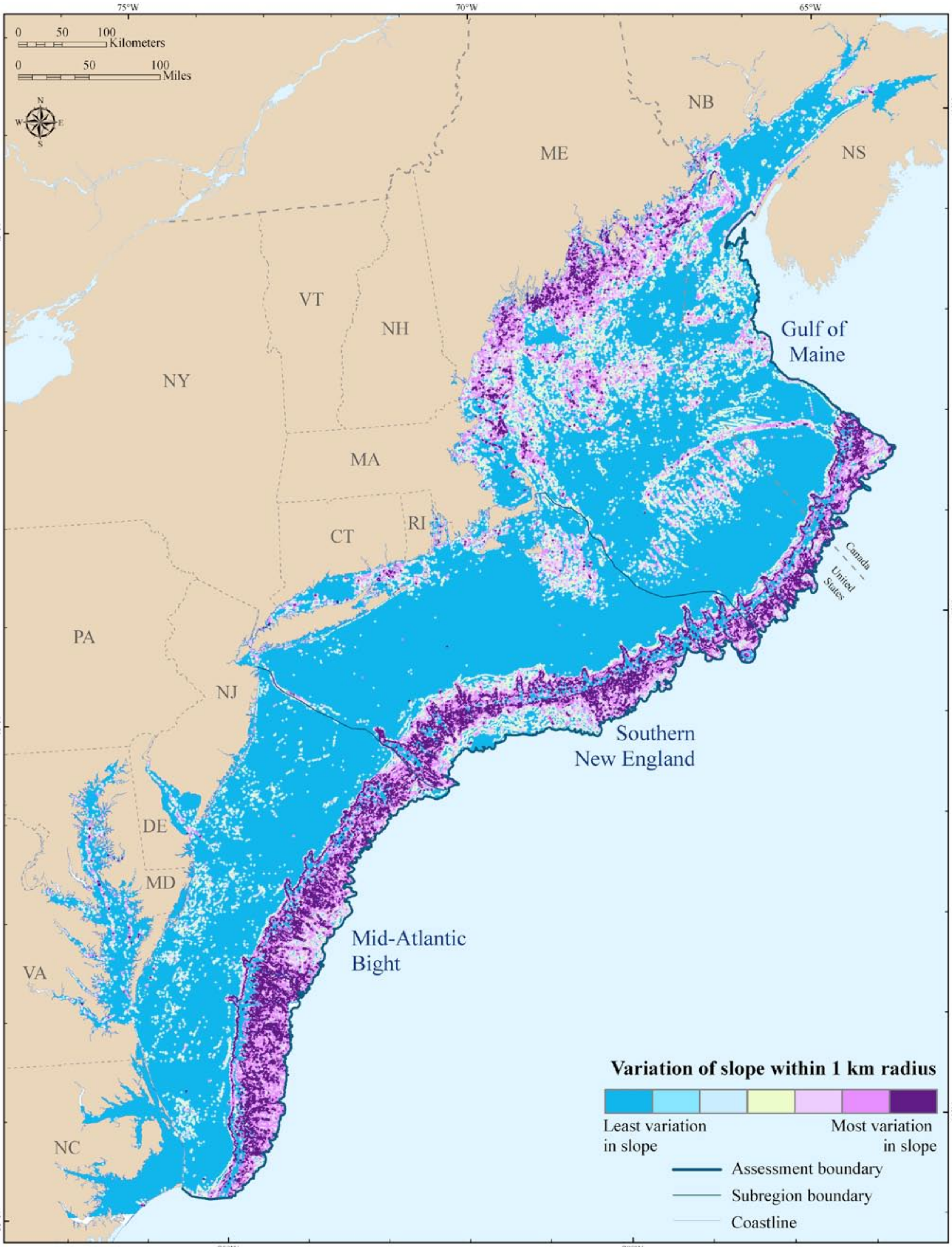


Figure 3-10. Map of standard deviation of slope using a 1 k focal window.

Table 3-5. Example of information for sample point #22254, a grab sample from the Mid-Atlantic Bight subregion classified in organism group 505. We calculated these metrics for each of the 11,132 grab sample points.

Sample ID	Organism Group	Subregion	Bathymetry (m)	Sediment Grain Size (mm)	Position	Slope	Seabed Form	STD_ Slope_1K
22254	505	Mid-Atlantic Bight	-996.62	0.143	Low	Steep	Canyon	0.8

variables). The analysis required each benthic grab sample to be attributed with the benthic community type that it belonged to, overlaid on the standardized base maps, and attributed with the information on depth, sediment grain size and seabed form appropriate to the point (Table 3-5).

Regression trees were first built using all variables collectively to identify the variables driving organism differences. Each analysis was run separately by subregion because initial data exploration revealed that the relationships between the species and the physical factors differed markedly among subregions.

After examining the variable contributions collectively, individual regression trees were built for depth, grain size, and seabed forms to identify critical thresholds that separated sets of organism groups from each other (see Appendix 3-1). In recursive partitioning, these cuts are identified by exhaustively searching all possible cuts and choosing the one that best separates the dataset into non-overlapping subsets. For example, the first run of the organism groups on the bathymetry data separated the deep water samples from the shallow water samples while identifying the exact depth that most cleanly separated the two sets.

Statistical significance was determined for each variable in each organism group using chi-squared tests. This method compares the observed distribution of each benthic organism group across each physical variable against the distribution expected from a random pattern. A variable and threshold was considered to be significant if it had a p-value less that 0.01 (less than a 99% probability that this pattern could have occurred by chance -Appendix 3-1).

Results

Based on the bathymetry dataset, the region varied in depth from 0 m at the coast to -2400 m along the shelf boundary, reaching a maximum of -2740 m at the deepest part. Critical depth thresholds for benthic organisms and habitats differed among the three subregions and are discussed under the organism classification. The three subregions also differed in physical structure, with the Gulf of Maine being made up of a moderately deep basin (-150 to -300 m), a distinctive shallower bank (-35 to -80 m), and a small portion of the deep slope. In contrast, the Mid-Atlantic Bight has extensive shallow water shoals (0 to -35 m), an extensive moderate depth plain (-35 to -80 m), and a large proportion of steeply sloping deep habitat along the Continental Shelf. The Southern New England region is similar in most ways to the Mid-Atlantic Bight.

The sediment maps show a seafloor dominated by coarse to fine sand with large pockets of silt in the Southern New England region, deep regions in the Gulf of Maine and along the Continental Slope. Large pockets of gravels are concentrated on the tip of Georges Bank, the eastern edge of Nantucket Shoals, around the Hudson Canyon, and in various other deep and shallow patches. Hard bottom points are concentrated near the Maine shoreline and offshore are loosely correlated with the gravel areas (Figure 3-7).

Organism Classification

For each subregion, we provide a summary of the characteristic species and their indicator values (Appendix 3-2). This table gives diagnostic species for each organism group and shows its distribution across all the organisms groups. The mean indicator value and the probability of this distribution being random chance is calculated for each species in the group that it is most closely associated with. Most species don't have a common name; Gosner (1979), Weiss (1995) and Pollock (1998) were used to add them where available. Often, these are common names for the family or genus, not the species.

Relationship of the organism groups to the physical factors

Across all subregions, depth was the most important explanatory variable, followed by grain size, and then seabed forms. Seabed forms were less important in the Mid-Atlantic Bight than the other regions. Standard deviation of depth was somewhat important in Southern New England, but not in the other regions. Basic relationships between each organism group and its characteristic physical setting are described below. Charts giving the distribution of the organism groups across each physical factor class, a chi-squared test for significance, and the class where this group is most likely to be found are given in Appendix 3-1. Tables of key physical factor values that correspond to ecological thresholds separating the distribution of one benthic habitat from another are provided in the subregion results (Table 3-6, 3-7, 3-8).

Benthic Habitat Types and Ecological Marine Units

The benthic habitat types identified for each subregion are presented in the following section of this document. Because the final results are a product of several steps, e.g. the macrofauna classification; the identification of relationships between the organism groups and the factors of depth, grain size and topography; and the mapping of benthic environments, the results and details on each step are provided separately in the appendices.

Two separate, but closely related final maps were created. The Ecological Marine Units (EMU) represent all three-way combinations of depth, sediment grain size, and seabed forms based on the ecological thresholds revealed by the benthic-organism relationships (Figure 3-11, 3-12, 3-13, 3-14). Benthic Habitats are EMUs clustered into groups that contain the same species assemblage (Figure 3-15). The two terms are not synonymous, but they are based on the same information, and thus, represent two perspectives on the seafloor. Essentially, the EMU maps show the full diversity of physical factor combinations, regardless of whether a specific habitat type was identified for the combination. The benthic habitat map shows only the combinations of factors, or groups of combinations, for which a benthic organism group was identified. It should be noted that the numbers of the EMUs and benthic habitats were derived from the statistical relationships and is completely arbitrary.

The Benthic Habitat map is simpler because a single organism group typically occurs across several EMUs, although in some instances a single EMU is synonymous with a single organism group. For example, in the Mid-Atlantic Bight, EMU 1101 (silty depression centers in water less than 15 m) is synonymous with organism group 768, a community identified by a specific set of amphipods, brittle stars, clams, whelks, and snails. More typical are organism groups that occur across several closely related EMUs such as Southern New England organism group 25. It ranges across both high position and mid position flats, very shallow to shallow water ranging in depth from 0-23 m, and medium to coarse sand. This community of shimmyworms, glass shrimp, hermit crabs, and surf clams is thus found across a small range of EMUs, and the habitat is mapped as the set of EMUs that define it.

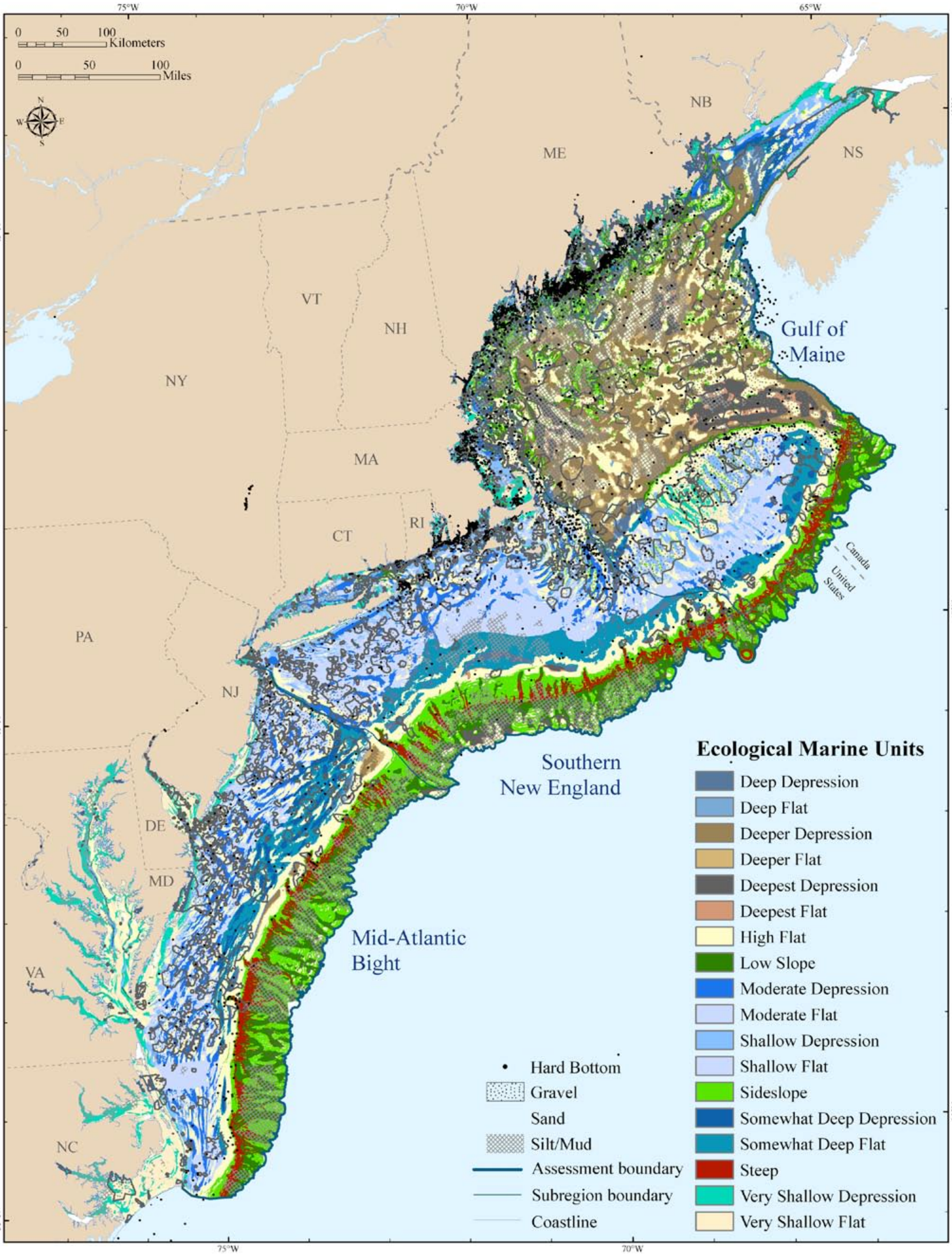


Figure 3-11. Ecological Marine Units of the Northwest Atlantic region. Scale 1:7,250.000

