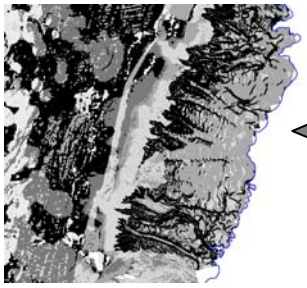

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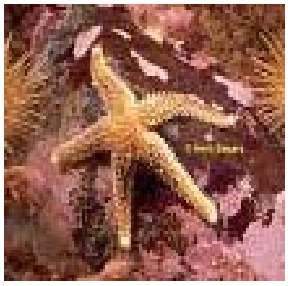
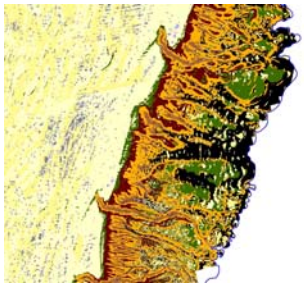


Benthic Habitats



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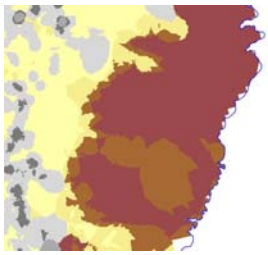

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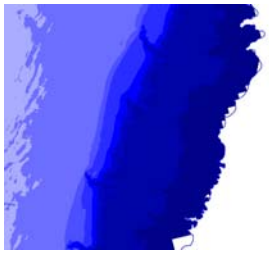

Bathymetry

Benthic Habitat Mapping for the Northwest Atlantic:

First Iteration for the Mid-Atlantic Bight and other Sub-regions

Mark G. Anderson, Daniel W. Morse, and
Jay G. Odell
October 15, 2008

Virginia Coastal Zone
MANAGEMENT PROGRAM

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First Iteration for the Mid-Atlantic Bight and other Sub-regions

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First Iteration: October 2008

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About this Report

This report represents an initial effort at defining and mapping benthic habitats directly from organism data and newly available maps of physical factors. Our objectives were to develop a solid methodology, apply it to a specific region, and evaluate the results. This work is ongoing and an updated report will be provided by June 2009. A team of recognized scientists familiar with benthic classification is serving as a peer review team for this project. Initial comments have greatly improved this report and additional recently suggested areas for improvement for this draft are being addressed. Member of this review team include Page Valentine, Kathryn Ford, Chris Madden, Les Kaufman, Ray Grizzle, Caroly Shumway, and Zach Ferdana. *Critical steps of accuracy assessment, cross-validation using independent data sets, comparisons with demersal fish habitat, and final expert peer review are ongoing and will be completed by June 2009.*

Background and Approach

Organisms that inhabit the ocean seafloor are known as benthic species, from the Greek word benthos, meaning "depths of the sea." Living directly in the bottom sediments and feeding on plankton and organic debris, individual species are adapted to variations in light, depth, sediment size, temperature and salinity. For example, filter feeders like sponges and mussels dominate on shallow sandy bottoms where they strain suspended matter directly out of the water. Deposit feeders like polychaete worms dominate fine-grained silts and muds where they consume detritus. Mobile species such as sea stars, crabs, squid and snails tend to be scavengers or predators.

Conservation of benthic habitats is critical both to conserve the rich diversity species that form the benthos and because of the key role that benthic systems play in converting and recycling nutrients. Moreover, benthic organisms tend to be near the bottom of the marine food chain. Cod and other demersal fish feed on invertebrates and small crustaceans that in turn feed on the polychaetes, amphipods, euphausiids (krill), limpets and smaller shrimp that form benthic communities.

The challenge of mapping seafloor habitats in the North Atlantic has produced an extensive body of research (World Wildlife Fund 2006, Kostyleu et al. 2001, Todd and Greene 2008, Auster 2006, Green et al. 2005), and comprehensive seafloor classification schemes have been proposed by many authors (Madden et al. 2005, CMECS 2008, Valentine et al. 2005, Greene et al 1999, Greene et al. 2005, Kutcher et al. 2005, Allee et al. 2001, Brown 1993, Brown 2002, Conner et al 2004, Davies et al. 2004, Dethier 1992, EEA 1999 and see reviews in Lund and Wilber 2007, NERRS 2000). The majority of these classification systems are based on physical factors such as bathymetry, sediment grain size, sediment texture, salinity, bottom temperature and topographic features. Our work builds off of these schemes both explicitly and implicitly although we focus narrowly on producing an accurate map of benthic habitats as opposed to proposing a new classification system. We intend to crosswalk our results to the existing schemes.

Our approach to benthic habitat mapping was based primarily on the distribution and abundance of benthic organisms. We then use that information to identify key thresholds in the physical factors that explain those patterns. Specifically, we use quantitative

analysis to identify distinct and reoccurring assemblages of benthic organisms. We relate these species assemblages to physical factors (bathymetry, sediment types and seabed topographic forms) using recursive partitioning. Lastly, we use the statistical relationships, in combination with data on the distribution of the physical factors, to map benthic habitats. The final habitat maps, however, are composed solely of combinations of enduring physical factors and are thus closely related to the maps and classification schemes proposed by others. We build upon previous research by establishing explicit relationships with the biota and using the distribution patterns of benthic organisms to determine the cutoffs and thresholds between key physical variables.

While there are a host of promising new video and remote sensing technologies being developed (Kostyleu et al .2001) for benthic mapping, our study was guided by access to data from the unparalleled sampling effort of the Northeast's benthic invertebrate fauna by NOAA's National Marine Fisheries Service: Northeast Fisheries Science Center. A thorough analysis of the dataset including the distribution and ecology of the organisms can be found in the seminal work of Roland Wigley and Roger Theroux (1981 and 1998). This data consisted of quantitative surveys of macrobenthic invertebrate fauna conducted from the mid 1950's to the mid 1980's. Each year, samples of the seafloor were systematically taken during 25+ individual cruises by 5+ research vessels using grab samplers designed to collect 0.1 (Smith-McIntyre) to 0.6 (Cambell) m^2 of benthic sediments. In total, over 8000 samples were collected. Organisms collected in each sample were sorted and identified to the lowest taxonomic level possible, usually species, genus or family, and information on the sediment sizes, depth and other associated features were recorded for each sample. (see Theroux and Wigley 1998 for a thorough discussion of the sampling methodology, gear types and history of benthic studies).

Classification Methods

Our analysis focused specifically on the 4,912 samples taken between 1960 and 1965, the time span in which this ecoregion was most comprehensively and evenly covered (Fig. 1). We classified the grab samples into organism groups based on similarities in the composition and abundance of the macroinvertebrate species using hierarchical cluster analysis (PCORD, McCune and Grace 2002). Organism identifications were aggregated to the genus or family level due to incompleteness or taxonomic errors at the species level and abundances were entered as counts of individual. For the cluster analysis, we used the Sorenson similarity index and the flexible beta linkage technique with B set at -25 (McCune and Grace 2002). Indicator species analysis (Dufre and Legrande 1997) was performed to identify those genera that were faithful and exclusive to each organism group. We ran Monte Carlo tests of significance for each genus relative to the organism groups and considered a genus to be diagnostic for the group if the P value was 0.10 or less (90% probability). The analysis was done by three subregions the Mid Atlantic Bight, Southern New England and the Gulf of Maine (Fig. 2).

Linking the Organisms to Physical Factors

Relationships between the organism groups and physical factors were identified using recursive partitioning, a statistical method that creates a decision tree to classify members of a common population based on a set of dependent variables (JMP software package).

To perform this analysis, each grab sample was classified to an organism group, then overlaid on standardized base maps of depth, sediment grain size and topographic position and attributed with the information taken from the standardized data (see below) Regression trees were built individually for each physical variable to identify critical thresholds that separated sets of organism groups from each other (see Appendix 2 for graphics and statistical tests). In recursive partitioning, these cuts are identified by exhaustively searching all possible cuts. Regression trees were also built using all variables collectively to identify which variables were driving the organism differences. Each analysis was performed separately by ecological subregion after data exploration revealed that the relationships between genera and physical factors differed markedly among subregions.

We determined the significance of each variable to each organism group using standard 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. We considered a variable and threshold to be significant if it had a p value greater than 0.10 (90%) (Appendix 2).

Physical Factors: Base Maps and Data Sources

The process of linking the benthic invertebrates communities identified in the classification to mappable physical factors required the development of comprehensive data layers for those factors. We focused on bathymetry, sediment grain size and seabed topographic forms, features assumed to be relatively stable over time and important in determining the distribution and abundance of benthic organisms. Data to develop each of these layers were available from a separate source and the techniques used to create or derive a comprehensive map are discussed below.

Ecoregion Geography

Well known geographic features and reference points in this ecoregion include a series of banks, basins, ledges and channels in the north, the shoals, deltas and canyons to the south and the continental shelf to the east (Fig.2). These features have a large influence on the movement and concentration of oceanic processes. While these large scale geographic features themselves don't relate directly to smaller scale habitats of macrobenthic invertebrates, they correspond in a relatively direct way to the distribution of depths, sediments grain size and seabed forms discussed below.

Bathymetry

A comprehensive bathymetry grid was used to characterize seafloor depths across the ecoregion, uncover organisms' depth preferences, and to create the seabed-form layer described later. Our primary data set for mapping bathymetry was National Geographic Data Center's Coastal Relief Model (CRM) (http://www.ngdc.noaa.gov/mgg/coastal/coastal.html). The CRM is a "gridded" bathymetric surface (similar to an architect's site model) generated from soundings of the continental shelf. The soundings are from hydrographic surveys completed between 1851 and 1965, and from survey data acquired digitally on NOS survey vessels since 1965, and are stored in the National Ocean Service Hydrographic Data Base (NOSHDB).[i]

The CRM was prepared in a GIS format with cell values (82 m) representing depths. In some areas, however (particularly east of the Hudson Canyon) it shows distinct artifacts of interpolating a comprehensive coverage of depth from sparse point data. The resulting surface is stretched into a taut surface marked with peaks and valleys at survey locations where actual depths were taken. . In these places, we augmented the data with insets from the NOS Bathymetric & Fishing Maps (http://www.ngdc.noaa.gov/mgg/bathymetry/...) (BFM). The BFM contours were drawn by hand, by cartographers interpreting topography from soundings. The BFM contour maps provide a more credible topography in some of the problematic sections of the CRM. Appendix 4 includes additional details on BFM data processing.

The Canadian portion of the ecoregion, including the Bay of Fundy, was covered by USGS' Gulf of Maine 15' Bathymetry (http://pubs.usgs.gov/of/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. We removed a fringe from the CRM where data had been inferred up to 9 km beyond actual soundings.

The region varies 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 (Fig 3.). Critical depth thresholds for benthic organisms differ among the three subregions and are discussed under the organism classification. The three subregions also differ 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. The Mid Atlantic Bight in contrast 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.

Sediment Grain Size

Substrate data was obtained from usSEABED (http://walrus.wr.usgs.gov/usseabed/), a compilation of existing data from the USGS and other research groups that has been processed and extended to maximize their density and usability. The data contains a variety of attributes in addition to sediment grain-size depending on the source data.