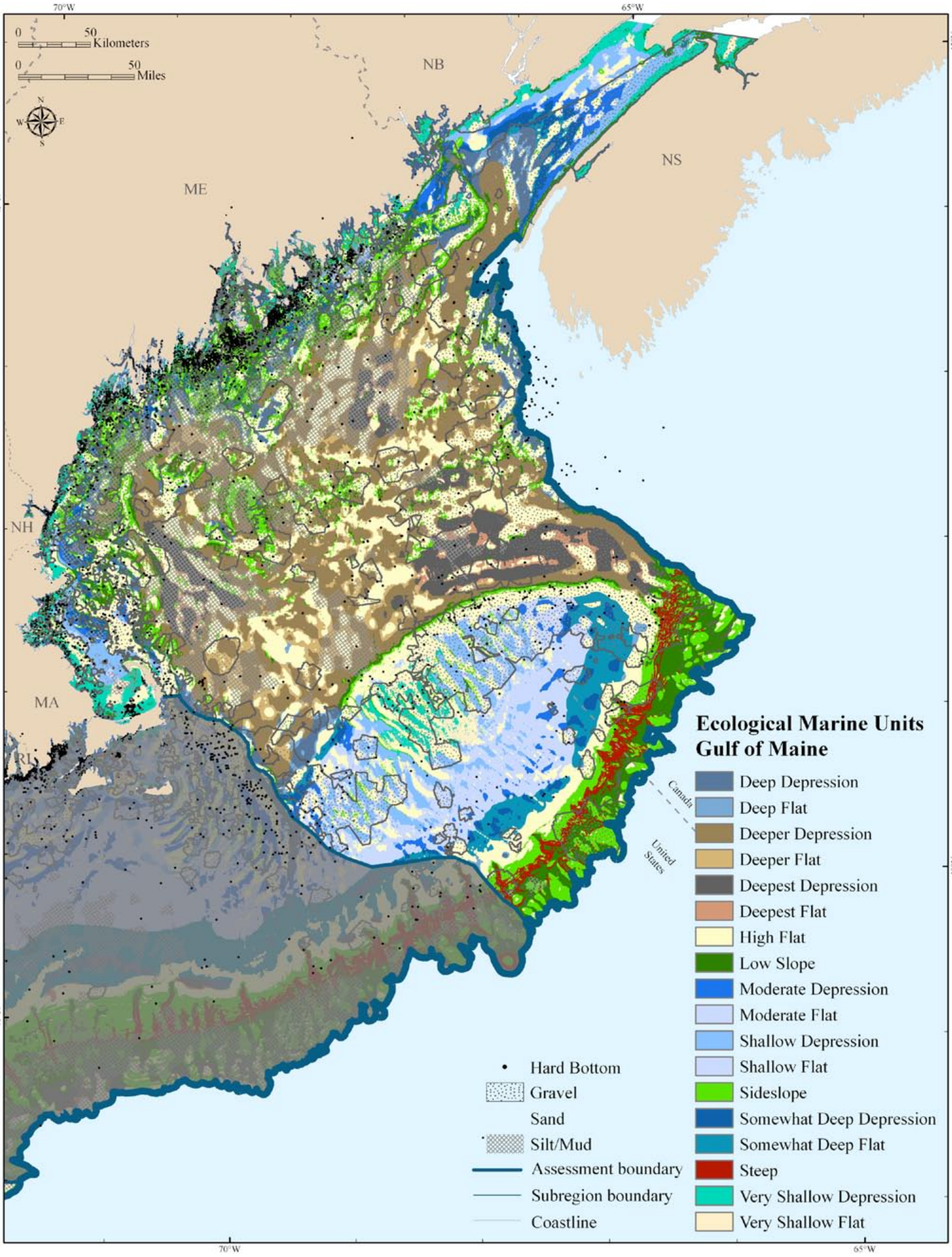


Figure 3-12. Gulf of Maine Ecological Marine Units. Scale 1:2,900,00

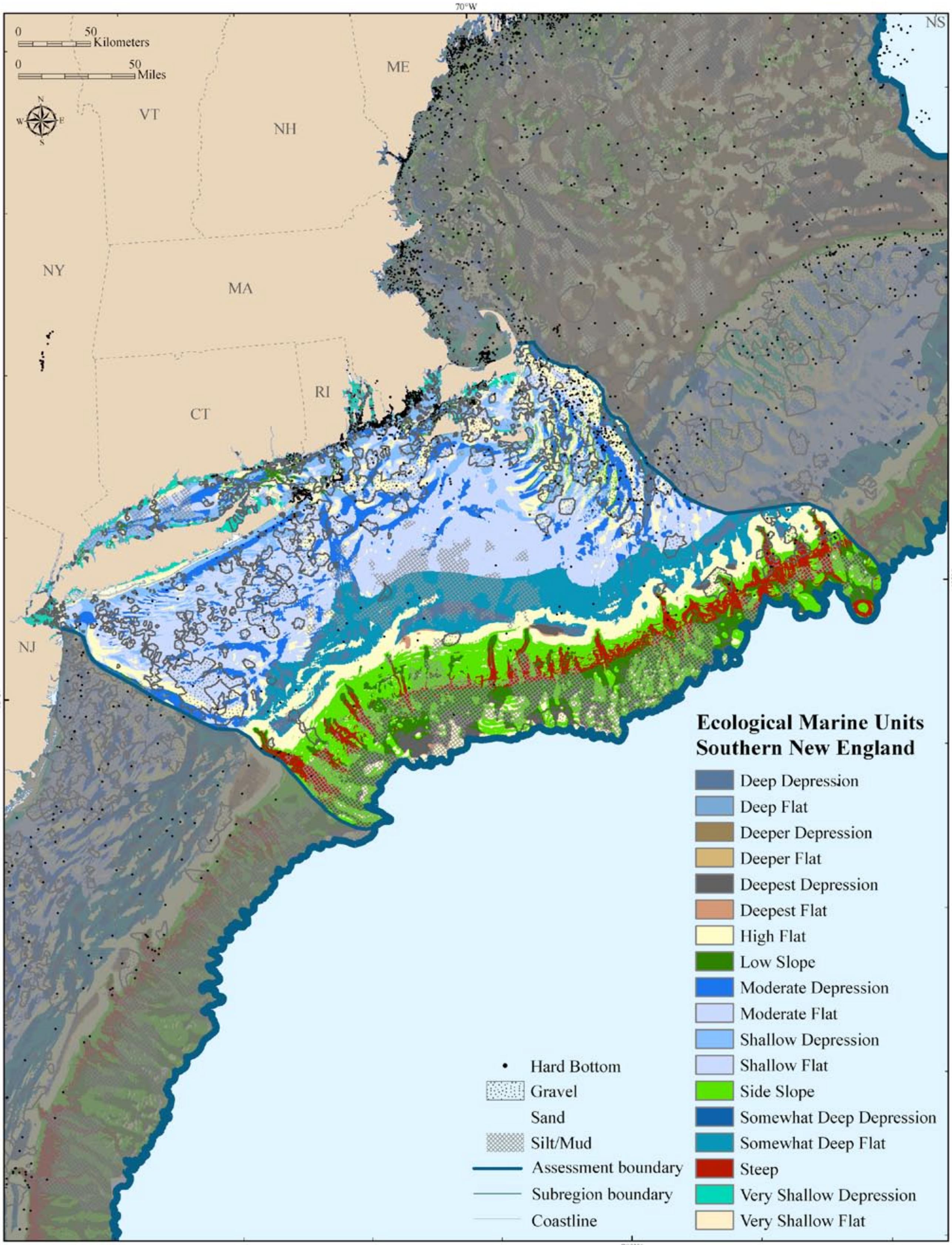


Figure 3-13. Southern New England Ecological Marine Units. Scale 1:2,600,000

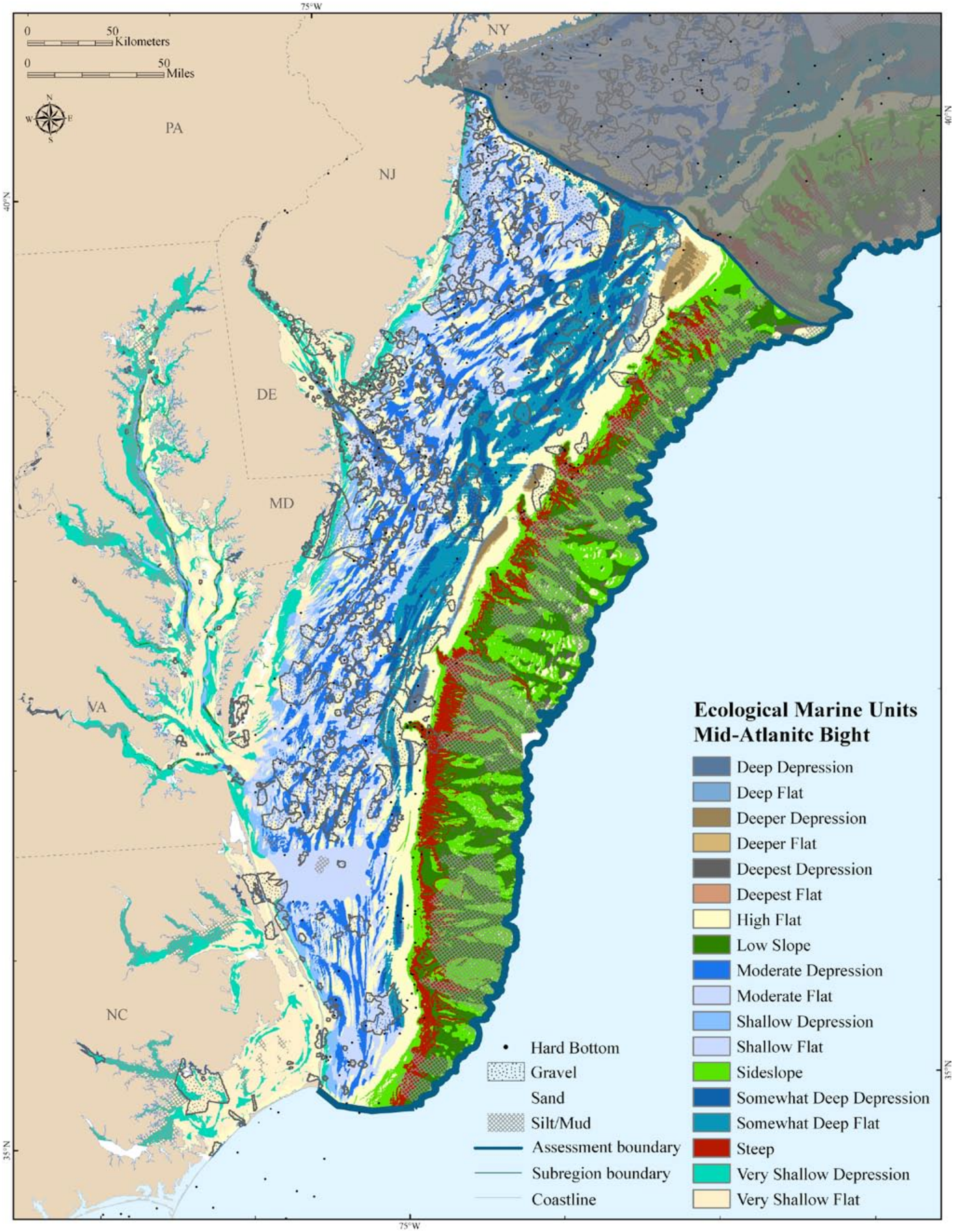


Figure 3-14. Mid-Atlantic Bight Ecological Marine Units. Scale 1:3,210,600

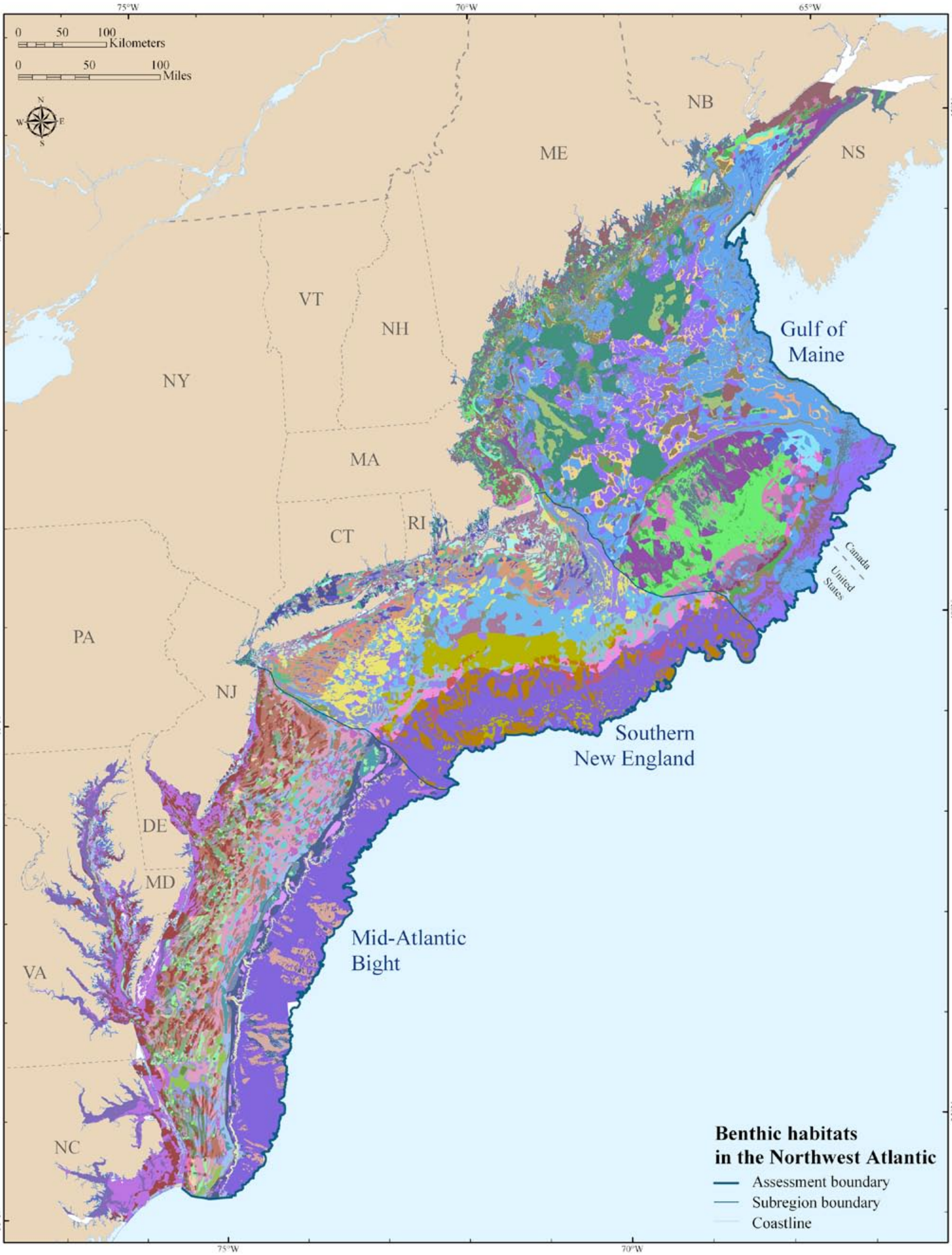
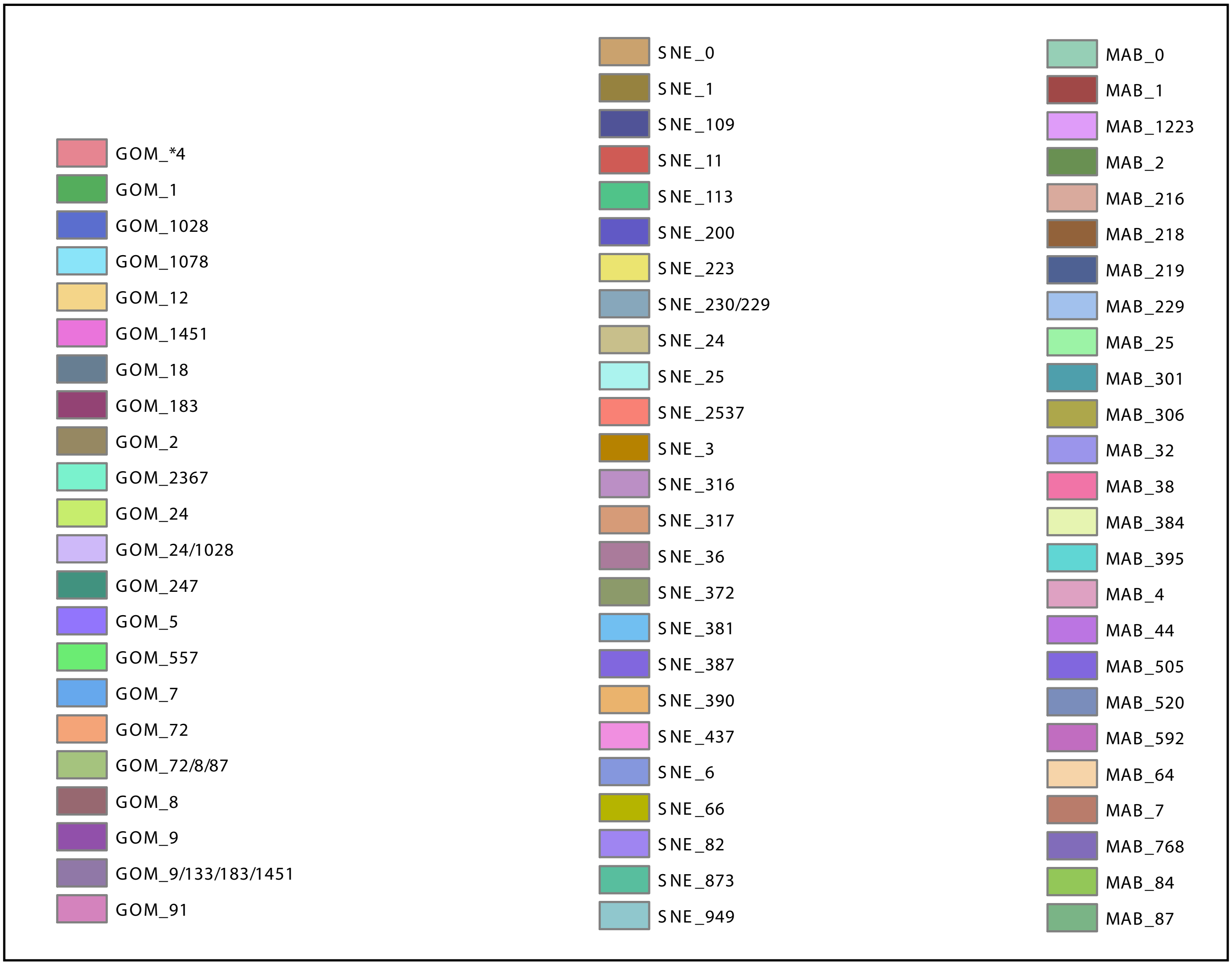


Figure 3-15. Benthic habitats of the Northwest Atlantic region.

Figure 3-15. Benthic Habitats Legend



Description of Benthic Habitats

Note: This section is arranged by subregion and benthic habitats are displayed from shallow to deep water habitats based on the average depth of each benthic habitat.

Gulf of Maine

Table 3-6. Physical factor values that correspond to ecological thresholds in the Gulf of Maine subregion.

Bathymetry (m)	Sediment Grain Size (mm)	Seabed Form
0-42	0-0.04 (mud and silt)	Depression
42-61	0.04-0.17 (very fine sand)	Mid Flat
61-70	0.17-0.36 (fine sand)	High Flat
70-84	0.36 -0.54 (sand)	Low Slope
84-101	>=0.54 (coarse sand and gravel)	Sideslope
101 - 143		Steep
143 -233		
>=233		

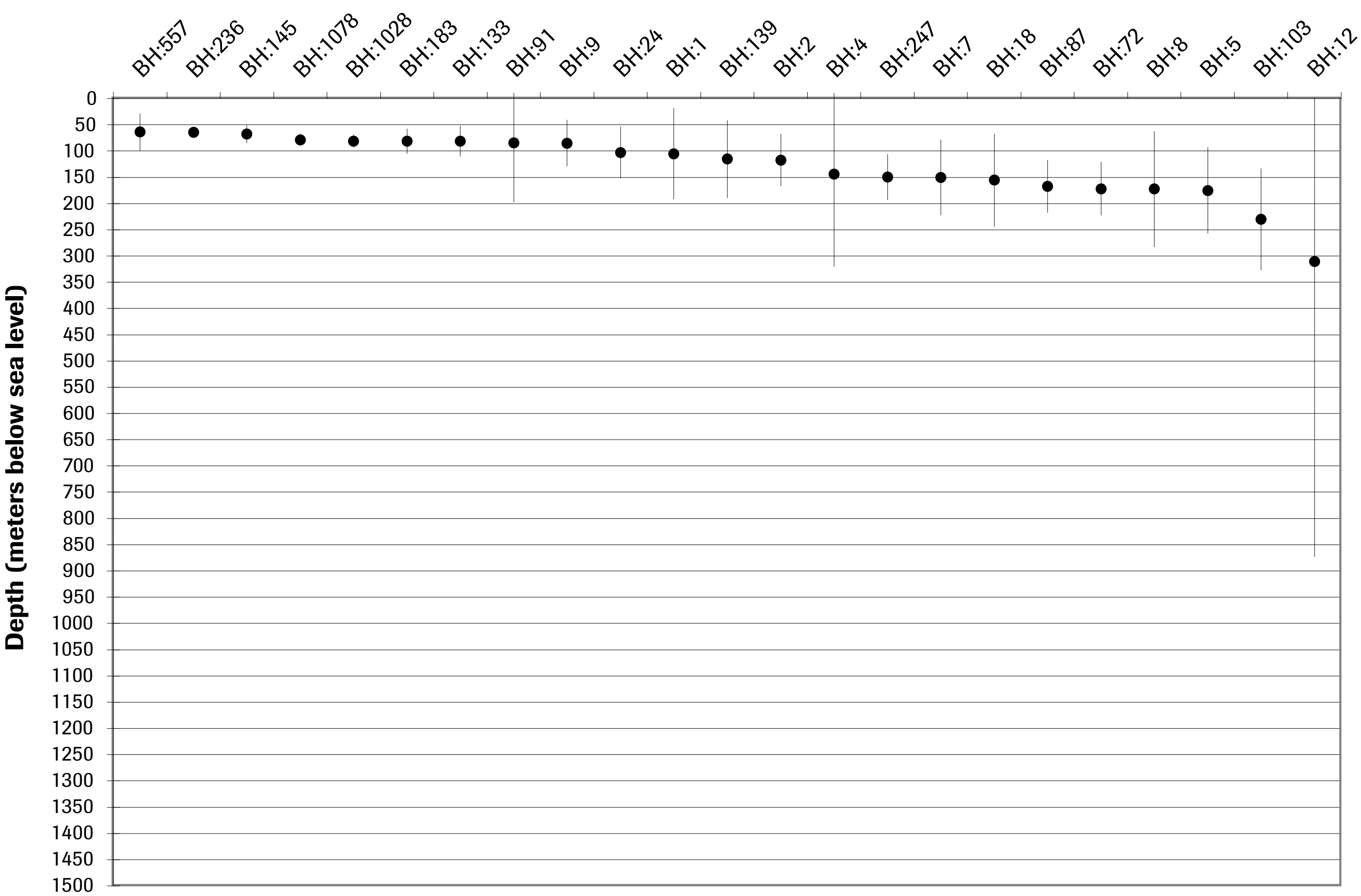


Figure 3-16. Average depth and range of each benthic habitat type in the Gulf of Maine subregion. Lines represent two standard deviations above and below the mean. Habitat types with the same depths often differ from each other by sediment grain size or topographic location. Habitats with very large depth ranges are widespread associations unrelated to, or weakly correlated with, depth.

Shallow to moderate (0 - 70 m)

Habitat 557 (125 Samples):
Mid position flats at shallow to moderate depth (42 - 79 m) on fine to medium sand.

Annelids
Bamboo worm *(Clymenella torquata)*
Bristle worm *(Spiophanes bombyx)*
Burrowing scale worm *(Sthenelais limicola)*
Paddle worm *(Anaitides mucosa)*
Paraonid worm *(Acmira catherinae)*
Scale worm *(Harmothoe extenuata)*
Shimmy worm *(Aglaophamus circinata)*
Spaghetti-mouth worm *(Ampharete arctica)*
Syllid worm *(Exogone hebes)*
Thread worm *(Lumbrineris acicularum)*

Arthropods
Cumacea *(Eudorellopsis deformis)*
Tanaidacea *(Tanaissus lilljeborgi)*
Other amphipods *(Byblis serrata, Corophium crassicorne, Ericthonius fasciatus, Orchomene minut, Leptocheirus pinguis, Monoculodes sp., Phoxocephalus holbolli, Pseudunciola obliquua, Parahaustorius longimerus , Protohaustorius sp., Rhepoxynius hudsoni, Unciola inermis, U. irrorata)*
Other isopods *(Chiridotea arenicola, Cirolana polita)*

Mollusks
False quahog *(Pitar morrhuana)*
Lea's spoon shell *(Periploma fragile)*
Paper clam *(Lyonsia arenos)*
Surf clam *(Spisula solidissima)*
Northern dwarf tellin *(Tellina agilis)*

Habitat 2367 (40 Samples):
Depressions at moderate depths (61 - 70 m) on very fine sand.

Annelids
Bamboo worm *(Maldane sarsi, Myriochelle oculata, Praxillella gracilis)*
Bristle worm *(Sternaspis fossor, Terebellides atlantis, Trochochaeta multisetosa)*
Chevron worm *(Goniada maculata)*
Clam worm *(Nereis grayi)*
Feather duster worm *(Euchone elegans, E. incolor)*
Fringe worm *(Chaetozone setosa, Tharyx acutus, Tharyx sp.)*

Spionid mud worm *(Laonice cirrata, Polydora socialis, Prionospio steenstrupi, Spio armata, S. filicornis)*
Sandbar worm *(Gattyana amondseni)*
Scale worm *(Antinoella sarsi, Hartmania moorei, Ophelina acuminate, Pholoe minuta)*
Shimmy worm *(Nephtys incisa)*
Spaghetti-mouth worm *(Asabellides oculata, Melinna cristata)*
Syllid worm *(Exogone verugera)*
Threadworm *(Cossura longocirrata, Heteromastus filiformis, Lumbrineris fragilis, Lumbrineris hebes, Ninoe nigripes)*
Other polychaetes *(Ancistrosyllis groenlandica, Anobothrus gracilis , Aricidea quadrilobata, Brada villosa, Diplocirrus hirsutus, Drilonereis longa, Haploscoloplos robustus, Leitoscoloplos mamosus, Mediomastus ambisetae, Paramphinome jeffreysii, Polycirrus sp., Tauberia gracilis)*

Arthropods
Skeleton shrimp *(Mayerella limicola)*
Cumacea *(Campylaspis rubicund, Diastylis cornuifer, Eudorella hispida, Eudorella pusilla, Leptostylis longimana, Leucon americanus)*
Other Amphipods *(Anonyx liljeborgi, Bathymedon obtusifrons, Byblis gaimardi, Haploops fundiensis, Harpinia propinqua, Metopa angustimana, Monoculodes sp., Stenopleustes sp.)*
Other isopods *(Edotea acuta, Pleurogonium rubicundum)*

Mollusks
Alvania *(Alvania carinata)*
Bean mussel *(Crenella decussata)*
Cone snail *(Oenopota concinnulus)*
Hatchet shell *(Thyasira flexuosa)*
Nutclam *(Nucula delphinodonta, N. tenuis)*
Short yoldia *(Yoldia sapotilla)*
Spoon shell *(Periploma papyratium)*
Stimpson's whelk *(Colus pubescens)*
Tusk shell *(Siphonodentalium occidentale)*
Yoldia *(Yoldiella iris, Y. sanesia)*
Other gastropods *(Cylichna alba, C. gouldi, C. occulta) Scaphander punctostriatus)*

Cnidarians
Burrowing anemone *(Edwardsia elegans)*
Twelve-tentacle burrowing anemone *(Halcampa duodecimcirrata)*

Echinoderms
Mud star *(Ctenodiscus crispatus)*
Sea cucumber *(Molpadia oolitica)*

Bryozoans
Hippodiplosia propinqua

Phoronids
Horseshoe worm *(Phoronis architecta)*

Sipunculids
Tube worm *(Phascolion strombi)*

Habitat 1451 (127 Samples):
Mid-position flats at shallow to moderate depths (42 - 101 m) on fine sand.

Arthropods
Atlantic rock crab *(Cancer irroratus)*
Hairy hermit crab *(Pagurus arcuatus)*
Lady crab *(Ovalipes ocellatus)*

Mollusks
Atlantic razor *(Siliqua costata)*
Dog whelk *(Nassarius trivittatus)*
Spotted northern moon-shell *(Lunatia triseriata)*
Common northern moon snail *(Euspira heros)*
Paper clam *(Lyonsia hyalina)*
Stimpson's whelk *(Colus stimpsoni)*

Cnidarians
Colonial anemone *(Epizoanthus americanus)*

Echinoderms
Common sand dollar *(Echinarachnius parma)*
Slender-armed star *(Leptasterias tenera)*

Habitat 1078 (305 Samples):
Mid-position flats on at moderate depths (61 - 101 m) on fine sand.

No diagnostic species, depauperate samples with occasional sea scallop *(Placopecten magellanicus)*

Habitat 1028 (67 Samples):
Mid-position flats at moderate depths (61 - 101 m) on fine sand.

Arthropods
American lobster *(Homarus americanus)*

Mollusks
Iceland scallop *(Chlamys islandica)*
Sea scallop *(Placopecten magellanicus)*
Other gastropods *(Stilifer stimpsoni)*

Habitat 183 (136 Samples):
Mid-position flats in shallow to moderate depths (42 - 101 m) on fine sand.

No diagnostic species, samples largely empty – some Northern shortfin squid *(Illex illecebrosus)*

Moderate Depths (70 - 233 m)

Habitat 133 (61 Samples):
Mid-position flats at moderate depths (70 - 101 m) on fine sand.

Annelids
Clam worm *(Nereis pelagica)*
Feather duster worm *(Chone infundibuliformis)*
Thread worm *(Lumbrinerides acuta)*
Spionid mud worm *(Scolelepis squamata)*
Paraonid worm *(Acmira cerruti)*
Shimmy worm *(Nephtys bucera)*
Syllid worm *(Streptosyllis arenae)*
Threadworm *(Notomastus latericeus)*

Arthropods
Fairy shrimp *(Erythrops erythrophthalma)*

Cumacea *(Pseudoleptocuma minor)*
Other amphipods (*Pontogeneia inermis)*

Mollusks
Sea butterfly *(Thecosomata spp.)*

Chaetognatha
Arrow worm *(Chaetognatha sp.)*

Habitat 91 (307 Samples):
Mid-position flats at moderate depths (42 to 83 m) on fine to medium sand.

Arthropods
Atlantic rock crab *(Cancer irroratus)*
Acadian hermit crab *(Pagurus acadianus)*
Cumacea *(Lamprops quadriplicata, Pseudoleptocuma minor)*
Krill *(Thysanoessa inermis, T. longicaudata)*
Mysid shrimp *(Mysidopsis bigelowi, Neomysis americana)*
Skeleton shrimp *(Caprella linearis)*
Sand shrimp *(Crangon septemspinosa)*
Sea spider *(Nymphon rubrum)*
Striped barnacle *(Balanus hameri)*
Other amphipods *(Ampelisca agassizi, A. macrocephala, Calliopius laeviusculus, Casco bigelowi , Ericthonius difformis, Haustorius arenarius, Hippomedon serratus, Melita sp., Monoculodes sp., Orchomene pinguis, Parahaustorius longimerus, Parathemisto bispinosa, P. compressa, Photis dentate, Podoceropsis nitida, Pontogeneia inermis, Protomedeia fasciata, Psammonyx terranovae, Rhepoxynius epistomus, Tmetonyx cicada, Unciola inermis)*
Other isopods *(Chiridotea arenicola, Chiridotea tuftsi, Cirolana concharum, Edotea triloba, Politolana polita)*

Mollusks
Atlantic razor *(Siliqua costata)*
Chestnut astarte *(Astarte castanea)*
Convex slipper shell *(Crepidula plana)*
Dog welk *(Nassarius trivittatus)*
Northern moon shell *(Lunatia triseriata)*
Pearly top snail *(Margarites groenlandicus)*

Cnidarians
Northern red anemone *(Urticina felina)*

Echinoderms
Dwarf brittlestar *(Amphipholis squamata)*

Bryozoans
Lacy crusts *(Electra pilosa)*

Chaetognatha
Arrow worm *(Chaetognatha sp.)*

Habitat 9 (219 Samples):
High and mid-postion flats at moderate depth (42 - 101 m) on fine to medium sand.