Initially, we focused on the mapping of two standard sediment classification schemes: Shepard (1954)[ii] and Folk (1954)[iii] that classify sediment types by their principal component (e.g. sand) and secondary components (e.g. muddy sand). usSEABED includes the percentages of clay, silt or mud, sand, and gravel or pebbles in each sample to facilitate the mapping of such ternary schemes. These "soil triangles" have been adopted from the terrestrial world by marine geologists, and seemed to provide an attractive existing classification. Following Sarretta et al. (2007)[iv], we used the Kriging interpolation method in ArcGIS to create surfaces representing the relative percentage of the four grain-size components above, and combined the components in Shepard's

scheme. Kriging is a method of interpolation which predicts unknown values from data observed at known locations (Lang, 1995). Although many interpolation methods exist, kriging provides consistent results across areas that have been sparsely and densely sampled. However, the data fields were incompletely filled out and our interpolation of such schemes from sample points to cover the entire seafloor produced poor results. Variability in the spatial arrangement of sample points tended to suppress isolated features that differed from their neighbors.

Alternatively, we shifted our focused to the average grain-size for each sample. This attribute was available for almost every sample and produced a more robust interpretation of sediment texture, showing local variation as well as large-scale patterns (Fig 4, Table 1). The point samples were interpolated to create a map for the ecoregion using the following parameters: ordinary Kriging; spherical semivariogram; variable search radius type using 12 points with no maximum distance; output cell size of 500 meters.

Table 1. Average Grain size and Sediment Class Names

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	0.0625	Coarse silt	16	32	Coarse pebbles
0.0625	0.125	Very fine sand	32	86	Very coarse pebbles to cobbles
0.125	0.25	Fine sand			

Seabed Topographic Forms

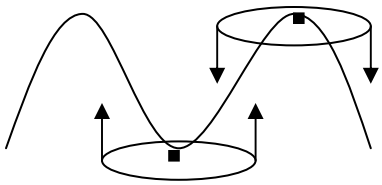
We classified the seafloor topography into discrete units based on position and slope as derived from the digital bathymetry (the units are hereto referred to as "seabed forms"). These units of depressions, high and low flats, upper slopes, lower slopes, steep-slopes and canyons (Fig 5) represent depositional and erosional environments that typically differ in fluvial processes, sediments and organism composition (Wigley and Theroux 1981).

Seabed position (a.k.a. topographic position or slope position) describes the topography of the area surrounding a particular 30 m cell. We based our calculations on the methods of Fels and Zobel (1995) that evaluates the elevation differences between any 30 m 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).

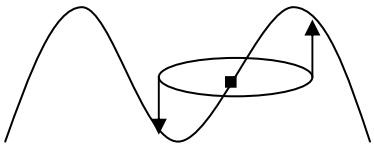
The seabed position value is the mean of the distance-weighted elevation differences between a given point and all other model points within a specified search radius. We set

the search radius at 200 cells after examining the effects of various radii. The following diagrams illustrate the seabed position index values along slopes:

Ridge: seabed position = positive value

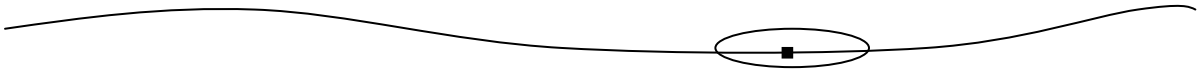


Sideslope: seabed position = 0



Slope Bottom: seabed position = negative value

Flat: seabed position = 0



Where seabed position = 0, slope was used to distinguish sideslopes from flats. Slope is calculated as the difference in elevation between two neighboring raster cells, expressed in degrees. After examining the distribution of slopes across the ecoregion, slopes were grouped according to the following thresholds:

0° - 0.015°:	Depression center
0.015° - 0.05°:	Depression
0.05° - 0.5°:	Flat
0.05° - 2.5°:	Sideslope
2.5° - 8°:	Steep slope
Steeper than 8°:	Cliff/canyon

Although 8° would not be considered a cliff in the terrestrial world, there are very few locations on the continental shelf with slopes in this category. Even the relatively steep continental slope has large areas with less than 8° slope, so this break point was useful for distinguishing canyons from the slow transition to the continental rise.

Slope was also used to bypass small errors in the bathymetry grid, by identifying very small-scale variations in depth. Sloped areas with a perimeter less than 2000 meters (37 grid cells) were removed from our model using a mask operation. This allowed us to ignore thousands of “dimples” present in the CRM bathymetry without having to edit the original grid.

Seabed position and slope were combined to create “seabed forms”, which are unique formations of the seafloor (Fig. 5). Mid-position Flats and depressions represent the broad plains common in Southern New England; Low-position canyons/steep-slopes identify the canyons of the continental slope; and highest-position side-slopes occur on the cusp of the shelf-slope break. When the six slope classes were combined with the four

seabed position classes, 23 of the 24 possible classes were found to occur in the ecoregion. This method uses cell-based raster modeling in ESRI's ArcGIS GRID module.

Results

The results of 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 are presented by subregion.

Classification: For each subregion, we provide a summary of the characteristic species and their indicator values (Page 8-15, Appendix 1). This table gives diagnostic genera for each organism group and shows its distribution across all the organisms groups. The mean indicator value and the probability of this being a random chance is calculated for each genus in the group that it is most closely associated with (Fig. 6). Most genera don't have a common name; we used Gosner (1979) to add them where available.

Linking the classification to the physical factors, Charts showing 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 is given in a separate document (Appendix 2, Physical Factors Profiles for the Organism Groups). A table of key physical factor values that correspond to ecological thresholds separating the distribution of one benthic habitat from another (Tables 2, 3, and 4) is provided below. Lastly, we describe in detail the twenty dominant organism groups in the ecoregion and each group's corresponding physical factor signatures.

Ecological Marine Units

Benthic Habitats and Ecological Marine Units

We use two terms to refer to the final maps. **Ecological Marine Units** (EMUs), which are the three-way combination of depth, sediment grain size and seabed forms based on the ecological thresholds revealed by the organism relationships (Fig.7, 8, 9). **Benthic Habitats a**re EMUs considered with their species assemblage (Fig. 10, 11, 12). The two terms represent two sides of the same coin, one emphasizing the biota and the other the physical setting. In many cases, a single EMU is synonymous with a single organism group. For example in the Mid Atlantic Bight the EMU 7106 = Habitat 63.

Habitat 63: **Very deep waters (>1000m), side slopes, steep slopes and cliffs**, **clays and silts**. Diagnostic species: tube worms *(Sipuculus spp., Goldfingia spp,)* and mollusks *(Alvania spp., Limopsidae)*. BH63 Most Likely: Depth 7, Grain 1, Form 6. EMU:7106

In this case, the habitat has an explicit and confirmed relationship with a group of benthic organisms. In some cases, an organism group is widespread (for instance, some of the bryzoan dominated types) and occurs across many EMUs. In other cases, an EMU may not have any known diagnostic group of organisms.

The scaling of the EMUs by the organism classification was critical in ensuring that the EMUs represent truly different environments as perceived by the benthic macrofauna.

This has been a problem in determining which of the many proposed physical factor classifications is best for a given region. If, for example, we recognized 20 depth classes, 17 sediment classes and 6 seabed form classes the number of EMU types would be 2,040 and we would be unable to point to a set of organisms that actually corresponded to each of the types. Conversely 2 depth classes, 3 sediment classes and 2 seabed forms would create only 12 EMU types and would not be partitioned fine enough to explain the organism patterns. We strove to find the most important physical thresholds for each organism group to determine a meaningful number of EMUs for which we could link a clear organism group or set of groups to each EMU type. The results presented here range from 108 to 168 EMUs per subregion (Fig.7 -10)

A visual example for Georges Bank (Fig 7) shows how this singular feature is subdivided by depth, seabed form and sediment types into a complex of EMUs each representing a slightly different benthic habitat. The northwest half of the bank is characterized by high and low position gently sloping flats (A), shallower depths of -35 m to -85 m (B), and coarse sands with areas of pebbles and gravel (C). The southeast portion is characterized by flats with level basins (A), moderate depths of -85 m to 150 m (B) and patches of clays, silts and very fine sands (C). The EMU map (D) illustrates how the feature corresponds to habitats for benthic organism.

Demersal Fish Habitats and Ecological Marine Units

We have examined the application of this methodology to demersal fish data collected over 40 years in annual trawl surveys. At this point we have only explored the proof-of-concept analysis for demersal fish data using data from one year (2005), and have not performed the statistical analysis necessary to solidly connect the organism groups with the physical factors. However, initial results look promising (Appendix 3), for example in the Mid Atlantic Bight the EMU 1602 and 1603 = Habitat 83.

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Habitat 83: Shallow (0 to 38 m) coarse and very coarse sand on flats. Diagnostic species:

- Blueback Herring *(Alosa aestivalis)*
- Northern Sand Lance *(Ammodytes dubius)*
- Atlantic Herring *(Clupea harengus)*

This habitat has an explicit relationship with a group of demersal fish. Developing the demersal relationships more completely and comparing them with the benthic relationships may help us to cross-check and generalize from our results. Further analysis incorporating data from additional years, statistically robust association with physical factors, and potential integration with benthic habitat results below will be presented in the June 2009 update.

Benthic Habitats
Subregion Results

Mid-Atlantic Bight Benthic Habitats

Table 2. Physical factor values that correspond to ecological thresholds in the Mid Atlantic Bight subregion.

Code	Bathymetry (depth in meters)	Code	Sediment Grain Size (mm)	Code	Seabed Form
1000	0-17.5	100	0.00 to 0.08 cla y and silt	01	Depression flat
2000	17.5- 31.6	200	0.08 to 0.21 fine sand	02	Upper Flat
3000	31.6-85.1	300	0.21 to 0.24 fine sand	03	Lower flat
4000	85.1-102.5	400	0.24 to 0.26 fine sand	04	Upper slope
5000	102.5- 280.1	500	0.26 to 0.52 sand	05	Lower slope
6000	280 – 996	600	> 0.52 coarse sand	06	Canyon/steep-slope
7000	996+				

Benthic Habitats
In the descriptive profiles below an "NS" indicates "not significant" and these are indicated with a "?" in the most likely EMU type. These organism groups either occur across a wide range of environments or we did not have enough samples to detect a significant relationship to a given variable

Very Shallow 0 – 31 meters
Habitat 16: Found on flats in **very shallow (-12 meters)** water on sand. Diagnostic species: Lady crab *(Ovalipes spp.)*, Sharp-tailed Cumacean *(Oxyurostylis spp.)* and Sand shrimp *(Crangon spp.)*. Too few samples for testing in this iteration.

Habitat 95: **Depressions** and flats, shallow water 0-31 meters, in **fine to coarse sand**. Diagnostic species: dove shells *(Mitrella spp.)*, cone snails *(Kurtziella spp.)*, brittle star (*Ophiocten spp.)* and sea cucumber *(Stereoderma spp*.) BH95 Most likely setting: Depth ns, Grain ns (2,6), Form ns(1). EMU:NS

Habitat 77: Flats and slopes in shallow water (7-85 meters) on **sand**. Diagnostic species: Gammarid amphipods, encrusting bryzoans, commensal crabs and heart urchin. BH77 Most likely setting: Depth 2, Grain 4, Form ns. EMU:240?