Annelids
Beard worm *(Pogonophora sp.)*
Mosaic worm *(Nothria conchylega)*

Arthropods
Acadian hermit crab *(Pagurus acadianus)*

Mollusks
Convex slipper shell *(Crepidula plana)*
Jingle shell *(Anomia simplex)*

Echinoderms
Green sea urchin *(Strongylocentrotus droebachiensis)*
Northern sea star *(Asterias vulgaris)*
Spiny sun star *(Crossaster papposus)*

Habitat 12 (56 Samples):
Steep slopes and flats at depths over 69 m, on fine to medium sand.

Arthropods
Sand shrimp *(Crangon septemspinosa)*
Other amphipods *(Diastylis quadrispinosa*, *D. sculpta)*

Mollusks
Bean mussel *(Crenella glandula)*
Black Clam *(Arctica islandica)*

Cone snail *(Oenopota harpularia)*
Hatchet shell *(Thyasira equalis, T. trisinuata)*
Northern moon snail *(Euspira immaculata)*
Paper bubble *(Philine quadrata)*
Rusty axinopsid *(Mendicula ferruginosa)*
Solitary glassy bubble *(Retusa obtusa)*
Top snail *(Solariella obscura)*

Bryozoans and Protozoans
Tessarodoma gracilis
Foraminiferida

Echinoderms
Dwarf brittle star *(Axiognathus squamatus)*
Sea cucumber *(Stereoderma unisemita)*

Habitat 24 (139 Samples):
Mid-position flats at moderate depths (70 - 101 m) on silt to fine sand.

Arthropods
Mysid shrimp *(Pseudomma affine)*
Cumacea *(Petalosarsia declivis, Lamprops quadriplicata)*

Habitat 1 (153 Samples):
High flats and slopes at any depth on silt, fine sand or sand.

Arthropods
Bristled longbeak shrimp *(Dichelopandalus leptocerus)*

Mollusks
Northern shorfin squid *(Illex illecebrosus)*

Echinoderms
Basket star *(Gorgonocephalus eucnemis)*

***Habitat 139** (90 Samples):
Various seabed postions in moderately shallow water (42 - 70 m) on fine to medium to coarse sand. Not a habitat type, but listed here for completeness.

No diagnostic species, samples largely empty – some squid *(Sepioidea)*

Habitat 2 (116 Samples):
Flats and slopes at moderate depth (70 - 233 m) on very coarse sand or pebbles.

Arthropods
Spiny lebbeid *(Lebbeus groenlandicus)*
Aesop shrimp *(Pandalus montagui)*
Sars shimp *(Sabinea sarsii)*

***Habitat 4** (791 Samples):
Any seabed form at any depth and any substrate. Not a habitat type, but included in this list for completeness.

Apparently poor samples, no diagnostic species, samples mostly krill *(Euphausia krohni)*

Habitat 247 (62 Samples):
Depressions and high flats in moderate to deep water (101 - 233 m) on silt and mud.

Arthropods
Pink glass shrimp *(Pasiphaea multidentata)*
Northern shrimp *(Pandalus borealis)*
Other decapods *(Geryon quinquedens)*

Habitat 7: (157 samples)
Depressions, and high flats and slopes, in deep water (143 - 233 m) mostly on silt and fine sand, but substrate is variable.

Annelids
Plumed worm *(Onuphis opalina)*
Sea mouse *(Laetmonice filicornis)*

Arthropods
Arctic eualid *(Eualus fabricii)*
Friendly blade shrimp *(Spirontocaris liljeborgii)*
Hermit crab *(Pagurus pubescens)*
Norwegian shrimp *(Pontophilus norvegicus)*
Parrot shrimp *(Spirontocaris spinus)*
Polar lebbeid *(Lebbeus polaris)*
Pycnogonum *(Pycnogonum littorale)*
Sea spider *(Nymphon grossipes, Nymphon longitarse, Nymphon*

macrum, Nymphon stroemi)
Other amphipods *(Epimeria loricata, Haploops tubicola, Stegocephalus inflatus)*
Other decopods *(Stereomastis sculpta)*

Mollusks
Arctic rock borer *(Hiatella arctica)*
Ark shell *(Bathyarca pectunculoides)*
Bean mussel *(Crenella pectinula)*
Broad yoldia *(Yoldia thraciaeformis)*
Chalky macoma *(Macoma calcarea)*
Astarte *(Astarte elliptica, A. subequilatera, A. undata)*
Chiton-like mullusk *(Amphineura sp.)*
Cone snail *(Pleurotomella packardi)*
Cup-and-saucer limpet *(Crucibulum striatum)*
Dipperclam *(Cuspidaria fraterna, C. glacialis)*
Dove shell *(Anachis haliaecti)*
Duckfoot snail *(Aporrhais occidentalis)*
Heart clam *(Cyclocardia borealis)*
Jingle shell *(Anomia aculeata)*
Keyhole limpet *(Puncturella noachina)*
Little cockle *(Cerastoderma pinnulatum)*
Moon snail *(Natica clausa)*
Mussel *(Musculus discors, M. niger)*
Northern moon shell *(Lunatia pallida)*
Nutclam *(Nuculana pernula)*
Nutmeg snail *(Admete couthouyi)*
Occidental tuskshell *(Antalis occidentale)*
Offshore octopus *(Bathypolypus arcticus)*
Pearly top snail *(Margarites costalis)*
Stimpson's whelk *(Colus pygmaeus)*
Ten-ridged whelk *(Neptunea decemcostata)*
Top shell *(Calliostoma occidentale)*
Turret snail *(Tachyrhynchus erosus)*
Velvet snail *(Velutina laevigata)*
Waved whelk *(Buccinum undatum)*
Wentletraps *(Epitonium greenlandicum)*
Yoldia *(Yoldiella lucida)*
Other bivalves *(Cyclopecten pustulosus)*

Brachipods and Bryozoans
Lamp shell *(Brachiopoda)*
Other bryozoan *(Bugula sp., Caberea ellisii, Idmonea atlantica)*

Chordates
Cactus sea squirt *(Boltenia ovifera)*

Cnidarians
Sea feather *(Pennatula aculeata)*
Soft coral *(Alcyonacea spp.)*

Echinoderms
Blood star *(Henricia sanguinoleata)*
Brittle star *(Ophiocten sericeum, Ophiura sarsi, Amphiura otteri, Ophiopholis amphiuridae)*
Cushion star *(Leptychaster arcticus)*
Hairy sea cucumber *(Havelockia scabra)*
Margined sea star *(Psilaster andromeda)*
Orange-footed cucumber *(Cucumaria planci)*
Psolus cucumber *(Psolus phantapus)*
Scarlet psolus cucumber *(Psolus fabricii)*
Sea urchin *(Brisaster fragilis)*
Sun star *(Lophaster furcifer)*
Other sea stars *(Diplopteraster multiples, Poraniomorpha hispida)*
Sea lilies *(Crinoidea sp.)*

Habitat 18 (204 Samples):
High flats at moderate to deep depths (over 101 m) on silt to fine sand.

Annelids
Bristle worm *(Trochochaeta carica)*
Clam worm *(Ceratocephale loveni)*
Thread worm *(Abyssoninoe winsnesae, Lumbrineris magalhaensis)*
Plumed worm *(Onuphis opalina)*
Others polychaetes *(Paramphinome pulchella)*

Arthropods
Horned krill shrimp *(Meganyctiphanes norvegica)*
Cumacea *(Eudorella truncatula)*
Other amphipods *(Tmetonyx cicada)*
Other decapods *(Calocaris templemanni, Stereomastis sculpta)*
Other isopods *(Politolana impressa)*

Mollusks
Alvania *(Alvania pelagica)*
Baltic macoma *(Macoma baltica)*
Broad yoldia *(Yoldia thraciaeformis)*
Cone snail *(Oenopota exarata)*
Conrad's thracia *(Thracia myopsis)*
Dipperclam *(Cuspidaria parva)*
Hatchet shell *(Thyasira equalis, T. gouldii, T. pygmaea, T. trisinuata)*
Mussel *(Dacrydium vitreum)*
Nutclam *(Nucula proxima)*
Softshell Clam *(Mya arenaria)*
Tusk shells *(Polyschides rushii)*
Yoldia *(Yoldia regularis)*

Echinoderms
Brittle star *(Ophiocten sericeum, Ophiura robusta)*

Habitat 87 (132 Samples):
Depressions and high flats at moderate depths (101 - 233 m) on silt and mud.

Arthropods
Sevenline shrimp *(Sabinea septemcarinata)*
Prawn *(Sergestes arcticus)*

Echinoderms
Mud star *(Ctenodiscus porcell)*

Deep 143 - 233 m

Habitat 72 (152 Samples):
Depressions and high flats at deep depths (143 - 233 m) on silt and mud.

Arthropods
Shrimp *(Pandalus propinquus)*
Others amphipods *(Epimeria loricata)*

Habitat 8 (266 Samples):
Depressions and side slopes in deep water (143 - 233 m) on silt and mud.

Annelids
Bristle worm *(Trochochaeta carica)*
Clam worm *(Ceratocephale loveni)*
Thread worm *(Abyssoninoe winsnesae, Lumbrineris magalhaensis)*
Plumed worm *(Onuphis opalina)*
Other polychaetes *(Paramphinome pulchella)*

Arthropods
Horned krill shrimp *(Meganyctiphanes norvegica)*
Other decopods *(Stereomastis sculpta)*

Mollusks
Alvania *(Alvania pelagica)*
Broad yoldia *(Yoldia thraciaeformis)*
Conrad's thracia *(Thracia myopsis)*
Dipper clam *(Cuspidaria parva)*
Hatchet shell *(Thyasira equalism, T. gouldii, T. pygmaea, T. trisinuata)*
Mussel *(Dacrydium vitreum)*
Nutclam *(Nucula proxima)*
Softshell Clam *(Mya arenaria)*
Tusk shells *(Polyschides rushii)*
Yoldia *(Yoldia regularis)*

Echinoderms
Brittle star *(Ophiocten sericeum)*

Habitat 5 (130 Samples):
Depressions, high flats and slopes in deep water (101 - 233 m) on silt, fine sand and sand.

Annelids
Sea mouse *(Aphrodita hastata)*

Arthropods
Shrimp *(Pandalus propinquus)*

Habitat 103 (42 Samples):
High slopes, steep slopes and depressions in deep water (over 233 m) on silt and fine sand.

Arthropods
Prawn *(Sergestes arcticus)*
Pink glass shrimp *(Pasiphaea multidentata)*

Southern New England

Table 3-7. Physical factor values that correspond to ecological thresholds in the Southern New England subregion.

Bathymetry (m)	Sediment Grain Size (mm)	Seabed Form
0-9	0-0.03 (mud and silt)	Depression
9-23	0.03- 0.16 (very fine sand)	Mid Flat
23-31	0.16-0.34 (fine sand)	High Flat
31-44	0.34 -0.36 (sand)	Low Slope
44-76	>=0.36 (medium and coarse sand)	Sideslope
76-139		Steep
>=139		

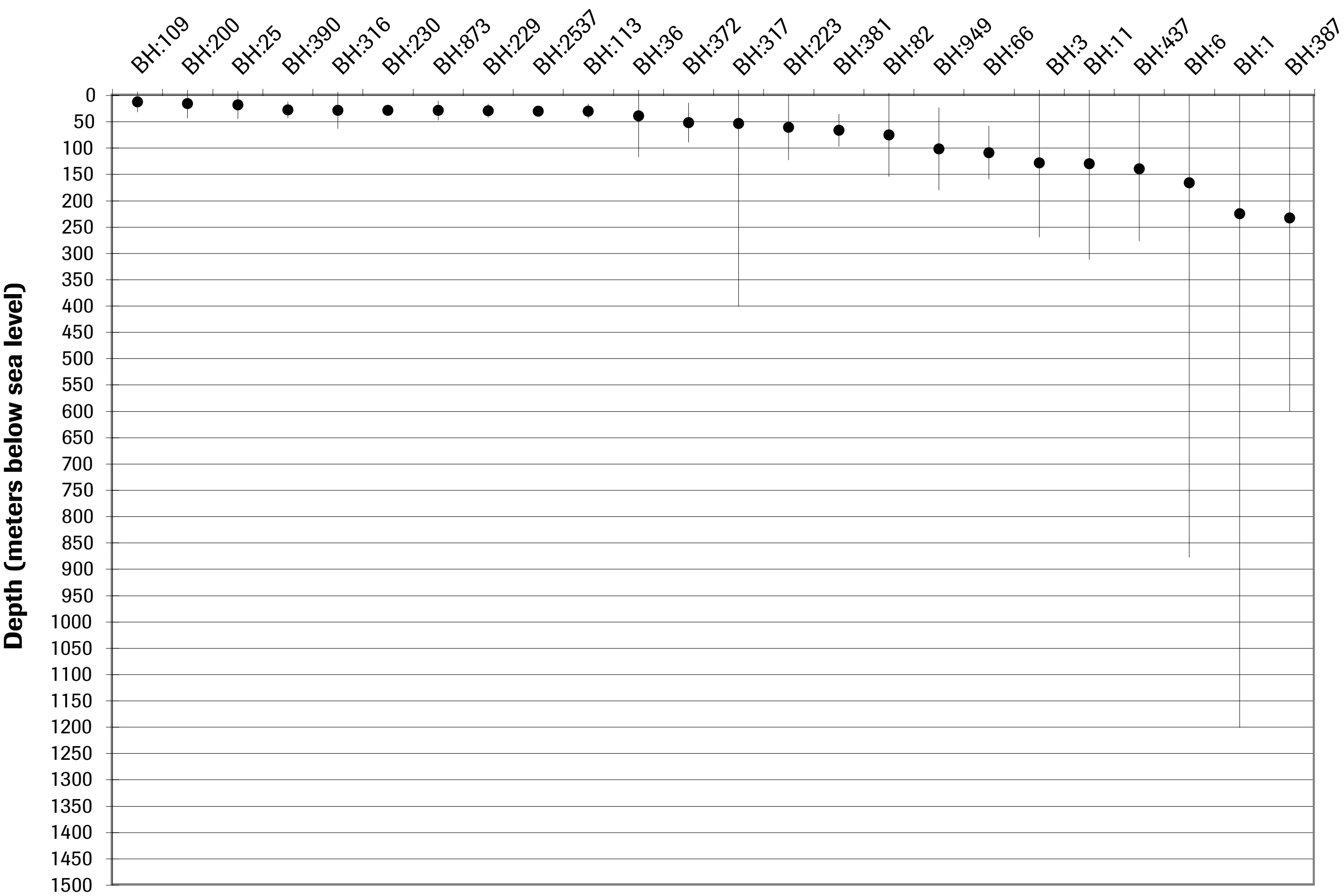


Figure 3-17. Average depth and range of each benthic habitat type in the Southern New England subregion. Lines represent two standard deviations above and below the mean. Habitat types with the same depths often differ from each other by sediment grain size or topographic location. Habitats with very large depth ranges are widespread associations unrelated to, or weakly correlated with, depth.

Shallow (0 - 31 m)

Habitat 109 (134 Samples):
Depressions in very shallow water (0 - 23 m) mostly on medium to coarse sand but occasionally on silt.