Habitat 74: **Sand and coarse sand**, Shallow water 17-31 meters, flats. Diagnostic species: Sand dollar *(Echinarachnius spp.)*, sea star *(Leptasterias spp.)*, scale worm *(Sigalionidae spp.)* and cleaner shrimp *(Hippolytidae spp.)*. BH74 Most likely setting: Depth 2, Grain 5,6, Form ns(2,3). EMU:2502 2503 2602 2603

Habitat 141: Upper flats, very shallow 0-31 meters, **Coarse sand**. Diagnostic species; Amphipods *(Haustoridae, Oedicerotidae)*, worms *(Magelonidae)* and barnacles. BH141 Most likely setting: Depth ns, Grain 6, Form ns(2). EMU:?602

Shallow: 31 - -100 meters

Habitat 42: Sandy **low flats** between 35-85 meters. **Sand or coarse sand**. Diagnostic species: palped palychaete *(Spionidae)*, isopods *(Cirolana spp.)* and anthropod *(Hippomedon spp.)*. BH42 Most likely setting: Depth 3, Grain 5, Form 3. EMU:3503

Habitat 45: Sandy **depression flats** between 32 and 85 meters. **Sand**. Similar setting to Habitat 42. Diagnostic species: Cockles *(Cerastoderma spp.)*, Carditas *(Cyclocardia spp.)*, smaller clams *(Astarte spp.)* and feather duster worms *(Sabellidae spp.)*. BH45 Most likely setting: Depth 3, Grain 5, Form 1. EMU:3501

Habitat 48: **Flats**, 85 meters or shallower, **sand** (fine to coarse). Diagnostic species: amphipods *(Byblis, Cumacea, Diastylis, Rhepoxynius)*, bristleworms *(Spionidae)*, and bryzoans *(Cupuladria)*. BH48 Most likely setting: Depth 2,3, Grain 5, Form 2(3). EMU:2502 3502 2503 3503

Habitat 51: **Flats to side slopes** Clays to coarse sand, mostly shallow but found all the way to great depths. Diagnostic species: Razor clam *(Enis)*, surfclam *(Spisula)*, macoma clam *(Macoma)*, fireworm *(Amphinomidae)*, ophillid worm *(Travisia)*. Highly variable. BH51 Most likely setting: Depth 1,2, Grain ns(2), Form ns. EMU:NS

Moderate depths: -100 - -280

Habitat 152: **Clay, silt and very fine sand**. Shallow to moderately deep, **steep-slopes.** Diagnostic species: Arc clams and Bivalves *(Arca, Thraciidae)*, fringeworm *(Cirratulidae)*, plume worm *(Onuphidae)* and amphipods *(ampeliscidae)*. BH152 Most likely setting: Depth 4,5, Grain 2,3, Form ns(6). EMU:4206 5206 4306 5306

Habitat 144. **Silts and fine sand**, Shallow to 280 meters, **low flats**. Diagnostic species: Bivalves *(Corbulidae, Gemma, Periploma, Tellinidae, Capitellidae, Nuculanidae, Lucinoma, Mendicula)* and brittle stars *(Amphioplus, Ophiuroidea)*. BH144 Most likely setting: Depth 5, Grain 4, Form 4. EMU:5404

Habitat 14: **Slopes** and **low flats,** most common between 100 and 280 meters. **Fine sands** (ranges from silts to coarse sand). Diagnostic species: Squid *(Rossia, Loligo)*, asteriid seastars *(Asterias)* and spider crab *(Euprognatha)* with a variety of less restricted mollusks, anthropods and enchidoderms. BH14 Most likely setting: Depth 5, Grain 2, Form 4. EMU:5204

Habitat 22: Krill (*Euphausiid* shrimp). Samples dominated by krill were found at depth between 100 and 280 meters on **upper flats** and **side-slopes** with **fine sand.** BH22 Most likely setting: Depth 5, Grain 3, Form 4. EMU:5304

Habitat 111: **Fine sand**, moderately deep (100 m to 280 m) **flats.** Diagnostic species: Shrimp *(Sergestes, Pandalidae, Dichelopandalus)* boreal squid *(Illex)* and sea star *(Astropectinidae)*. BH111 Most likely setting: Depth 5, Grain 2, Form ns. EMU:52

Habitat 44: High and low flats of **coarse sands**, depths less than 280 meters. Poorly defined, this Habitat is distinguished by a widespread warm-water polychaete *(Marphysia)*, and a variety of non diagnostic mollusks, mussels, isopods and encrusting bryzoans. BH44 Most likely setting: Depth ns, Grain 6, Form 3(2). EMU:?603 ?602

Deep water: -280+

Habitat 63: **Very deep waters (>1000m), Steep slopes and canyons**, **clays and silts**. Diagnostic species: tube worms *(Sipuculus spp., Goldfingia spp,)* and mollusks *(Alvania spp., Limopsidae).* BH63 Most likely setting: Depth 7, Grain 1, Form 6. EMU:7106

Habitat 87: **Clay, silt, very fine sand**, Deep water 280 – 1000 meters, **steep slopes and canyons**. Diagnostic species: Sea cucumbers *(Holothuroidea, Havelockia)*, Mollusks *(Antalis)*, and a variety of worms *(Ceratocephale, Hyalinoecia, Pogonophora, Siboglinum, Ampharetidae).* BH87 Most likely setting: Depth 6, Grain 1,2, Form 6. EMU:6106 6206

Habitat 213: **Slopes** in **very deep** water, over 1000 meters, **clay and silt**, very fine sand Diagnostic species: small sea snail *(Balcis)* softshell clam *(Mya)* and deep water Sea squirts *(Ascidiaceae).* BH213 Most likely setting: Depth 7, Grain ns (1), Form 4(6). EMU:7104 7106

Any Depth

Habitat 145: Low flats and slopes. Mostly shallow but a few samples from deep and very deep settings. *Plectodon* is characteristic. A poorly defined habitat. BH145 Most likely setting: Depth 1, Grain ns(1), Form ns(3). EMU:1103

Habitat 1: *Chiridotea almyra*: Samples characterized by a southern brackish water isopod (excluded due to lack of environmental information, essentially a fresh/brackish community)

Southern New England Benthic Habitats

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

Code	Bathymetry (meters)	Code	Sediment Grain Size (mm)	Code	Seabed Form
1000	0-6.9 meter	100	0-0.027 fine silt	01	Level flat
2000	6.9 – 26 meters	200	0.027 – 0.117 very fine sand	02	Flat
3000	26 – 72 meters	300	0.117-0.99 sand and coarse sand	03	Gently sloping flat
4000	72 – 108 meters	400	0.99 – 3.1 very coarse sand	04	Side slope
5000	108-331 meters	500	3.1 – 10.7 very fine pebbles to fine pebbles	05	Steep slope
6000	331+ meter	600	>10.7 medium pebbles	06	Cliff

Very Shallow 0 – 26 meters
Habitat 5: **Very shallow** (0-6.9 meters) **gentle-slope flats**, sand to **very coarse sand**. Diagnostic species: Green crab *(Carcinus)*, grass shrimp (Hippolyte), gulf periwinkle (Littorina), mud crab (neopanope) and oysterdrill (Urosalpinx)

Shallow: 26 – 72 meters
Habitat 69: **Level flats, flats** and gentle-slope flats, Depth 26-72 meters, **sand** and very fine sand. Diagnostic species: sea mouse *(Aphrodita spp.)*, asteroid sea stares *(Astereias spp. , Asteroidea)* waved whelk *(Buccinum spp.)*, jonah crab *(Cancer spp.)* stimpson's whelk *(Colus spp.)*, sand shrimp *(Crangon spp.)*, slipper shell *(Crepidula spp.)* sand dollar *(Enchinarachnius spp.)* lacy crusts *(Electra spp.)*, blood stars *(Henricia spp.)*, hermit crab *(Paguras spp.)* sea gooseberry *(Pleurobranchaea spp.)* and sea cucumber *(Steroderma spp.)*

Habitat 85: **Sand and very fine sand**, Depth 26-72 meters, flats and **gentle-slope flats**. Diagnostic species: Razor clam *(Ensis)*, a cumacean *(Eudorella)*, cheveron worm *(Goniada)* feather duster worm *(Sabellidae)* red-lined worm *(aglaophamus)* sand-builder worm *(Euchone)* arrow worm *(Sagitta)*

Habitat 86: **Flats to gentle-slope flats**, mostly 26-72 meters but varies from shallow to deep, **fine sand**. Diagnostic species: Fairy shrimp *(erthrops)* Poorly defined Habitat that may occasionally include burrowing brittlestars *(Amphiura)*, basket clam *(Corbula)* and krill *(Euphausia)*

Habitat 94: Shallow (7 to 72 meters) **flats and gentle-slope flats** with **fine to coarse sand**. Diagnostic species: Amphipods *(Bathyporeia, Byblis, Corophium, Haustoriidae, Hippomedon)* and polychaete worms *(Ophelia, Orbinia, Chaetozone, Phyllodocidae, Scoloplos)*.

Habitat 98: Shallow (26 to 108 meters), **flats and gentle-slopes** with **very fine sand** or sand. Diagnostic species: many polychaete worms *(Ampharetidae, Arabella spp., Lumbrineridae, Maldane spp., Ninoe spp., Scalibregma spp., Spionidae, Terebellida spp.)*

and amphipods *(Ampelisca spp., Casco spp., Diastylis spp., Ericthonius spp., Eriopisa spp., Harpinia spp., Leptocheirus spp., Orchomene spp., Photis spp., Phoxocephalidae)*

Habitat 136: Shallow depths (26-72 meters), **level flats, flats** and gentle-slopes on **sand.** Diagnostic species: two species of bivales, deep sea scallop *(Placopecten)* and black clam *(Arctica)*

Moderate Depths 72 – 300 meters
Habitat 44: **Very fine sand**, moderately deep water (70 – 331 meters). **Gentle-slope flats and side slopes**. Sea stars *(Astropecten spp., Odontaster spp)*, hermit crab *(Catapagurus spp.)* red shrimp *(Dichelopandalus spp.)*, squat lobsters *(Munida spp.)* spider crab *(Euprognatha spp.)* and toad crab *(Hyas spp.)*

Habitat 45: **Gentle-slopes and sideslopes**, Shallow to moderate depths (26-300 meters) v**ery fine sand**. Profile much like 44 only somewhat shallower. Basket star *(Gogonocephalus)* tube worm, *(Filograna)*, shrimp *(lebbeus, pandalidae, spirontocaris)* bobtailed squid *(rossia)*. Moon shells *(polinices)*

Habitat 47: Moderate depth 100- 300 meters, **very fine sand**, **gentle-slopes** and side slopes. Diagnostic species: Lobster *(homarus)*, cuttlefish *(Sepeiodea)*, mud star *(Ctenodiscus)*

Habitat 112: Moderate depths (72 to 331 meters), **levels, flats, gentle-slopes and sideslopes** with fine silt or very fine sand. Diagnostic species: none. Occasional species include a bivalve *(Cardiomya)*, a brittle star *(Amplhilepis)* and fairy shrimp *(Bathymysis)* Poorly defined

Habitat 121: Moderate (71 to 331 meters) **flats and gentle-slopes** on fine **silt and very fine sand.** Diagnostic species: Annelids *(Capitellidae, Cirratulidae, Drilonereis spp., Pectinaria spp., Apistobranchidae,)* brittle star *(Amphioplus spp.)* and Mollusks *(Astarte spp., Bathyarca spp., Cuspidaria spp., Cyclocardia spp., Lucinoma spp., Nuculana spp., Periploma spp., Polyschides spp., Thyasira spp.)*

Habitat 157: Moderate depths (72-108 meters), **flats and gentle-slopes** on fine **silt** or very fine sand. Diagnostic species: sea grapes *(Mogula)*, salp *(Salpa)*, brittle stars *(Amphilimna, Ophiurida)*, sea urchin *(Brisaster)* and sea cucumbers (*Chiridota, Havelockia, Holothuroidea)*

Habitat 476: Shallow to moderate (26-331 meters), **flats and side-slopes**, fine to very **coarse sand**. Diagnostic species: Longfin squid *(Loligo)* and Sunstar *(Solaster)*

Habitat 483: Shallow to moderate (26-331 meters) flats to steep slopes, on **highly variable** substrates mostly very fine sand but ranges from fine silt to medium pebbles. Diagnostic species: none

Habitat 483: Moderate (108-331 meters), **gentle-slopes on very fine sand** to sand.

Diagnostic species: Boreal squid *(Ilex)*

Deep 300+ meters
Habitat 90: **Fine silt and very-fine sand**, very deep, 331 + meters, gentle-slopes **sidelslopes and steep slopes**. Diagnostic species Beardworm *(Pogonophora)* tube building worm *(Serpulidae)* squid *(Cephalopoda)*

Habitat 458: Very deep (> 331 meters) **slopes canyons gentle-slopes** on **fine silt** or very fine sand. Diagnostic species: Bivalves *(Malletia spp., Mendicula spp., Nucula spp., Saturnia spp., Mulinia spp., Mya spp.)* and crusts *(Membranipora spp.)*

Any Depth
Habitat 115: **Slopes at all depths**, very fine sand, sand. Diagnostic species: low fidelity diagnostic Habitat of worms *(Polydora, Ceratocephale, Siboglinum)* bivalves *(Yoldiella)* and tusk shell mollusks *(Antalis, Cadulus, Alvania, Dentalium)*

Habitat 1: **All depths and landforms** may contain the poorly defined Habitat characterized by planktonic amphipod *(Calliopius)*, bryzoans and the mollusk *Mitrella spp*.

Gulf of Maine Benthic Habitats

Table 4. Physical factor values that correspond to ecological thresholds in the Gulf of Maine subregion

Code	Bathymetry (depth in meters)	Code	Sediment Grain Size (mm)	Code	Seabed Form
1000	0-45	100	0 -0.03 clay and silt	01	Level flat
2000	45-53	200	0.03 – 0.05 coarse silt	02	Flat
3000	53-97	300	0.05 – 0.1 very fine sand	03	Gently sloping flat
4000	97-126	400	0.1 – 0.4 fine to med sand	04	Side slope
5000	126-368	500	0.4 – 1.7 coarse to vc sand	05	Steep slope
6000	368+	600	1.7+ pebbles	06	Cliff

Organism Habitats
Shallow 0- 126 meters
Habitat 10: Primarily shallow waters less than 97 meters, but may be found at any depth, slopes: **gentle to steep on silts and sands**. Diagnostic species: many bivalves *(Brevinucula spp., Corbula spp., Crenella spp., Macoma spp., Malletia spp., Mendicula spp., Mya spp., Nucula spp., Nuculana spp., Periploma spp., Thyasira spp., Yoldia spp.)*, gastropods *(Alvania spp., Cylichna spp., Oenopota spp., Retusa spp., Scaphander spp.)*, cumaceans *(Cumacea spp., Eudorella spp.)* and polychaete worms *(Lumbrineridae spp., Maldane spp., Sternaspis spp)*

Habitat 11: Primarily shallow water (50-97 meters) but possible at any depth on **silt**, any landform Diagrnostic species: arrow worm *(Sagitta)* and to a lesser extent silky sea cucumber *(Chiridota)* and little surf clam *(Mulinia)*

Habitat 183 and Habitat 185: Shallow (53-97 meters), **flats and gentle-slopes** on **silt or fine sand**. No diagnostic species.

Habitat 291: Shallow (0-97 meters**), flats and gentle-slopes** on **silt or fine sand**. Diagnostic species: a sea star *(Luidia)* and polychaete *(Chaetoperidae)*. The sea cucumber, *Stereoderma*, is also typical.

Habitat 526: Shallow (53-97) **flats and gentle-slopes** on **silt and fine sand**. Diagnostic species: sea scallop *(Placopecten)*

Habitat 549: Shallow (0-97 meters) **flats and gentle-slopes** on **silt.** Diagnostic species: sea mouse *(Aphrodita spp.)*, sand dollar *(Echinarachnius spp.)*, true oyster *(Ostreidae spp.)*, numerous whelks *(Buccinum spp., Busycon spp., Colus spp., Nassarius spp., Neptunea spp.)*, moon shell *(Lunatia spp.)*, moon snail *(Euspira spp.)*, surf clam *(Spisula spp.)* and a barnacle *(Cirripedia spp.)*.

Moderate 126 – 368 meters
Habitat 1 Deep water (126 – 368) meters, **gentle-slopes and side slopes**, Grain size **highly variable** (silt to pebble). Diagnostice Species: sea urchin *(Brisaster)*, hairy sea cucumber *(Havelockia)*, polychaete worms *(Ampharetidae, Ceratocephale, Chaetozone,*

Nephtyidae, Onuphidae, Paramphinome, Eunice) and mollusks *(Aporrhais, Astarte, Cyclocardia, Dacrydium, Musculus, Anachis, Bathyarca, Cuspidaria, Puncturella)*

Habitat 7: Moderate to deep (53-368 m) **gentle-slopes and side slopes** fine to coarse **sands.** Diagnostic species: none. The Habitat is occasional for two bryzoans *(Amphiblestrum, pseudoflustra)* and a polychaete *(Ancistrosyllis)*

Habitat 8: Moderate to deep (53-368), gentle-slopes and **side slopes** on any substrate. Diagnostic species: none. Characterized by a bobtailed squid *(Stoloteuthis spp.)*.

Habitat 16: Moderate depths (126-368 meters), **gentle-slopes** and side slopes, silt, **sand or pebbles.** Diagnostic species: a calanid copepod *(Calanus spp.)*, a sea star *(Leptychaster spp.)*, a brittle star *(Ophiocten spp)*, and a sea spider *(Nymphon spp.)*

Habitat 24: Moderate depths (126 – 368 meters), **gentle-slopes and side slopes** on **any substrate.** Diagnostic species: No good diagnostic species. Typical species include tuskshells *(Polyschides spp.)*, sea star *(Pseudarchaster spp.)* and basket star *(Gorgonocephalus spp.)*.

Habitat 31: Moderate depths (53 – 368 meters), **gentle-slopes and side slopes** on **sand** (silt to pebbles). Diagnostic species: Many diagnostic species including polychaete worms *(Filograna spp., Flabelligera spp.)*, grass shrimp *(Hippolyte spp.)*, toad crab *(Hyas spp.)*, horned krill shrimp *(Meganycitiphanes spp.)*, Acadian hermit crab *(Pagurus spp.)*, boreal red shrimp *(Pandalidae spp.)*, other shrimp *(Pontophilus spp.)*, sea spider *(Pycnogonida spp.)*, lamp shell *(Brachiopoda spp.)*, cactus sea squirt *(Boltenia spp.)*, sea grapes *(Molgula spp.)*, and a rich array of echinoderms including asteroid sea stars *(Asterias spp.)*, mud star *(Ctenodiscus spp.)*, sea star *(Hippasteria spp.)* polar sea star *(Leptasterias spp.)*, orange-footed sea cucumber *(Cucumaria spp)*, burrowing brittlestar *(Amphiura spp)*, daisy brittle star *(Ophiopholis spp.)*, other brittle stars *(Ophiura spp.)*, jingle shell *(Anomia spp.)* and a peanut worm *(Sipuncula spp.)*.

Habitat 43: Moderate (126-368 meters), **flats, gentle-slopes** and sideslopes **fine and coarse sand** (silt to pebble). Diagnostic Species: sea stars *(Psilaster, Pteraster)*, sea urchins *(Strongyloctrotus)*, sea squirt *(Ascida)*, bivalves *(Cyclopecten*) and amphipods *(Stegocephalus)*

Habitat 153: Moderate (53-368 meters) All **flats and slopes** on **coarse sand and pebbles**. Diagnostic species: none, characterized by the decapod *(Geryon)*

Habitat 178: Moderate (53-369 meters) flats, and **gentle-slopes** on **silt or fine sand**. Diagnostic species: One species, boreal squid *(Ilex spp.)* characterizes this Habitat.

Habitat 266: **All depths, all flats and slopes** on silt, fine sand or coarse sand. Diagnostic species: Isopods *(Calathura, Cirolana, Isopoda)* tusk shells *(Antalis, Dentalium, Scaphopoda)* and worms *(Streblosoma, Phascolion)*. Broadly distributed

Habitat 423: Deep (126-368 meters), **gentle-slopes and side slopes** on **coarse sand**. Diagnostic species: Krill *(Euphasia)*, a sea star *(Pentagonaster)*, a decopod *(Sergestes)*, a sea slug *(Velutina)*, and bobtailed squid *(Rossia)*.

Any Depth
Habitat 2: Any depth, **gentle-slopes and side slopes** on **silts or fine** to coarse sands. Diagnostic species: sea squirts *(Aplidium)*, sea star *(Astropecten)*, sand shrimp *(Crangon)*, lobster *(homarus)*, long finned squid *(Loligo)*.

Habitat 34: Any depth,
flats and slopes, fine and coarse sands
Diagnostic species: none, this habitat is characterized by bryzoans and crusts *(Callopora, Tessaradoma, Electra, Conopeum)*

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[i] http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html

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Figure 1: Distribution of the 4,912 benthic grab samples: 1960 - 1964