Annelids
Others polychaetes *(Maldanopsis elongate, Sigambra tentaculata)*
Bamboo worm *(Euclymene collaris, Owenia fusiformis)*
Blood worm *(Glycera americana)*
Burrowing scale worm *(Sthenelais boa)*
Clam worm *(Neathes succinea)*
Spionid mud worm *(Polydora ligni, Spio filicornis, Streblospio benedicti)*
Orbiniid worm *(Scoloplos acutus)*
Paddle worm *(Eteone heteropoda, Eumida sanguinea)*
Spaghetti-mouth worm *(Ampharete arctica, Melinna cristata)*
Syllid worm *(Exogone dispar)*
Terebellid worm *(Polycirrus medusa)*
Thread worm *(Heteromastus filiformis)*

Arthropods
Bay barnicle *(Balanus improvisus)*
Longwrist hermit crab *(Pagurus longicarpus)*
Other amphipods *(Ampelisca abdita, Corophium bonelli, Corophium insidiosum, Microdeutopus gryllotalpa, Unciola serrata)*

Mollusks
Channeled barrel-bubble *(Acteocina canaliculata)*
Common razor clam *(Ensis directus)*
Slipper shell *(Crepidula convex, C. fornicata)*
Dog welk *(Nassarius trivittatus)*
False anglewing *(Petricola pholadiformis)*
File yoldia *(Yoldia limatula)*
Gould's pandora *(Pandora gouldiana)*
Hard-shelled clam *(Venus gallina)*
Little surf clam *(Mulinia lateralis)*
Northern quahog *(Mercenaria mercenaria)*
Paper clam *(Lyonsia hyalina)*
Pyramid snail *(Turbonilla elegantula)*
Softshell clam *(Mya arenaria)*
White baby ear *(Sinum perspectivum)*
Other bivalves *(Mysella planulata)*

Habitat 200 (163 Samples):
Depressions at very shallow to moderate depths (0 – 44 m) on very fine to medium sand.
Annelids
Sludge worm *(Peloscolex gabriellae)*

Mollusks
Pitted baby-bubble *(Acteon punctostriatus)*

Habitat 25 (492 Samples):
Flats and side slopes in very shallow to shallow water (0 - 23 m) on fine to coarse sand.

Annelids
Blood worm *(Hemipodus roseus)*
Mageloni worm *(Magelona rosea)*
Spionid mud worm *(Scolelepis squamata)*
Shimmy worm *(Nephtys bucera)*
Other polychaetes *(Pisione remota)*

Arthropods
Glass shrimp *(Leptochelia savignyi)*
Hermit crab *(Pagurus politus)*
Cumacea *(Leptocuma minor)*
Tanaidacea *(Leptognathia caeca)*
Other isopods *(Chiridotea arenicola)*
Other amphipods *(Acanthohaustorius millsi, A. similis, Ampelisca verrilli, Parahaustorius attenuatus, P. longimerus, Protohaustorius sp.)*

Mollusks
Surf clam *(Spisula solidissima)*

Habitat 36 (61 Samples):
Depressions and high flats in very shallow to moderate depths (0 – 75 m) on medium to coarse sand.

Arthropods
Green crab *(Carcinus maenas)*
Portly spider crab *(Libinia emarginata)*

Mollusks
Bittium snail *(Bittium alternatum)*
Egg cockle *(Laevicardium mortoni)*

Habitat 390 (117 Samples):
Depressions in shallow water (23 - 44 m) in very fine to fine sand.

Annelids
Feather duster worm *(Euchone rubrocincta)*
Fringeworm *(Tharyx acutus, T. annulosus)*
Paraonid worm *(Aricidea jeffreysii, Paraonides lyra)*
Other polychaetes *(Protodrilus sp., Schixtomeringos caecus)*

Arthropods
Other amphipods *(Elasmopus laevis)*

Mollusks
Oval yoldia *(Yoldia myalis)*
Pyramid snail *(Odostomia sp.)*
Swamp snail *(Hydrobia minuta)*
Northern dwarf tellin *(Tellina agilis)*

Habitat 316 (301 Samples):
Flats in shallow water (8-44 m) on very fine to medium sand.

Annelids
Other polychaetes *(Polygordius triestinus, Protodrilus symbioticus)*
Bamboo worm *(Clymennella zonalis)*
Mageloni worm *(Magelona riojai)*

Arthropods
Other amphipods *(Protohaustorius sp.)*
Other isopods *(Chiridotea tuftsi)*

Habitat 230 (227 Samples):
Depressions in shallow depths (23 - 44 m) on very fine sand.

Annelids
Burrowing scale worm *(Sthenelais limicola)*
Fan worm *(Potamilla reniformis)*
Spionid mud worm *(Polydora quadrilobata)*
Other polychaetes *(Autolytus cornutus, Pherusa affinis)*

Arthropods
Other amphipods *(Ischyrocerus sp., Photis pollex)*

Mollusks
Pyramid snail *(Fargoa gibbosa)*

Habitat 873 (113 Samples):
Flats and side slopes in shallow water (8 - 31 m) on very fine to medium sand.

Annelids
Blood worm *(Glycera dibranchiata)*
Bristle worm *(Spiophanes bombyx)*
Thread worm *(Lumbrineris fragilis)*
Spionid mud worm *(Prionospio malmgreni)*
Shimmy worm *(Nephtys picta, N. schmitti)*
Other polychaetes *(Haploscoloplos fragilis, Phyllodoce arenae, Scoloplos armiger)*

Mollusks
Atlantic razor *(Siliqua costata)*

Habitat 229 (225 Samples):
Depressions in shallow depths (8.4 to 44 meter) on very fine sand.

Annelids
Bamboo worm *(Asychis elongata)*
Blood worm *(Glycera robusta)*
Clam worm *(Neanthes virens)*
Spionid mud worm *(Scolelepis bousfieldi, Spio setosa)*
Other polychaetes *(Haploscoloplos robustus)*

Arthropods
Cephalocarid *(Hutchinsonella macracantha)*
Other isopods *(Politolana polita)*

Mollusks
Black Clam *(Arctica islandica)*
Conrad's thracia *(Thracia sp.)*
False Quahog *(Pitar morrhuana)*
Little Cockle *(Cerastoderma pinnulatum)*
Nutclam *(Nucula proxima)*
Pyramid snail *(Turbonilla sp.)*
Other gastropods *(Acteocina oryza)*

Cnidarians
Lined anemone *(Edwardsia sipunculoides)*

Echinoderms
Rat tailed cucumber *(Caudina arenata)*

Habitat 2537 (37 Samples):
Depressions and high flats in shallow water (23 - 31 m) on very fine to fine sand.

Annelids
Clam worm *(Nereis zonata)*
Hesion worm *(Microphthalmus sczelkowii)*
Paddle worm *(Eteone flava)*
Plumed worm *(Diopatra cuprea)*
Thread worm *(Capitella capitata)*

Arthropods
Atlantic rock crab *(Cancer irroratus)*
Lady Crab *(Ovalipes ocellatus)*
Other amphipods *(Melita nitida)*

Habitat 36 (61 Samples):
Depressions and high flats in very shallow to moderate depths (0 – 75 m) on medium to coarse sand.

Arthropods
Green crab *(Carcinus maenas)*
Portly spider crab *(Libinia emarginata)*

Mollusks
Bittium snail *(Bittium alternatum)*
Egg cockle *(Laevicardium mortoni)*

Moderate Depths (31 - 76 m)

Habitat 113 (314 Samples):
Depressions and mid-position flats at moderate depths (23 - 44 m) on very fine sand.

Annelids
Paddle worm *(Parougia caeca)*
Paraonid worm *(Paraonis fulgens)*
Spaghetti-mouth worm *(Asabellides oculata)*
Other polychaetes *(Paranaitis speciosa)*

Arthropods
Other amphipods *(Dulichia monocantha)*

Habitat 372 (125 Samples):
Depressions and los slopes at moderate depths (44 – 75 m) on very fine sand.

Annelids
Feather duster worm *(Euchone incolor)*
Fringe worm *(Tharyx dorsobranchialis, T. marioni)*
Thread worm *(Cossura longocirrata, Lumbrineris hebes, Ninoe nigripes)*
Spionid mud worm *(Polydora socialis, Prionospio steenstrupi)*
Paddle worm *(Eteone lacteal, E. longa)*
Paraonid worm *(Acmira catherinae, Aricidea quadrilobata, Tauberia gracilis)*
Scale worm *(Hartmania moorei, Pholoe minuta)*
Shimmy worm *(Nephtys incisa)*
Other polychaetes *(Apistobranchus typicus, Drilonereis longa, Mediomastus ambiesetae, Polycirrus sp.)*

Arthropods
Cumacea *(Campylaspis affinis, Campylaspis rubicund, Diastylis abbreviate, D. cornuifer, Jassa falcata, Leptostylis longimana)*
Other amphipods *(Argissa hamatipes, Metopa angustimana, Photis macrocoxa, Stenopleustes)*
Other isopods *(Edotea acuta)*

Mollusks
Alvania *(Alvania carinata)*
Nutclam *(Nucula delphinodonta)*
Short yoldia *(Yoldia sapotilla)*

Echinoderms
Burrowing anemone *(Edwardsia elegans)*
Twelve-tentacle burrowing anemone *(Halcampa duodecimcirrata)*

Phoronids
Horseshoe worm *(Phoronis architecta)*

Habitat 317 (190 Samples):
Mid-position flats at moderate depths (31 - 75 m) on fine to medium sand.

Annelids
Bamboo worm *(Clymenura dispar, Euclymene zonalis)*
Burrowing scale worm *(Sigalion areicola)*
Chevron worm *(Goniadella gracilis)*
Feather duster worm *(Euchone elegans)*
Fringe worm *(Caulleriella killariensis, Chaetozone setosa)*
Thread worm *(Lumbrinerides acuta, Lumbrineris acicularum)*
Orbiniid worm *(Orbinia swani, Scoloplos acmeceps)*
Paraonid worm *(Aricidea wassi, Cirrophoris brevicirratus, C. furcatus, Paraonis pygoenigmatica)*
Sandbar worm *(Ophelia denticulata)*
Scale worm *(Harmothoe extenuata)*
Shimmy worm *(Aglaophamus circinata)*
Spionid mud worm *(Polydora caulleryi)*
Syllid worm *(Exogone hebes, Sphaeroyllis erinaceus, Streptosyllis arenae, Syllides sp.)*
Other polychaetes *(Drilonereis magna)*

Arthropods
Acadian hermit crab *(Pagurus acadianus)*
Lysianisid shrimp *(Hippomedon serratus)*
Sand shrimp *(Crangon septemspinosa)*
Cumacea *(Petalosarsia declivis)*
Tanaidacea *(Tanaissus lilljeborgi)*
Other amphipods *(Acanthohaustorius spinosus , Byblis serrata, Corophium crassicorne, Pseudunciola obliquua, Phoxocephalus holbolli, Protomedeia fasciata, Monoculodes sp., Rhepoxynius hudsoni, Siphonoecetes sp., Unciola inermis)*
Other isopods *(Cirolana polita)*

Mollusks
Chestnut astarte *(Astarte castanea)*
Northern moon shell *(Lunatia triseriata)*
Northern moonsnail *(Euspira immaculata)*
Paper clam *(Lyonsia arenos)*
Pearly top snail *(Margarites groenlandicus)*
Stimpson's whelk *(Colus pygmaeus)*
Top snail *(Solariella obscura)*

Echinoderms
Common sand dollar *(Echinarachnius parma)*

Habitat 223 (98 Samples):
Mid-position flats and depressions at moderate depths (44 - 75 m) on fine to medium sand.

Annelids
Bristle worm *(Spiophanes kroeyeri)*
Terebellid worm *(Polycirrus eximius)*

Arthropods
Cumacea *(Eudorella emarginata, E. truncatula, Eudorellopsis deformis)*
Other amphipods *(Ampelisca macrocephala, A. vadorum, Dyopedos porrectus, Ericthonius rubricornis, Leptocheirus pinguis, Orchomella pinguis, Rhepoxynius epistomus, Unciola irrorata)*
Other decapods *(Stereomastis sculpta)*
Other isopods *(Idotea balthica)*

Mollusks
Bean mussel *(Crenella pectinula)*
Hatchet shell *(Thyasira gouldii)*
Mussel *(Musculus niger)*
Pyramid snail *(Turbonilla interrupta)*
Other gastropods *(Cylichma gouldi, C. alba)*

Nemerteans
Ribbon worm *(Nermertea spp.)*

Sipunculids
Tube worm *(Phascolion strombi)*

Habitat 381 (99 Samples):
Mid and high position flats in moderate depths (44 - 79 m) on fine to very fine sand.

Annelids
Bristle worm *(Spiophanes wigleyi, Sternaspis fossor, Terebellides atlantis)*
Chevron worm *(Goniada maculata)*
Clam worm *(Nereis grayi)*
Fan worm *(Myxicola infundiliulum)*
Feather duster worm *(Chone infundibuliformis)*
Thread worm *(Lumbrineris magalhaensis)*
Spionid mud worm *(Laonice cirrata)*
Paraonid worm *(Acmira cerruti)*
Sandbar worm *(Ophelina acuminata)*
Scale worm *(Gattyana amondseni, Harmothoe imbricata)*
Sea mouse *(Aphrodita hastata)*
Spaghetti-mouth worm *(Melinna elisabethae)*
Sphaerod worm *(Sphaerodoropsis minuta)*
Syllid worm *(Exogone verugera)*
TereblIid worm *(Nicolea venustula, Polycirrus phosphoreus, Streblosoma spiralis)*
Thread-like worm *(Notomastus latericeus, Notomastus luridus)*
Other polychaetes *(Anobothrus gracilis, Asychis biceps, Brada villosa, Clymenella torquata, Leitoscoloplos mamosus, Myriochelle oculata, Praxillura ornate, Protodorvillea gaspiensis, Rhodine gracilior, Scalibregma inflatum)*

Arthropods
Cumacea *(Eudorella pusilla)*
Long-horned skeleton shrimp *(Aeginina longicornis)*
Other amphipods *(Ampelisca agassizi, Anonyx liljeborgi, A. sarsi, Casco bigelowi, Diastylis quadrispinosa, D. sculpta, Eriopisa elongate, Ericthonius brasiliensis, Ericthonius fasciatus, Harpinia propinqua, Melita sp., Orchomene minuta, Photis dentata)*
Other decapod *(Axius serratus)*
Other isopods *(Pleurogonium inerme, P. runicundum, P. spinossimum, Ptilanthura tenuis, P. tricarina)*

Mollusks
Alvania *(Alvania exarata)*
Arctic paper-bubble *(Diaphana minuta)*
Astarte *(Astarte undata)*
Bean mussel *(Crenella decussate, C. glandula)*
Hatchet shell *(Thyasira flexuosa, T. trisinuata)*
Spoon shell *(Periploma fragile, P. papyratium)*
Stimpson's whelk *(Colus pubescens)*

Echinoderms
Sea cucumber *(Pentamera calcigera)*
Slender-armed star *(Leptasterias tenera)*

Bryozoans
A bryozoan *(Hippodiplosia propinqua)*

Hemichordates
Acorn worm *(Stereobalanus canadensis)*

Moderate to Deep Depths (76 - 139 m)

Habitat 82 (92 Samples):
All types of flats in moderately deep water (44 – 139 m) on medium to coarse sand.

Mollusks
Sea scallop *(Placopecten magellanicus)*
Cup-and-saucer limpet *(Crucibulum striatum)*
Limpet *(Acmaea testudinalis)*

Echinoderms
Green sea urchin *(Strongylocentrotus droebachiensis)*

Habitat 949 (31 Samples):
Mid and low flats in deep water (75-139 m) on medium to fine sand.

Mollusks
Longfin squid *(Loligo pealeii)*

Habitat 66 (121 Samples):
Hihg flats and slopes in moderately deep water (75 - 139 m) on very fine to fine sand.

Annelids
Bamboo worm *(Paralacydonia paradoxa)*
Fringe worm *(Tharyx tesselata)*
Hesion worm *(Gyptis vittata)*
Thread worm *(Lumbrineris brevipes)*
Shimmy worm *(Aglaophamus minusculus)*

Echinoderms
Dwarf brittlestar *(Amphipholis squamata)*

Cnidarians
Slender sea pen *(Stylatula elegans)*

***Habitat 3** (78 Samples):
Flats and slopes at moderate to very deep depths (average 128 m, min 44 m) on fine to very fine sand.

No diagnostic species, samples largely empty except for deep sea *Spirula* squid (*Sepioidea).* Not a benthic habitat type, but listed here for completeness.

Habitat 11 (78 Samples):
High slopes, canyons, flats in deep water (60 – 485 m) on medium to fine sand.

Arthropods
Shrimp *(Pontophilus brevirostris)*
Arthropods *(Pycnogonum littorale)*
Bristled longbeak shrimp *(Dichelopandalus leptocerus)*
Deepwater humpback shrimp *(Solenocera necopina)*
Friendly blade shrimp *(Spirontocaris liljeborgii)*
Hermit crab *(Catapagurus sharreri)*
Krill *(Thysanoessa longicaudata)*
Parrot shrimp *(Spirontocaris spinus)*
Rose shrimp *(Parapenaeus politus)*
Sand shrimp *(Crangon septemspinosa)*
Shrimp *(Palicus gracilis)*
Slender tube makers *(Ericthonius difformis)*
Squat lobsters *(Munida valida)*
Striped barnacle *(Balanus hameri)*
Other amphipods (*Monoculodes spp.*, *Tiron acanthurus*)

Mollusks
Bobtail squid *(Rossia tenera)*
Iceland cockle *(Clinocardium ciliatum)*
Iceland scallop *(Chlamys islandica)*
Offshore octopus *(Bathypolypus arcticus)*
Rock borer clam *(Panomya arctica)*

Cnidarians
Badge sea star *(Porania insignis)*
Blood star *(Henricia sanguinoleata)*
Margined sea star *(Astropecten americana)*
Northern sea star *(Asterias vulgaris)*

Habitat 437 (34 Samples):
High flats and slopes in deep to very deep water (75 - 200 m) on fine sand.

Arthropods
American Lobster *(Homarus americanus)*
Jonah Crab *(Cancer borealis)*
Swimming crab *(Bathynectes superba)*
Other decapods *(Geryon quinquedens)*

Mollusks
Northern shortfin squid *(Illex illecebrosus)*
Longfin squid *(Loligo pealeii)*

Echinoderms
Margined sea stars *(Astropecten cingulatus)*

Habitat 6 (105 Samples):
High slopes and flats at moderate to deep depths (44 - 139 m) on coarse to fine sand.

Arthropdoda
Aesop shrimp (*Pandalus montagui*)
Arctic lyre crab (*Hyas coarctatus*)
Hermit crab (*Pagurus pubescens*)

Mollusks
Chiton-like mullusk (*Amphineura spp.*)
Arctic rock borer (*Hiatella arctica*)
Jingle shell (*Anomia simplex*)
Mussel (*Musculus discors*)

Echinoderms
Daisy brittle star
(*Ophiopholis amphiuridae*)
Green sea urchin
(*Strongylocentrotus droebachiensis*)

***Habitat 1** (627 Samples):
Variable settings in a wide range of depths on fine to coarse sand. A very mixed set of samples with many unidentified species and few commonalities. Not a benthic habitat type, but listed here for completeness.

Deep to Very Deep (> 139 m)

Habitat 387 (29 Samples):
High slopes and flats in very deep water (>139 m) on fine sand.

Annelids
Beard worm *(Siboglinum ekmani)*
Plumed worm *(Onuphis opalina)*
Fairy shrimp *(Erythrops erythrophthalma)*
Cumacea *(Eudorella hispida)*

Molluks
Ark shell *(Bathyarca pectunculoides)*
Chestnut Astarte *(Astarte subequilatera)*
Nutclam *(Nuculana acuta)*
Occidental Tuskshell *(Antalis occidentale)*
Rusty Axinopsid *(Mendicula ferruginosa)*
Other bivalves *(Lucina filosa)*

Echinoderms
Sea butterfly *(Thecosomata)*
Burrowing brittle star *(Amphioplus macilentus, Amphilimna olivacea)*

Hemichordates
Acorn worm *(Enteropneusta)*

Nemotoda
Round worm *(Nematoda)*

Protozoans
Foraminiferida

Sipunculids
Peanut worm (*Golfingia catharinae, Onchnesoma steenstrupi*

Mid-Atlantic Bight

Table 3-8. Physical factor values that correspond to ecological thresholds in the Mid-Atlantic Bight subregion.

Bathymetry (m)	Sediment Grain Size (mm)	Seabed Form
0-15	0-0.18 (silt and very fine sand	Depression
15-22	0.18-0.35 (fine sand)	Mid Flat
22-45	0.35-0.36 (sand)	High Flat
45-48	0.36 -0.48 (sand)	Low Slope
48-82	>=0.48 (coarse sand)	Sideslope
82-95		Steep
95-592		
>592		

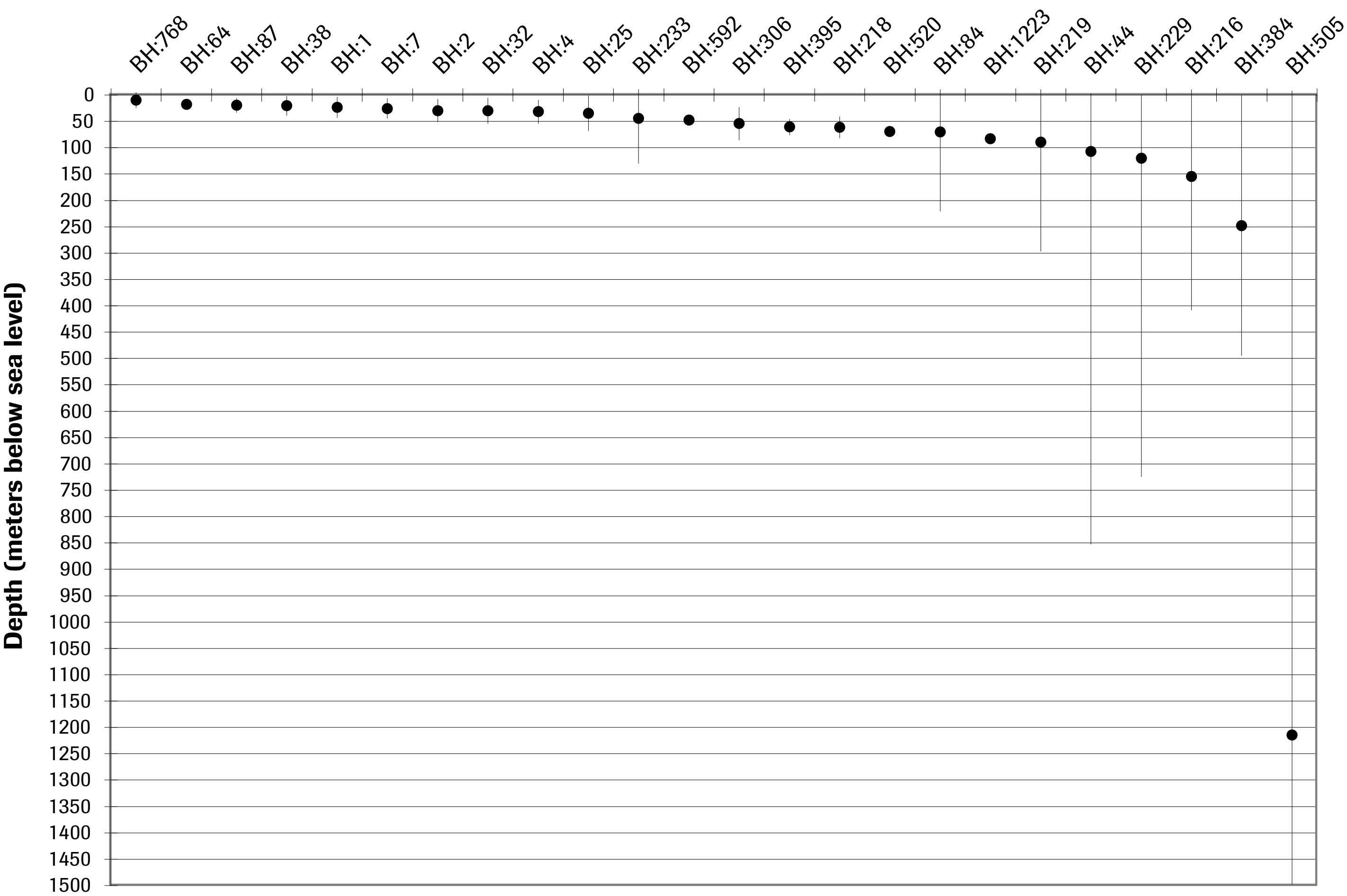


Figure 3-18. Average depth and range of each benthic habitat type in the Mid-Atlantic Bight subregion. Lines represent two standard deviations above and below the mean. Habitat types with the same depths often differ from each other by sediment grain size or topographic location. Habitats with very large depth ranges are widespread associations often unrelated to, or only weakly correlated with, depth.

Very Shallow (0 – 22 m)

Habitat 768 (22 Samples):
Depressions in very shallow water (0 - 15 m) on silt to fine sand.

Arthropods
Mysid shrimp *(Neomysis americana)*
Other amphipods *(Ampelisca abdita)*

Mollusks
Elongated macoma *(Macoma tenta)*
Tellin clam *(Tellina sybaritica)*
Channeled whelk *(Busycon canaliculatum)*
Cone snail *(Kurtziella cerina)*
Dove shell *(Mitrella lunata)*
Pyramid snail *(Odostomia winkleyi)*
Solitary glassy bubble *(Retusa canaliculata)*
Wentletraps *(Epitonium rupicola)*

Echinoderms
Burrowing brittle star *(Micropholis atra)*

Habitat 64 (62 Samples):
Depressions and mid-position flats in shallow water (15 and 22 m) on medium sand.

Annelids
Blood worm (*Hemipodus roseus*)
Fringe worm (*Tharyx* sp.)
Hesion worm (*Microphthalmus sczelkowii*)
Thread worm (*Lumbrineris acicularum*)
Paddle worm (*Hesionura augeneri*)
Paraonid worm (*Acmira catherinae, A. cerruti*)
Sandbar worm (*Ophelia denticulata*)
Spaghetti-mouth worm (*Ampharete arctica*)
Syllid worm (*Brania wellfleetensis, Streptosyllis pettiboneae, S. websteri, Syllides longicirrata*)
Other polychaetes (*Pisione remota*)

Arthropods
Sharp-tailed cumacean (*Oxyurostylis smithi*)
Other isopods (*Chiridotea arenicola*)

Mollusks
Blue mussel (*Mytilus edulis*)
Dove shell (*Anachis lafresnayi*)
Eastern aligena (*Aligena elevata*)

Habitat 87 (20 Samples):
Depressions and high flats in shallow water (15 - 22 m) on medium sand.

Annelids
Burrowing scale worm *(Sigalion areicola)*
Fringe worm *(Caulleriella killariensis)*
Mageloni worm *(Magelona riojai)*
Spionid mud worm *(Scolelepis squamata, Dispio uncinata, Polydora caulleryi)*
Sphaerod worm *(Sphaerodoropsis corrugata)*
Syllid worm *(Streptosyllis varians)*

Arthropods
Glass shrimp *(Leptochelia savignyi)*
Gammarid amphipods *(Acanthohaustorius bousfieli, A.intermedius, A. Similis)*
Other amphipods *(Bathyporeia quoddyensis, B. parkeri, B. quoddyensis, Parahaustorius attenuates, Synchelidium americanum)*
Tanaidacea *(Tanaissus lilljeborgi)*
Other isopods *(Chiridotea tuftsi)*

Echinoderms
Sand dollar *(Encope emarginata)*

Mollusks
Atlantic razor *(Siliqua costata)*
Gould's pandora *(Pandora trilineata)*
Lea's spoon shell *(Periploma leanum)*
Pandora *(Pandora trilineata)*
Surf clam *(Spisula solidissima)*
Margin shells *(Dentimargo eburneolus)*

Habitat 38 (95 Samples):
Depressions in water shallow (15 - 22 m) on medium to coarse sand.

Annelids
Bamboo worm (*Owenia fusiformis*)
Chevron worm (*Glycinde solitaria*)
Orbiniid worm (*Scoloplos rubra*)
Paddle worm (*Eteone heteropoda, Eteone lactea*)
Plumed worm (*Diopatra cuprea*)
Shimmy worm (*Nephtys picta*)
Spionid mud worm (*Paraprionospio pinnata, Polydora ligni, Prionospio pygmaea, Scolelepis bousfieldi, Spio pettiboneae, S. setosa*)
Thread worm (*Notomastus hemipodus, N. luridus*)

Arthropods
Olivepit porcelain crab (*Euceramus praelongus*)
Pea crab (*Pinnixa sayana*)
Other amphipods (*Corophium tuberculatum, Parametopella cypris*)

Mollusks
Arctic paper-bubble (*Diaphana minuta*)
Common razor clam (*Ensis directus*)
Pandora (*Pandora bushiana*)
Margin shells (*Marginella virginiana*)
Miniature moonsnail (*Tectonatica pusilla*)
Pitted baby-bubble (*Acteon punctostriatus*)
Pyramid snail (*Odostomia* sp., *Turbonilla interrupta*)
Solitary glassy-bubble (*Haminoea solitaria*)
Northern dwarf tellin (*Tellina agilis*)
Other gastropods (*Acteocina oryza*)

Hemichordates
Acorn worm (*Stereobalanus canadensis*)

Shallow (22 - 45 m)

Habitat 1(109 Samples):
Depressions and mid-position flats, shallow to moderate depth (0 - 45 m) on coarse to fine sand.

Annelids
Shimmy worm *(Nephtys bucera)*

Arthropods
Other amphipods *(Protohaustorius deichmannae, Acanthohaustorius spinosus, A. shoemakeri)*

Mollusks
Astarte *(Astarte borealis)*
Lunate crassinella *(Crassinella lunulata)*

Chordates
Lancelet *(Branchiostoma virginiae)*

Habitat 7 (83 Samples):
Mid-position flats and depressions in shallow water (25 - 45 m) on medium to coarse substrate.

Annelids
Blood worm (*Hemipodus armatus*)
Fringe worm (*Tharyx acutus, T. Annulosus*)
Hesion worm (*Microphthalmus aberrans*)
Thread worm (*Lumbrineris coccinea, L.fragilis*)
Spionid mud worm (*Prionospio malmgreni, Spio filicornis*)
Paraonid worm (*Aricidea jeffreysii, Paraonides lyra*)
Syllid worm (*Eusyllis blomstrandi, Syllis cornuta*)
Other polychaetes (*Protodrilus symbioticus*)

Arthropods
Tanaidacea (*Leptognathia caeca*)

Cnidarians
Frilled anemone (*Metridium senile*)

Echinoderms
Common sea star (*Asterias forbesi*)

Habitat 2 (58 Samples):
Flat depressions at shallow to moderate depth (0 - 45 m) in medium sand.