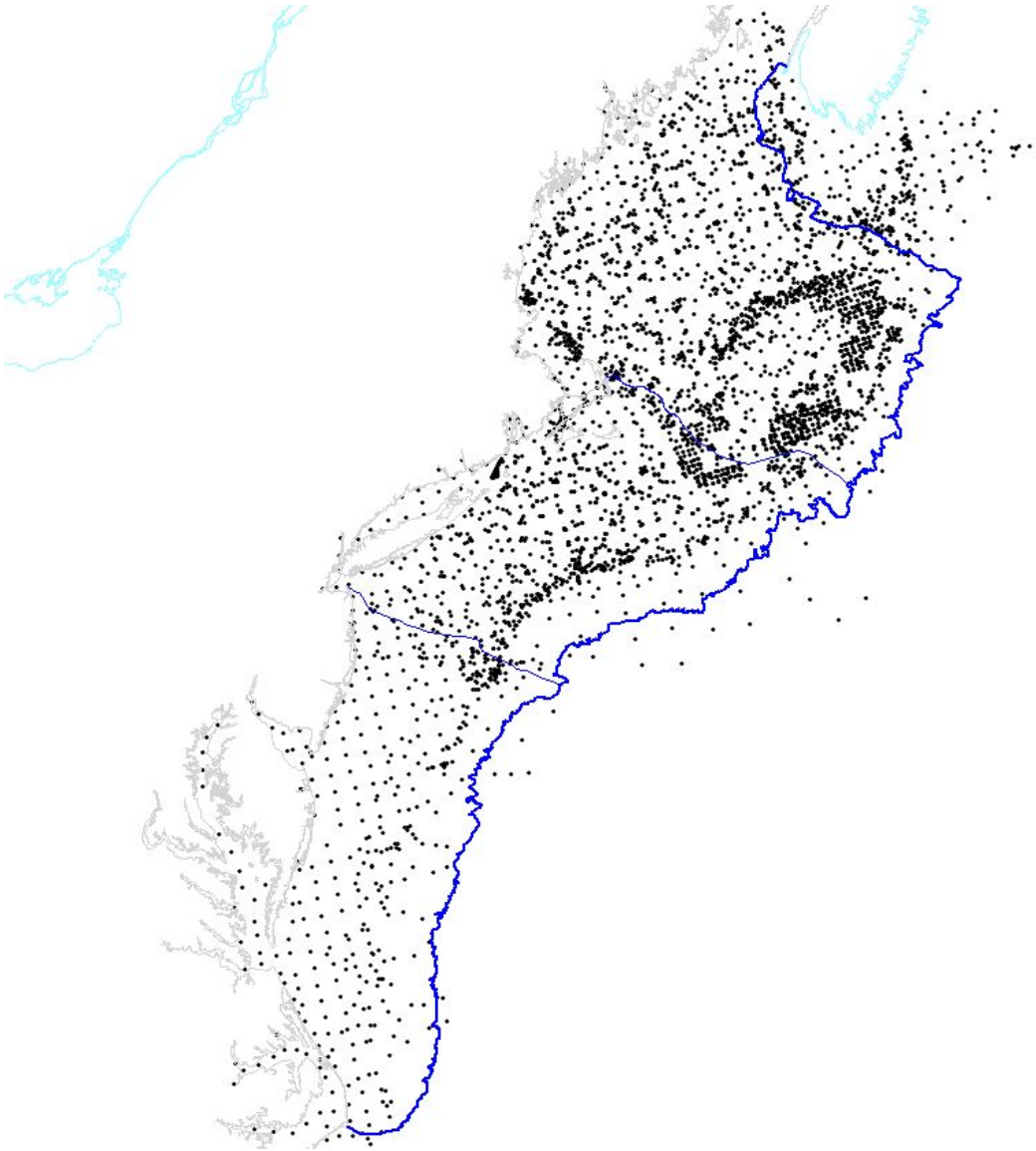


Figure 2 Geography of the ecoregion

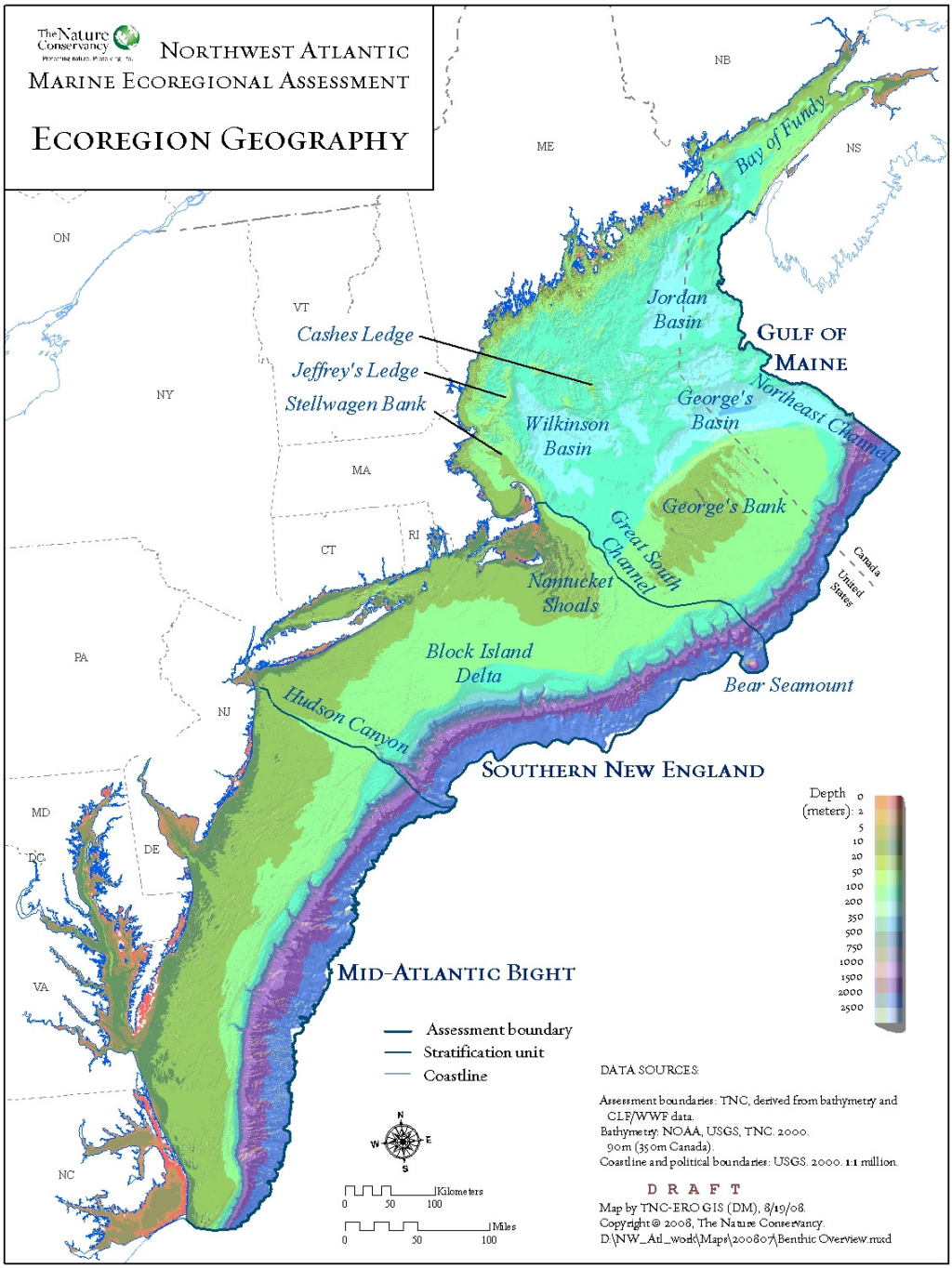


Figure 3 Bathymetry. 1: 6.600,000. Depth classes are shown in deeper blues. 0-35 m, 35-80 m, 80-100 m, 100-150m , 150-300 m, 300-500 m, 500-1000 m , 1000 – 2740 m

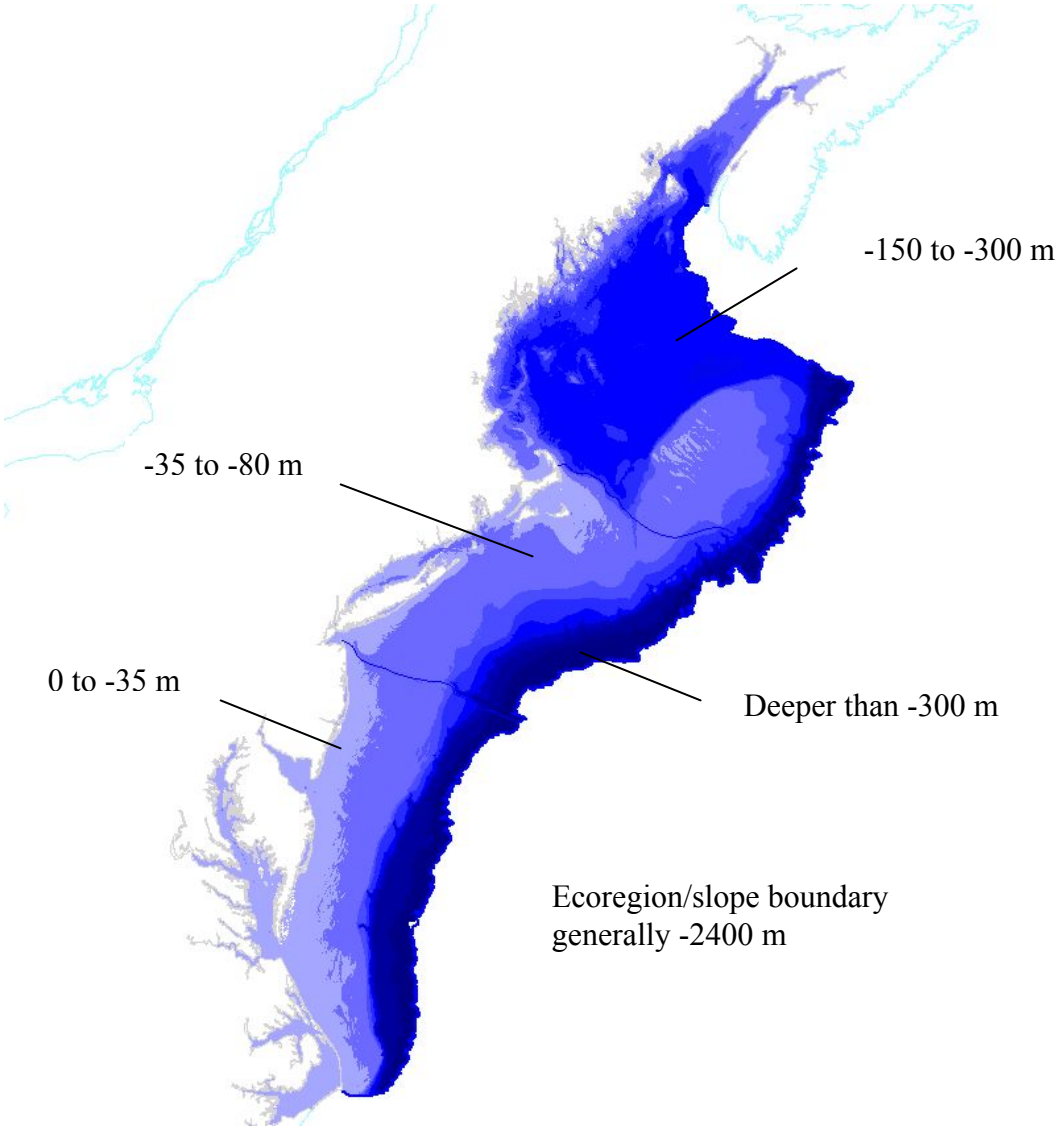


Figure 4 Sediment Grain Sizes: 5 classes: clay and silt (dark brown), very fine sand (brown), fine sand (olive), sand (tan), coarse sand (light grey), pebbles and gravel (dark grey

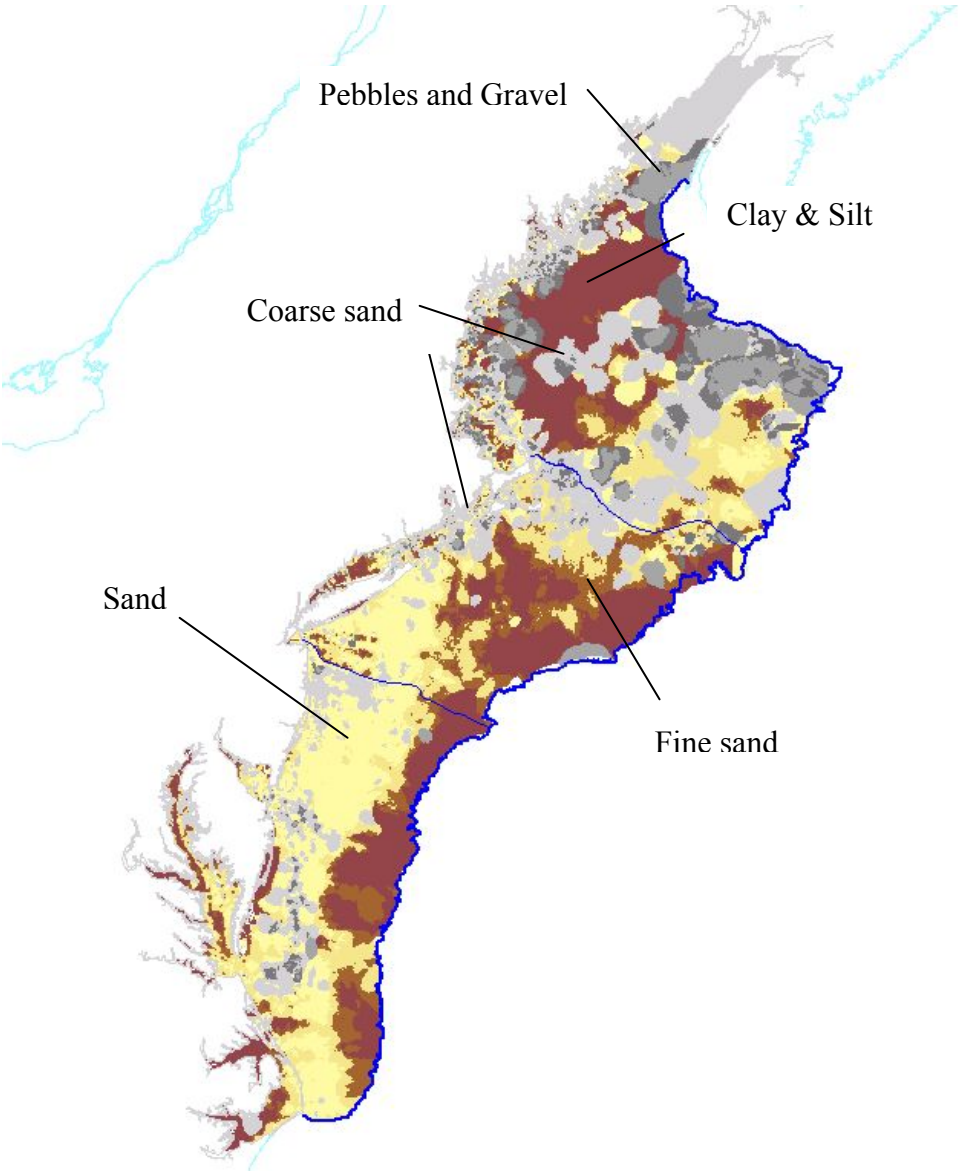


Figure 5 Seabed forms: Depressions, depression center flat, high flats, low flats, upper side-slope, lower side-slope, steep slopes, canyons

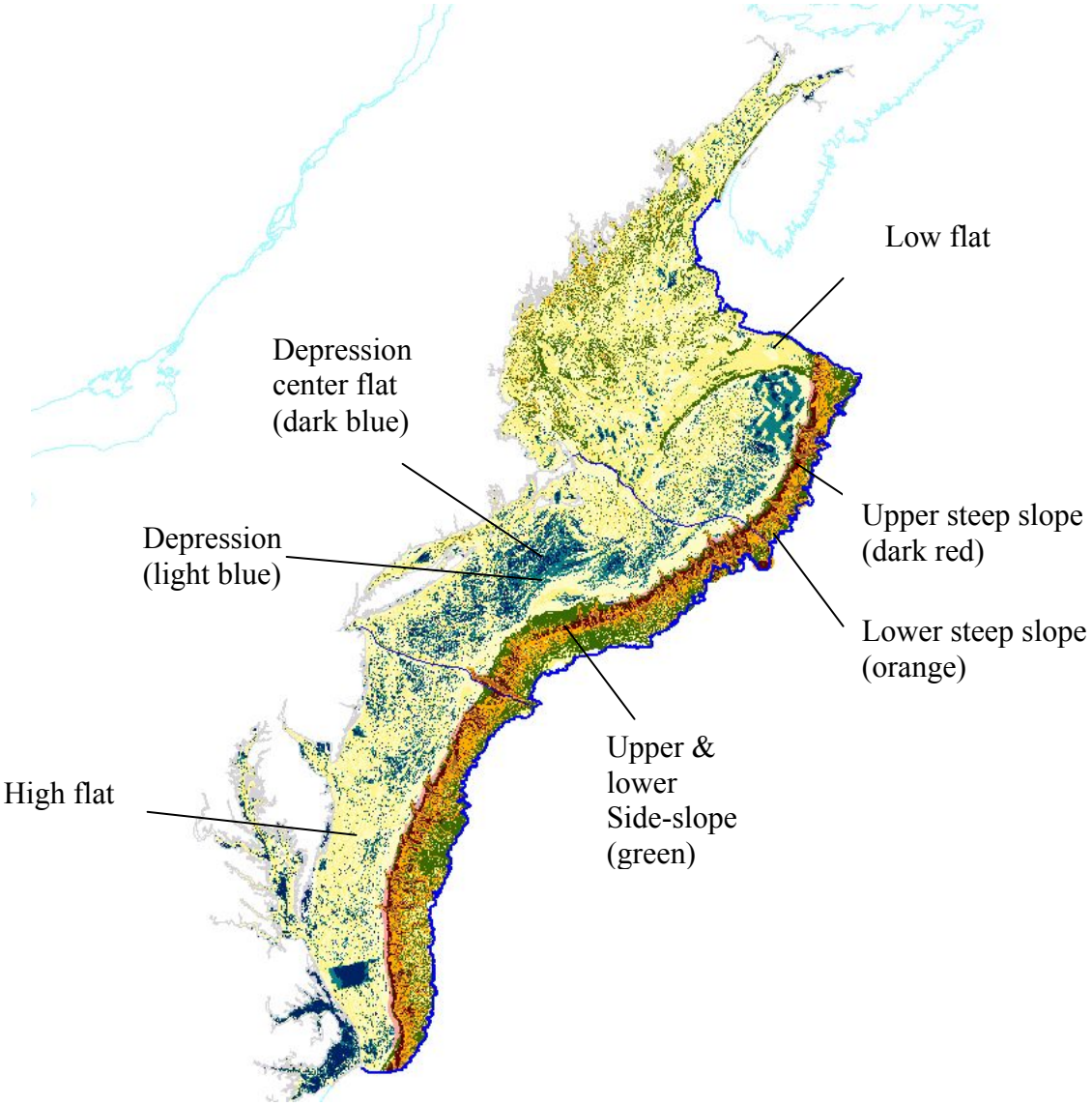


Figure 6. Indicator species analysis and importance values. Screen shot from excel table "ISA_printable.xls". Each row is a single genus. Column 1 gives the genus name. Column 2 gives the name of the organism group where this genus has the highest importance value. Column 3 gives the average importance value of that genus in each sample of the central group. Column 4 gives the p-value of a Monte-Carlo test to determine the probability of the genus having that high an indicator value by random chance. Columns 5 – 25 show the distribution and indicator value of each genus for each organism group. For example the genus Rossia (bobtailed squid, row 2) has an indicator value of 9 in group 14, whereas the genus Asterias (Asterid sea star, row 4) has a importance value of 11 in group 14 and also an importance value of 1 in group 74. Only Rossia and Loigo where considered diagnostic of group 14 (P-value of 0.1 or less). The other 24 genera centered in group 14 where considered characteristic but not diagnostic.

Genus | Central Group (rows) | Average Indicator value in samples of central group | P-value of genus in central group | Distribution and importance value of genus across all 20 groups | Organism Groups (columns) | Common Name (if any) Full table lists phylum , order and family

MID ATLANTIC BIGHT | **ORGANISM GROUPS**

Genus	Group	Avg	p_valu	1	14	16	22	42	44	45	48	51	63	74	77	87	95	111	141	144	145	152	213	CommonName
Chiridotea	**1**	5	0.1	91																				Chiridotea Sp
Rossia	**14**	0	0.1		9																			Bobtail Squid
Loligo	**14**	2	0.1		34																			Longfin Squid
Asteroidea	**14**	1	0.2		11									1										Sea Star unidentified
Asterias	**14**	1	0.2		11									1										Asteriid Sea Stars
Euprognatha	**14**	0	0.3		9																			Spider crabs
Catapagurus	**14**	0	0.4		9																			a decapod
Crustacea	**14**	0	0.4		9																			a crustacean
Bathynectes	**14**	0	0.4		9																			a decapod
Munida	**14**	0	0.4		8				1															a decapod
Nucula	**14**	1	0.5		8							1	1											Near Nut Shell
Octopoda	**14**	0	0.5		4																			Octopus unidentified
Ctenodiscus	**14**	0	0.6		4																			Mud Star
Copepoda	**14**	0	0.6		4							1												Copepod Uncl
Aphroditidae	**14**	0	0.6		4																			a polychaete
Edotea	**14**	0	0.6		4																			Edotea Sp
Oweniidae	**14**	0	0.7		3								1			1								Bamboo Worm (Owenii
Calliostoma	**14**	0	0.7		4																			a gastropod
Pleurobranchaea	**14**	0	0.7		4																			Sea Gooseberry
Strongylocentrot	**14**	0	0.7		4																			Green Sea Urchin
Pleoticus	**14**	0	0.7		4																			Royal Red Shrimp
Homarus	**14**	0	0.7		4																			American Lobster
Sepioidea	**14**	0	0.8		4																			a cephalopod
Crucibulum	**14**	0	0.8		2					2														Striate Cup-And-Sauce
Pitar	**14**	0	0.9		3						2													False Quahog
Hyas	**14**	0	0.9		2			1				1												Toad Crab
Decapoda	**14**	1	1		4					2	3						2							Decapod Uncl
Ovalipes	**16**	1	0.2			10																		Lady Crab
Oxyurostylis	**16**	1	0.2			17									1					3				Sharp-tailed Cumacean
Crangonidae	**16**	1	0.3		3	20								3										Sand shrimp

Figure 7 Conceptual diagram of the Ecological Marine Units (EMU) showing the three way intersection of Seabed forms, Grain size and Bathymetry.