Annelids
Bamboo worm (*Asychis elongata*)
Burrowing scale worm (*Sthenelais boa*)
Chevron worm (*Goniada norvegica, G. carolinae*)

Flabelliger worm (*Pherusa affinis*)
Fringe worm (*Tharyx dorsobranchialis, T. marioni*)
Spionid mud worm (*Polydora quadrilobata, Streblospio benedicti*)
Paddle worm (*Eteone longa, Paranaitis speciosa*)
Paraonid worm (*Tauberia gracilis*)
Shimmy worm (*Nephtys incisa*)
Spaghetti-mouth worm (*Asabellides oculata*)
Thread-like worm (*Cossura longocirrata*)
Threadworm (*Capitella capitata*)

Arthropods
Amphipod (*Dulichia monocantha, Photis macrocoxa*)

Cnidarians
Burrowing anemone (*Edwardsia elegans*)
Sea cucumber (*Pentamera calcigera*)

Mollusks
Dog welk (*Nassarius trivittatus*)
False quahog (*Pitar morrhuana*)
File yoldia (*Yoldia limatula*)
Hard-shelled clam (*Venus gallina*)
Nutclam (*Nucula annulata, N. proxima*)
Short yoldia (*Yoldia sapotilla*)

Phoronids
Horeshoe worm (*Phoronis architecta*)

Habitat 32 (52 Samples):
Mid-position flats at shallow to moderate depths (22 - 45 m) on medium sand.

Arthropods
Atlantic rock crab *(Cancer irroratus)*
Longnose spider crab *(Libinia dubia)*

Mollusks
Common northern moon snail *(Euspira heros)*
Northern moon shell *(Lunatia triseriata)*
Astarte *(Astarte quadrans)*
Blood ark *(Anadara ovalis)*

Echinoderms
Common sand dollar *(Echinarachnius parma)*

Habitat 4 (128 Samples):
Mid-position flats in shallow water (25 - 45 m) on coarse to medium sand.

Annelids
Bamboo worm (*Clymennella zonalis*)
Chevron worm (*Goniadella gracilis*)
Thread worm (*Lumbrinerides acuta*)
Syllid worm (*Streptosyllis arenae*)
Other polychaetes (*Polygordius triestinus*)

Arthropods
Other amphipods (*Parahaustorius longimerus*)
Other isopods (*Cirolana polita, Chiridotea coeca*)

Mollusks
Chestnut astarte (*Astarte castanea*)

Moderate depth (45 - 82 m)

Habitat 25 (46 Samples):
Depressions at moderate depths (15 - 82 m) on fine to coarse sand.

Annelids
Bamboo worm (*Myriochelle heeri*)
Bristle worm (*Spiophanes bombyx, S. missionensis*)
Mageloni worm (*Magelona rosea*)
Spionid mud worm (*Scolelepis sp.*)
Orbiniid worm (*Orbinia swani*)
Shimmy worm (*Nephtys schmitti*)
Other polychaetes (*Novaquesta trifurcata*)

Arthropods
Mysid shrimp (*Neomysis Americana*)

Mollusks
Moon snail (*Natica clausa*)

Cnidarians
Lined anemone (*Edwardsia sipunculoides*)

Habitat 592 (50 Samples):
Mid-position flats at moderate depth (45 - 82 m) on medium sand.

Annelids
Bamboo worm (*Clymenella torquata, Myriochelle oculata*)
Blood worm (*Glycera dibranchiata*)
Burrowing scale worm (*Sthenelais limicola*)
Fan worm (*Potamilla reniformis*)
Fringe worm (*Cirratulus cirratus*)
Paddle worm (*Anaitides maculata*)
Paraonid worm (*Paraonis fulgens*)
Shimmy worm (*Aglaophamus circinata*)
Other polychaetes (*Leitoscoloplos mamosus*)

Arthropods
Cumacea (*Eudorellopsis deformis*)
Other amphipods (*Argissa hamatipes, Corophium crassicorne, Diastylis sculpta, Hippomedon serratus, Parahaustorius holmesi, P. borealis, P. caroliniensis, Melita dentate, Monoculodes edwardsi , Photis pollex, Pontogeneia inermis, Rhepoxynius hudsoni, Stenopleustes gracilis*)
Other isopods (*Edotea acuta, Idotea metallica*)

Mollusks
Arctic rock borer (*Hiatella arctica*)
Black clam (*Arctica islandica*)
Little cockle (*Cerastoderma pinnulatum*)
Pearly top snail (*Margarites groenlandicus*)
Sea slug (*Acanthodoris pilosa*)
Other gastropods (*Scaphander punctostriatus*)

Habitat 306 (29 Samples):
All types of flats at medium depth (45 - 82 m) on medium sand.

Arthropods
Acadian hermit crab *(Pagurus acadianus)*

Echicoderms
Daisy brittle star *(Ophiopholis amphiuridae)*

Habitat 395 (78 Samples):
Depressions and high flats at moderate depths (45 - 82 m) on fine to medium sand.

Annelids
Bamboo worm *(Clymenura dispar, Macroclymene zonalis)*
Bristle worm *(Terebellides stroemi)*
Fringe worm *(Chaetozone setosa)*
Spionid mud worm *(Polydora socialis)*
Orbiniid worm *(Scoloplos acutus)*
Sandbar worm *(Ophelina cylindricaudata)*
Scale worm *(Antinoella sarsi)*
Spaghetti-mouth worm *(Ampharete acutifrons)*
Syllid worm *(Exogone gemmifera)*
Thread worm *(Lumbrineris tenuis)*
Other polychaetes *(Drilonereis magna, Schistomeringos caecus)*

Arthropods
Other amphipods *(Ampelisca macrocephala, Siphonoecetes smithianus)*
Cumacea *(Eudorella emarginata)*

Mollusks
Moon snails *(Euspira triseriata, E. immaculata)*
Paper clam *(Lyonsia hyalina)*
Paper bubble *(Philine finmarchia)*
Pearly top snails *(Margarites helicinus, M. umbilicatus)*

Echinoderms
Sea star *(Asterias tanneri)*
Purple-spined sea urchin *(Arbacia punctulata)*

Cnidarians
Burrowing anemone *(Ceriantheopsis americana)*

Sipunculids
Tube worm *(Phascolion strombi)*

Habitat 218 (96 Samples):
Depressions at moderate depths (45 - 82 m) on medium to coarse sand.

Annelids
Bamboo worm *(Praxillura ornata)*
Clam worm *(Nereis grayi)*
Feather duster worm *(Euchone incolor)*
Flabelliger worm *(Brada villosa, Diplocirrus hirsutus, Pherusa aspera)*
Thread worm *(Lumbrineris hebes, Ninoe nigripes, Lumbrineris hebes)*
Paddle worm *(Eulalia bilineata)*
Paraonid worm *(Cirrophorus lyriformis)*
Scale worm *(Harmothoe extenuata)*
Sea mouse *(Aphrodita hastata)*
Sphaerod worm *(Sphaerodoridium claparedi, S. minuta)*
Syllid worm *(Typosyllis alternata)*
Terebellid worm *(Nicolea venustula,Polycirrus sp.)*
Other polychaetes *(Drilonereis longa, Meiodorvillea minuta, Scalibregma inflatum)*

Arthropods
Cumacea *(Petalosarsia declivis, Campylaspis affinis)*
Other amphipods *(Ampelisca vadorum, Anonyx sarsi, Casco bigelowi, Leptocheirus pinguis, Orchomella minuta, O. pinguis)*
Other isopods *(Janira alta, Pleurogonium inerme)*

Mollusks
Bean mussel *(Crenella decussata)*
Conrad's thracia *(Thracia morrisoni)*
Mussel *(Musculus discors)*
Nutclam *(Nucula delphinodonta)*
Alvania *(Alvania carinata)*
Stimpson's whelk *(Colus pubescens)*
Striate aclis *(Aclis striata)*

Cnidarians
Twelve-tentacle burrowing anemone *(Halcampa duodecimcirrata)*

520 (31 Samples):
Mid position flats and depressions at moderate depths (45 - 82) on mostly coarse to occsasionaly fine sand.

Annelids
Bamboo worm (*Rhodine gracilior, R. Loveni*)
Bristleworm (*Spiophanes wigleyi, Terebellides atlantis*)
Chevron worm (*Goniada brunnea, G.maculata, Ophioglycera gigantea*)
Clam worm (*Nereis zonata*)
Fan worm (*Myxicola infundiliulum*)
Feather duster worm (*Euchone elegans*)
Fringe worm (*Dodecaceria corallii*)
Thread worm (*Lumbrineris brevipes*)
Spionid mud worm (*Laonice cirrata, Minuspio cirrifera, Polydora giardi, Prionospio steenstrupi*)
Orbiniid worm (*Scoloplos armiger*)
Paddle worm (*Anaitides mucosa, Eumida sanguinea, Mystides boreali, Notophyllum foliosum*)
Paraonid worm (*Aricidea belgicae, Cirrophorus furcatus*)
Parchment worm (*Spiochaetopterus oculatus*)
Sandbar worm (*Ophelina acuminata*)
Scale worm (*Arcteobia anticostiensis, Gattyana nutti, Gattyana sp. Harmothoe imbricate, Pholoe minuta*)
Spaghetti-mouth worm (*Amphicteis gunneri, Melinna cristata, M.elisabethae*)
Syllid worm (*Exogone verugera, Sphaerosyllis erinaceus, Typosyllis tegulum*)
Terebellid worm (*Eupolymnia nebulosa, Polycirrus eximius, P. Medusa, Streblosoma spiralis*)
Threadworm (*Notomastus latericeus*)
Other polychaetes (*Aberranta enigmatica*)

Arthropod
Long-horned skeleton shrimp (*Aeginina longicornis*)
Cumacea (*Eudorella pusilla*)
Other amphipods (*Eriopisa elongate, Anonyx liljeborgi, Ampelisca agassizi, Diastylis quadrispinosa, Ericthonius fasciatus, Harpinia propinqua, Photis dentata, Phoxocephalus holbolli, Unciola irrorata*)
Other decapods (*Axius serratus*)

Mollusks
Astarte (*Astarte undata*)
Hatchet shell (*Thyasira flexuosa*)
Heart clam (*Cyclocardia borealis*)

Spoon shell (*Periploma fragile, P. Papyratium*)
Mussel (*Dacrydium vitreum*)
Pyramid snail (*Odistomia sulcosa*)
Risso (*Boreocingula castanea*)
Other bivalves (*Lucina filosa, Mysella planulata*)

Echinoderms
Sea star (*Asterias rathbuni*)
Dwarf brittlestar (*Amphipholis squamata*)
Margined sea star (*Astropecten irregularis*)

Bryozoans
A bryozoan (*Hippodiplosia propinqua*)

Sipunculids
Peanut worm (*Themiste alutacea*)

Habitat 84 (104 Samples):
All types of flats at moderate depth (22 - 82 m) on fine to medium sand.

Annelids
Beardworm *(Siboglinum bayer, Diplobrachia ii, Oligobrachia floridana)*
Marphysa worm *(Marphysa belli)*
Paddle worm *(Anaitides arenae)*
Sandbar worm *(Ophelina aulogaster)*

Arthropods
Cumacea *(Eudorella truncatula, Pseudoleptocuma minor)*
Other decapods *(Calocaris macandreae)*
Other amphipods *(Ampelisca verrilli, Byblis serrata, Lembos Webster,Rhepoxynius epistomus)*

Echinoderms
Heart sea urchin *(Echinocardium cordatum)*
Sea urchin *(Brisaster fragilis)*
Burrowing brittle star *(Amphioplus macilentus)*

Mollusks
Cross-hatched lucine *(Divaricella quadrisulcata)*
Bean mussel *(Crenella pectinula)*
Astarte *(Astarte elliptica)*
Gould's pandora *(Pandora gouldiana)*
Hard-shelled clam *(Chione latilirata)*
Hatchet shell *(Thyasira trisinuata)*
Lucine clam *(Lucinoma blakeanum)*
Nutclam *(Nuculana acuta)*
Dove shell *(Mitrella dissimilis)*
Margin shells *(Marginella roscida)*
Pyramid snail *(Turbonilla areolata)*
Pyramid snail *(Turbonilla rathbuni)*
Ribbed moelleria *(Moelleria costulata)*
Wentletraps *(Epitonium dallianum)*
Other bivalves *(Cyclopecten nanus)*
Other gastropods *(Granulina ovuformis)*

Deep (82 - 592 m)

Habitat 1223 (35 Samples):
High flats in moderately deep water (82 - 95 m) on medium sand.

Annelids
Bamboo worm (*Clymenura borealis, Euclymene zonalis*)
Blood worm (*Glycera robusta*)
Eunice worm (*Eunice norvegica*)
Fan worm (*Manayunkia aestuarina*)
Feather duster worm (*Chone infundibuliformis, Fabricia sabella*)
Thread worm (*Lumbrineris magalhaensis*)
Spionid mud worm (*Malacoceros indicus, Polydora barbilla, P. concharum*)
Opal worm (*Arabella iricolor, Arabella mutans*)
Orbiniid worm (*Scoloplos acmeceps*)
Paraonid worm (*Acmira lopezi, Aricidea wassi, Paraonis pygoenigmatica*)
Plumed worm (*Onuphis opalina, O. pallidula*)
Sandbar worm (*Travisia parva*)
Shimmy worm (*Aglaophamus igalis, Nephtys squamosa*)
Syllid worm (*Exogone dispar, E.hebes, E.naidina*)
Tube worm (*Hydroides dianthus*)
Other polychaetes (*Drilonereis caulleryi, Protodorvillea gaspiensis*)

Arthropods
Other amphipods (*Idunella bowenae, Jerbarnia Americana, Rhachotropis inflate, Unciola serrata*)
Other isopods (*Apanthura magnifica, Ptilanthura tricarina*)

Mollusks
Bean mussel (*Crenella glandula*)
Eastern beaded chiton (*Chaetopleura apiculata*)
Heart clam (*Pleuromeris tridentata*)
Striate scallop (*Palliolum striatum*)
Other bivalves (*Cumingia tellinoides, Diplodonta punctata, Mysella grippi*)
Other gastropods (*Cocculina beani*)

Cnidarians
Burrowing anemone (*Haloclava producta*)
Twelve-tentacle parasitic anemone (*Peachia parasitica*)

Echinoderms
Margined sea stars (*Astropecten articulatus*)

Habitat 219 (44 Samples):
High flats at moderate depths (45 - 82 m) on coarse to fine sand.

Arthropods
Prawn *(Sergestes robustus)*

Mollusks
Broad yoldia *(Yoldia thraciaeformis)*
Sea scallop *(Placopecten magellanicus)*
Jingle shell *(Anomia simplex)*
Longfin squid *(Loligo pealeii)*
Duckfoot snail *(Aporrhais occidentalis)*

Echidoderms
Mud star *(Ctenodiscus porcell)*

Habitat 44 (82 Samples):
Depressions and mid-position flats mostly very shallow (0 - 22m), but occasionally very deep on fine to coarse sand.

Arthropods
Prawn (*Sergestes arcticus*)
Jonah crab (*Cancer borealis*)
Other isopods (*Chiridotea nigrescens*)

Mollusks
Amethyst gemclam (*Gemma gemma*)
Baltic macoma (*Macoma baltica*)
Little surf clam (*Mulinia lateralis*)

Echinoderms
Northern sea star (*Asterias vulgaris*)

Habitat 229 (57 Samples):
High flats and depressions at shallow to deep depths (22 - 592 m) on a fine to medium sand.

Arthropods
Jonah crab *(Cancer borealis)*

Echinoderms
Common sea star *(Asterias forbesi)*
Northern sea star *(Asterias vulgaris)*
Green sea urchin *(Strongylocentrotus droebachiensis)*

Cnidarians
Anemone *(Actiniaria spp.)*

Habitat 216 (41 Samples):
High slopes in deep water (95 - 592 m) on medium to fine sand.