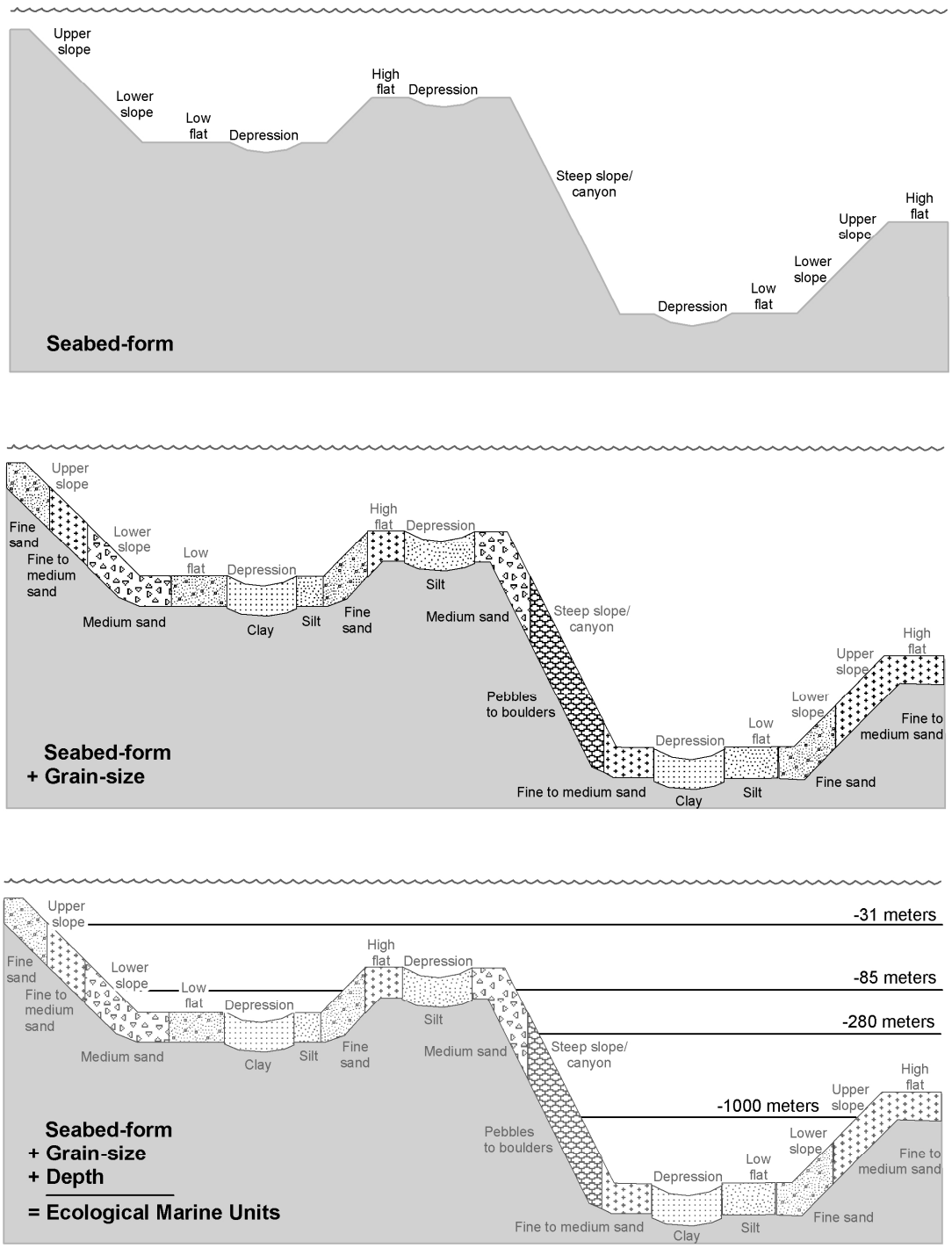


Figure 8 Example of A. Seabed forms, B. Bathymetry, C. Sediment grain size, and D. Ecolgical Marine Units (EMU)/Benthic Habitats for the Georges Bank area

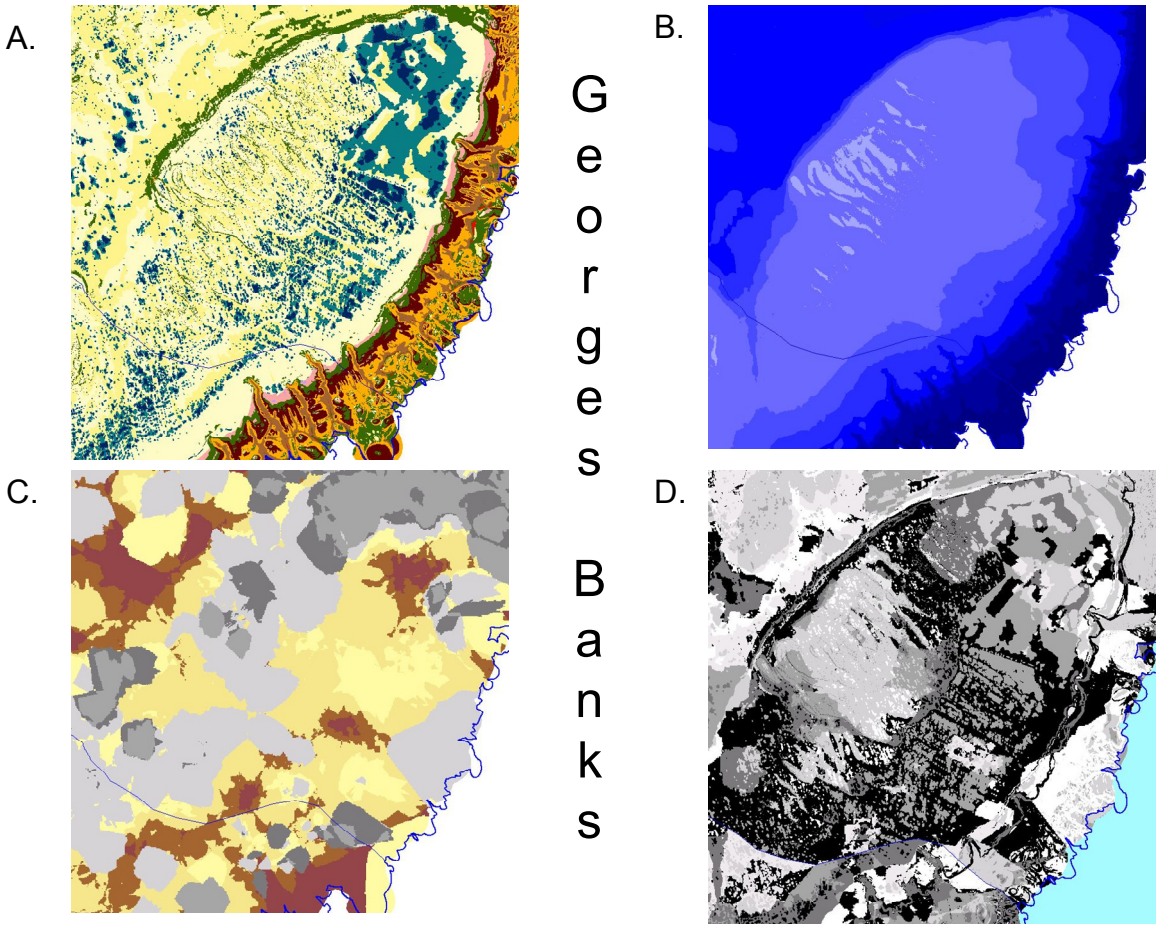


Figure 9. Ecological Marine units and Benthic Habitats for the Northwest Atlantic Marine Ecoregion.. Scale 1: 7,250.000

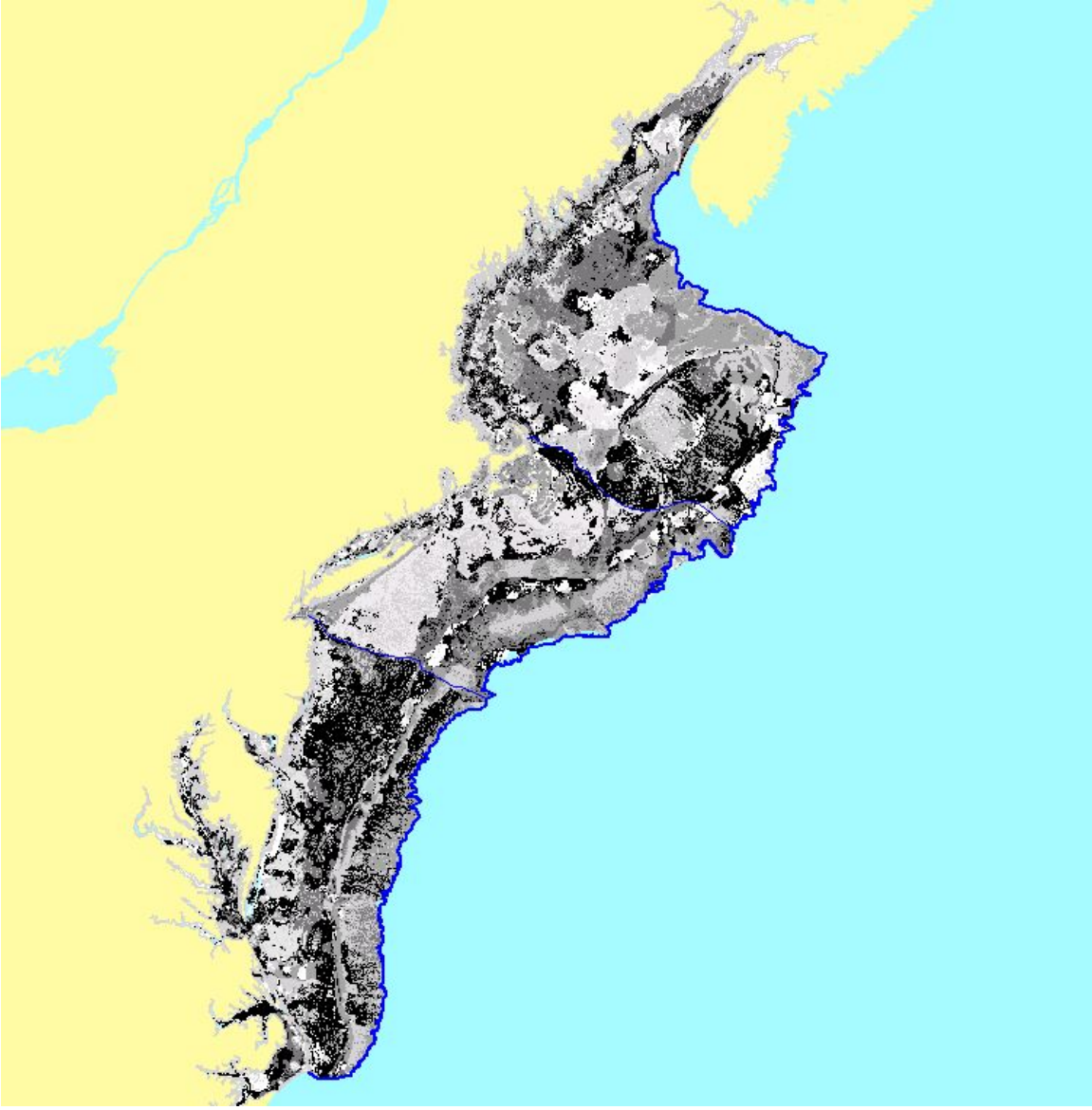


Figure 10. Mid Atlantic Bight Ecological Marine Units and example of Benthic Habitats 74 , 45, 63 and 87. Scale 1:3,210,600