Arthropods
American lobster *(Homarus americanus)*
Bristled longbeak shrimp *(Dichelopandalus leptocerus)*
Fairy shrimp *(Bathymysis renocullata)*
Friendly blade shrimp *(Spirontocaris liljeborgii)*
Hermit crab *(Pagurus politus)*
Norwegian shrimp *(Pontophilus norvegicus)*
Rose shrimp *(Parapenaeus politus)*
Shrimp *(Palicus gracilis)*
Squat lobsters *(Munida iris, M. valida)*
Other decapods *(Nematocarcinus ensifer, Scyllarus depressus)*

Echinoderms
Margined sea stars *(Astropecten americana)*
Sea urchin *(Genocidaris maculata)*

Cnidarians
Sea feather *(Pennatula aculeata)*

Cephalopods
Bobtail squid *(Rossia glaucopis)*
Offshore octopus *(Bathypolypus arcticus)*
Squid *(Sepioidea)*

Habitat 384 (14 Samples):
High slopes and canyons in deep water (95 - 592 m) on any substrate.

Annelids
Scale worm (*Alentiana aurantiaca*)

Arthropods
Florida lobsterette (*Nephropsis aculeata*)
Royal red shrimp (*Pleoticus robustus*)
Prawn (*Sergestes arcticus*)
Swimming crab (*Bathynectes superba*)

Very Deep (> 592 m)

Habitat 505 (51 Samples):
Slopes and canyons in very deep water (>592 m) on silt and mud.

Annelids
Beardworms *(Pogonophora sp., Siboglinum angustum, S.ekmani, S. holmei, S. pholidotum, Diplobrachia similis)*

Mollusks
Dipperclams *(Cuspidaria glacialis, Cuspidaria parva)*
Hatchet shells *(Thyasira elliptica, T. equalis, T. gouldii)*
Limops *(Limopsis affinis, L. minuta)*
Nutclams *(Nucula tenuis, Nuculana carpenteri)*
Rusty axinopsid *(Mendicula ferruginosa)*
Small-ear fileclam *(Limatula subauriculata)*
Alvania *(Alvania brychia)*
Cone snails *(Mangelia bandella, Oenopota bicarinata, O. ovalis)*
Dove shell *(Anachis haliaecti, Mitrella pura)*
Sea snail *(Cylichna alba)*
Small sea snail *(Balcis stenostoma)*
Whelks *(Colus pygmaeus, C. obesus, C. pygmaeus)*
Wentletraps *(Epitonium pandion)*
Chiton-like mullusk *(Amphineura sp.)*
Occidental tuskshell *(Antalis occidentale)*
Tusk shell *(Dentalium meridionale)*
Other bivalves *(Malletia obtuse, Saturnia subovata)*

Echinoderms
Hairy sea cucmber *(Havelockia scabra)*
Rat-tailed cucumber *(Caudina arenata)*
Brittle star *(Ophiomusium lymani)*
Burrowing brittle star *(Amphiura otteri)*

Cnidarians
Soft coral *(Alcyonacea)*
Stony corals *(Zoantharia)*

Sipunculids
A sipuculid worm *(Golfingia catharinae, G. minuta)*
A tube worm *(Sipunculus norvegicus)*

Habitat 301 (34 Samples):
Any seabed form at moderate to deep depths (45 -592) on any substrate.

Mollusks
Gould's pandora *(Pandora gouldiana)*
Other bivalves *(Lucina filosa)*

Cnidarians
Calcareous coral *(Madreporaria spp.)*

Protozoans
Foraminiferida

Discussion

In the Gulf of Maine/Georges Bank/Scotian Shelf region, World Wildlife Fund and the Conservation Law Foundation conducted an earlier analysis of the seafloor, resulting in "seascapes," a concept similar to EMUs (World Wildlife Fund and Conservation Law Foundation 2006). In their approach, they used fixed depth, bottom temperature and salinity, and sediment type to define a seascape. Our approach was influenced by their work, with some differences. This analysis extends to the entire Northwest Atlantic region and depth and sediment classes were not pre-assigned, but as described above, the cluster analysis of grab samples was used to determine the ecologically relevant splits. Seabed forms were also correlated with the benthic invertebrate assemblages. In addition, temperature and salinity were explored as variables, but not used in this analysis. The assumption was that these two factors may not be geographically stable over long time periods, especially in light of climate change, and the goal was to understand the importance of enduring physical places on benthic habitats.

The thresholds used to define depth, grain size, and seabed forms for the EMUs were extracted directly from the organism data. This step was important in ensuring that the EMUs represent truly different environments as perceived by the benthic macrofauna. Moreover, this approach allowed us to sidestep the problem of determining which of the many proposed physical factor classifications is best for a given region. Finding the most important physical thresholds for each organism group in order to determine a meaningful number of EMUs to which we could link a clear organism group or set of groups was an important part of this process. The results presented here range from 108 to 168 EMUs per subregion with correspondingly different thresholds for each subregion. Because this approach used the actual types and amounts of seafloor structures, the results are not generalizable to other regions. In other words, the patterns uncovered are ecological, not physiological, and presumably somewhat different relationships between depth and grain-size and benthic assemblages would be observed in other regions.

The use of habitat complexity as a metric for separating *among* examples of the same habitat type is still being explored. The complexity of a habitat can affect whether an animal survives predation. It also affects the number of available niches. To date, habitat complexity has been shown to be correlated with a number of biological variables, including species richness, diversity, abundance, and community composition. Other variables under consideration for distinguishing and prioritizing among examples of the same habitat type include: confirmed rare species such as corals, diversity (phyla to species), size of the feature, intactness relative to human uses, and confirmed importance from other sources. As it will not be possible to conserve all examples of every benthic habitat type, these metrics are intended to help focus conservation on the most critical examples of each type.

Future Research: Demersal Fish Habitats

We will apply this methodology to demersal fish data collected over 40 years in the NMFS bottom trawl surveys. At this point, the proof-of concept analysis has been initiated for demersal fish using data from one year (2005), but the statistical analysis necessary to solidly connect the organism groups with the physical factors have not been performed. However, initial results look promising and a draft of the fish-based habitats will be completed in 2010.

Human Interactions

Benthic habitats are vulnerable to a wide variety of human activities that disturb the physical structure of seafloor sediments or alter the composition of the community. In shallow environments, soft sediment habitats are susceptible to the effects of shoreline hardening and dredging for marinas and navigation. In deeper subtidal habitats, biological resource harvest, particularly trawling in mud and sand, and overfishing affect habitat structure (Gulf of Maine Council 2005).

Commercial fishing is one of the most studied human impacts on the marine benthic environment. Bottom contact nets and dredge fisheries disturb benthic habitats as gear is dragged across the seafloor. Experimental studies suggest that up to 20% of the variability in the macrofauna composition of some benthic communities might be attributed to fishing effects. Overall effects include a decrease in the total number of species and individuals, as well as decreases in the density of several functional groups including deposit feeders, echinoderms, long-lived surface dwellers, and large epifauna (Thrush et al. 1998; Gaspar 2009). Moreover, diversity of the very small "meiofauna," the major contributor to benthic production, also decreases after trawling because of direct mortality or displacement, changes in sediment structure and geochemistry, and alterations in the abundance of predators or competitors. (Schratzberger and Jennings 2002). As these changes are identifiable over broad spatial scales, they are likely to have important ramifications for the development of sustainable fisheries that depend on productive benthic communities.

There is a need to document commercial and recreational fishing efforts on the communities mapped in this chapter, as well as the sensitivities and recovery rates of each habitat type. It may be important to address regulatory efforts pertaining to specific habitat types. For example, vulnerable habitats, such as eelgrass and cold water corals, might be protected through regulations that designate some of these areas as off-limits to bottom tending gear. Other areas, like mud, gravel and cobble, which are much more widespread, could be subjected to rotational closures (Gulf of Maine Council 2005).

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APPENDIX 1

Distribution of benthic habitats in each subregion across each physical factor (depth, sediment grain size, and seabed forms). A p-value of <0.01 for the chi-square test indicates that the observed distribution is significantly different than expected if the habitat was randomly distributed.

Gulf of Maine Benthic Habitat (Code)	Depth (m)									Sediment Grain Size (mm)						Seabed Forms						
	0-42	42-61	61-70	70-84	84-101	101-143	143-233	>=233	p-value	0-0.04 (mud and silt)	0.04-0.17 (very fine sand)	0.17-0.36 (fine sand)	0.36-0.54 (sand)	>=0.54 (coarse sand and gravel)	p-value	Depression	Mid Flat	High Flat	Low Slope	High Slope	Sideslope/Steep**	p-value
1		32%	16%	2%	46%	5%			0.00	16%		69%	15%		0.00			63%		37%		0.05
2			8%	18%	47%	28%			0.00	41%		38%	21%		0.00			90%	5%	5%		0.03
*4		1%	11%	23%	51%	14%			0.00	19%		68%	13%		0.00		53%	47%				0.00
5						37%	63%	0%	0.00	15%		67%	18%		0.00	35%		30%	22%	13%		0.24
7				12%	15%	8%	66%		0.00	39%		33%	14%	15%	0.00	55%		32%		12%		0.04
8							100%		0.00	89%		8%	3%		0.00	93%			3%		4%	0.00
9		19%	19%	42%	21%				0.00			89%	11%		0.00		88%	12%				0.00
12			22%	44%	11%	4%		20%	0.00			85%	16%		0.00		56%			9%	35%	0.00
18						14%	56%	30%	0.01	34%		55%	11%		0.00			100%				0.00
24			3%	35%	62%				0.00	7%		87%	7%		0.00		100%	0%				0.00
72						1%	99%		0.00	96%		4%			0.00	78%		22%				0.03
87						12%	88%		0.00	95%		5%			0.00	80%		20%				0.00
91		34%	41%	21%	4%				0.00			89%	11%		0.00		100%					0.00
103								100%	0.00	50%		49%	2%		0.00	47%				49%	4%	0.04
133			3%	75%	22%				0.00			97%	3%		0.00		100%					0.00
*139		44%	11%	39%		5%			0.00			86%	14%		0.00		48%	12%		32%	8%	0.00
183		12%	17%	41%	30%				0.00			92%	8%		0.00		88%	12%				0.00
247				9%		32%	59%		0.00	92%		9%			0.00	45%		49%	6%			0.15
557	3%	57%	39%	2%					0.00			72%	29%		0.00		100%					0.00
1028			15%	27%	59%				0.00			87%	13%		0.00		95%	6%				0.00
*1078			16%	50%	35%				0.00			97%	3%		0.00		100%					0.00
1451		24%	18%	48%	10%				0.00			90%	10%		0.00		100%					0.00
2367			100%						0.00	5%	95%				0.00	100%						0.00

*Apparently poor samples, few species, no diagnostics. Not a habitat type, but included here for completeness.

**Groups were combined due to few sampling points.

Southern New England Benthic Habitat (Code)	Depth (m)								Sediment Grain Size (mm)						Seabed Forms						
	0-9	9-23	23-31	31-44	44-76	76-139	>=139	p-value	0-0.03 (mud and silt)	0.03-0.16 (very fine sand)	0.16-0.34 (fine sand)	0.34-0.36 (sand)	>=0.36 (medium and coarse sand)	p-value	Depression	Mid Flat	High Flat	Low Slope	High Slope	Sideslope/Steep**	p-value
*1	78%	22%						0.00		18%	34%		48%	0.00	42%		27%		30%	1%	0.00
3						78%	22%	0.00		58%	42%			0.00		12%	42%		47%		0.00
6				24%	63%	13%		0.00			14%	16%	71%	0.00	18%	30%	52%				0.01
11					24%	62%	15%	0.00			21%	79%		0.00		28%	29%		40%	3%	0.00
25	27%	60%	14%					0.00		3%	25%		72%	0.00	60%		17%			24%	0.00
36	65%	17%	6%		12%			0.00				27%	73%	0.00	50%		41%	9%			0.00
66						100%		0.00	70%	30%				0.00	51%	31%	18%				0.00
82					81%	19%		0.00			7%	48%	45%	0.00	21%	54%	25%				0.00
109	63%	24%	14%					0.00	29%				71%	0.00	100%						0.00
113			98%	2%				0.00		100%				0.00	67%	33%				1%	0.00
200	71%	7%	11%	11%				0.00		47%	16%		38%	0.00	100%						0.00
223		4%		4%	92%	0%		0.00			42%		58%	0.00	13%	87%					0.00
229		12%	79%	9%				0.00		100%				0.00	100%						0.00
230			92%	8%				0.00		100%				0.00	99%					1%	0.00
316		41%	59%					0.00		34%	48%		18%	0.00	69%	11%	20%				0.00
317			9%	66%	26%			0.00			68%		33%	0.00		100%					0.00
372			32%	10%	58%			0.00		100%				0.00	88%			12%			0.00
381					99%	1%		0.00		18%	83%			0.00		79%	21%				0.00
387						14%	86%	0.00		1%	99%			0.00			42%		58%		0.00
390		8%	80%	12%				0.00		85%	15%			0.00	94%					7%	0.00
437						77%	23%	0.00		5%	95%			0.00			41%		59%		0.00
873		9%	90%	0%				0.00		49%	29%		22%	0.00	52%	4%	33%			11%	0.00
949						100%		0.00			25%	75%		0.00		89%	11%				0.00
2537			90%	10%				0.00		55%	45%			0.00	81%		19%				0.00

*Apparently poor samples, few species, no diagnostics. Not a habitat type, but included here for completeness.

**Groups were combined due to few sampling points.

Mid-Atlantic Bight Benthic Habitat (Code)	Depth (m)									Sediment Grain Size (mm)						Seabed Forms						
	0-15	15-22	22-45	45-48	48-82	82-95	95-592	>592	p-value	0-0.18 (silt and very fine sand)	0.18-0.35 (fine sand)	0.35-0.36 (sand)	0.36-0.48 (sand)	>=0.48 (coarse sand)	p-value	Depression	Mid Flat	High Flat	Low Slope	High Slope	Sideslope/Steep**	p-value
1		66%	34%						0.00		19%	30%		51%	0.00	95%	5%					0.00
2		28%	73%						0.00			100%			0.02	100%						0.00
4		29%	64%	7%					0.00			19%	30%	51%	0.00		100%					0.00
7		45%	54%	1%					0.00				16%	84%	0.00	17%	83%					0.00
25		53%	23%		24%	1%			0.00		51%		30%	19%	0.00	100%						0.00
32		4%	96%						0.00		3%	97%			0.00		100%					0.00
38		100%	0%						0.00				82%	18%	0.00	100%						0.00
44	57%	27%					16%		0.00		45%		32%	23%	0.00	88%	12%					0.01
64		100%							0.00			9%	91%		0.00	53%	47%					0.00
84			69%		31%				0.00		64%		36%		0.00	15%	39%	46%				0.00
87		100%							0.00			11%	89%		0.00	85%		15%				0.00
216					20%		80%		0.00		21%	79%			0.00			4%		96%		0.00
218					100%				0.00			78%		22%	0.00	100%						0.00
219					53%	31%	16%		0.00		24%	30%	21%	25%	0.00			100%				0.00
229			25%	0%	28%		47%		0.00		12%	67%	22%		0.00	28%		72%				0.07
301					38%	5%	57%		0.00		NS		NS	NS	0.44	NS		NS				0.52
306			21%		79%				0.00			100%			0.00	38%	51%	11%				0.08
384				7%			94%		0.00	NS					0.79					74%	26%	0.00
395				4%	96%				0.00		70%		30%		0.00	85%	15%					0.00
505							19%	81%	0.00	100%					0.00				25%	39%	35%	0.00
520					98%	2%			0.00		13%			87%	0.00	43%	57%					0.00
592				100%					0.00			100%			0.00		100%					0.00
768	84%	17%							0.00	56%	44%				0.00	100%						0.00
1223						100%			0.00			100%			0.00			100%				0.00

**Groups were combined due to few sampling points.