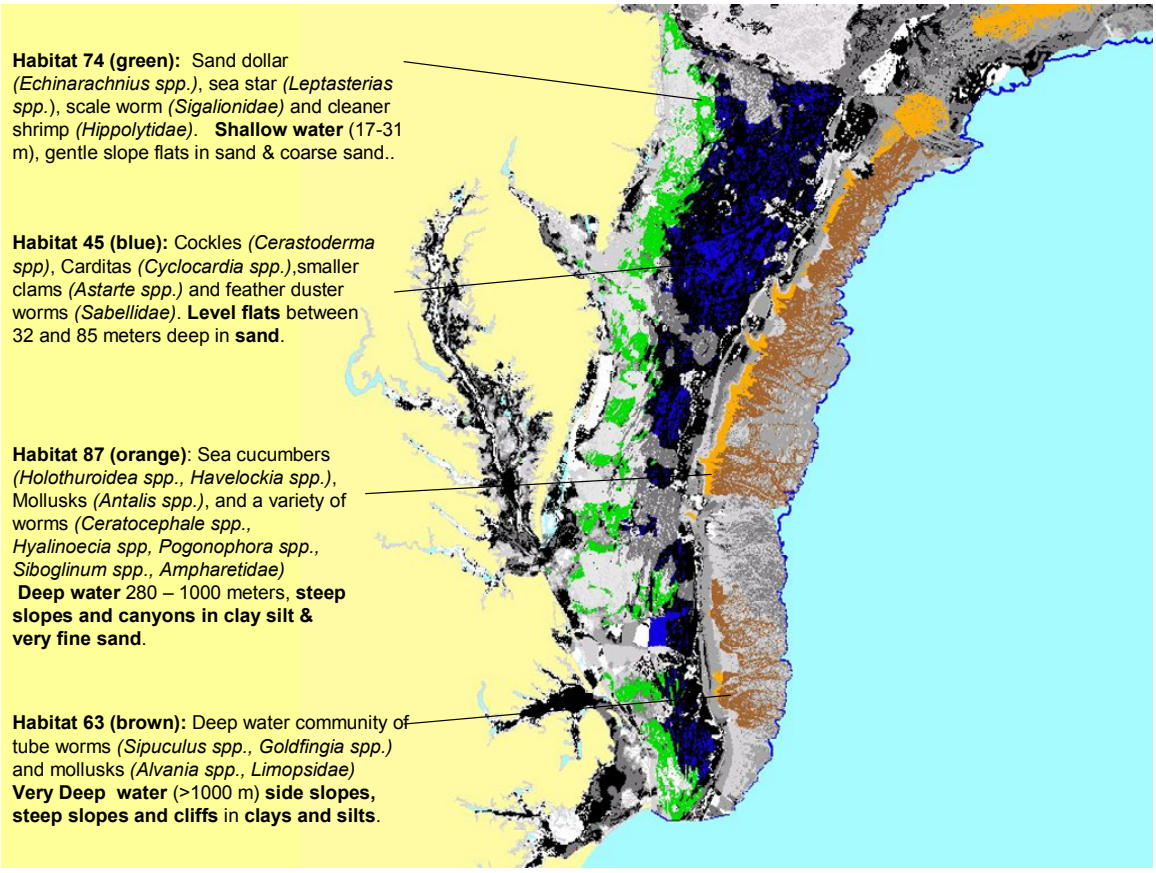


Figure 11. Southern New England Ecological Marine Units and examples of Benthic Habitats 69, 98, 121, 44, 468. 1:2,600,000

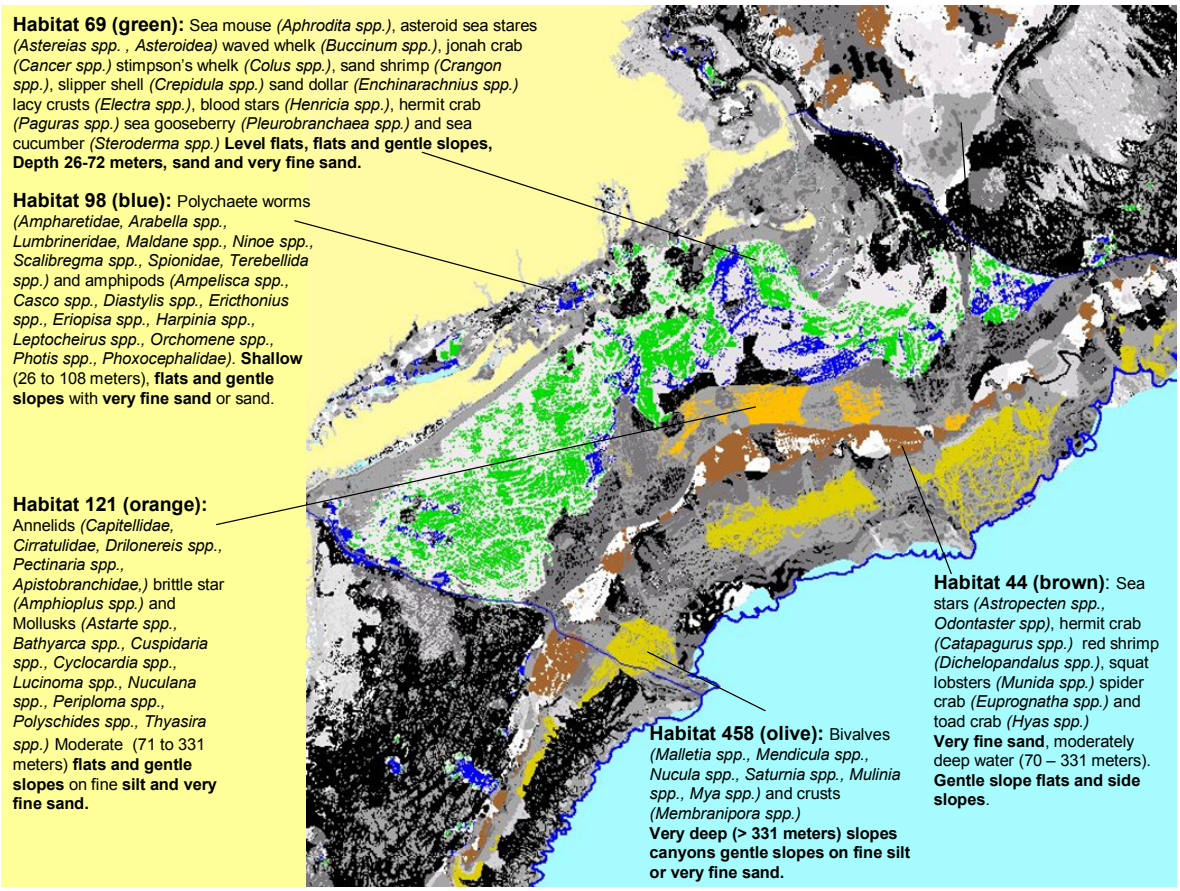
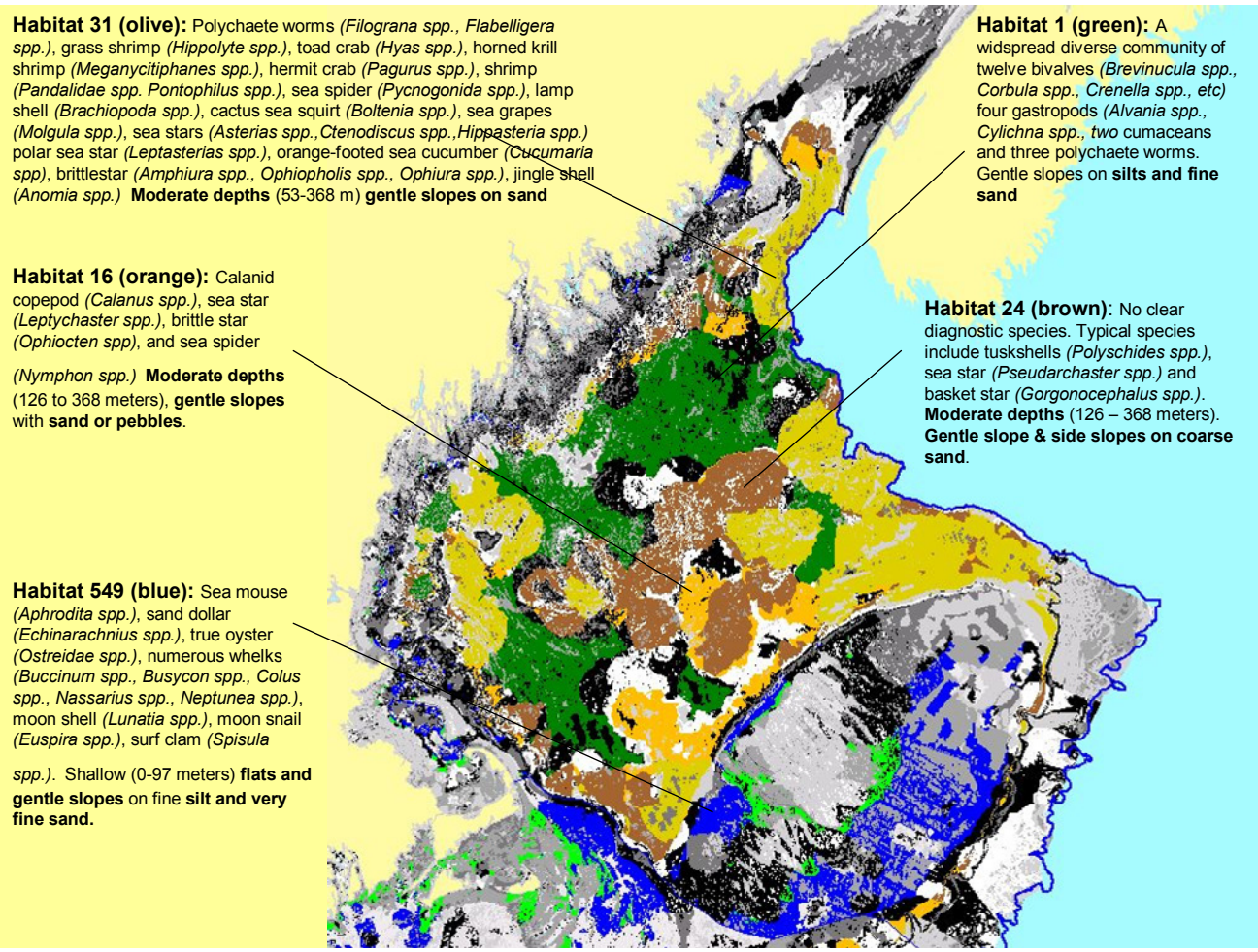


Figure 12. Gulf of Maine Ecological Marine Units and examples of Benthic Habitats 1, 31, 16, 24 and 543. Scale 1:2,900,00



Appendix 2. Indicator Species Analysis

MID ATLANTIC BIGHT				ORGANISM GROUPS																														
Genus	**Group**	Avg	p_value	**1**	**14**	**16**	**22**	**42**	**44**	**45**	**48**	**51**	**63**	**74**	**77**	**87**	**95**	**111**	**141**	**144**	**145**	**152**	**213**	**CommonName**	**phylum**	**class**	**order**	**family**	**clus20order**	**twnorder**	**Max**	**Genus**
Chiridotea	**1**	5	0.1	91																				Chiridotea Sp	Arthropoda	Malacostraca	Isopoda	Chaetiliidae	1	160	91	Chiridotea
Rossia	**14**	0	0.1		9																			Bobtail Squid	Mollusca	Cephalopoda	Sepiolida	Sepiolidae	2	134	9	Rossia
Loligo	**14**	2	0.1		34																			Longfin Squid	Mollusca	Cephalopoda	Teuthida	Loliginidae	3	232	34	Loligo
Asteroidea	**14**	1	0.2		11									1										Sea Star Uncl	Echinodermata	Asteroidea			4	231	11	Asteroidea
Asterias	**14**	1	0.2		11									1										Asteriid Sea Stars	Echinodermata	Asteroidea	Forcipulatida	Asteriidae	5	233	11	Asterias
Euprognatha	**14**	0	0.3		9																			Spider crabs	Arthropoda	Malacostraca	Decapoda	Inachoididae	6	106	9	Euprognatha
Catapagurus	**14**	0	0.4		9																			a decapod	Arthropoda	Malacostraca	Decapoda	Paguridae	7	105	9	Catapagurus
Crustacea	**14**	0	0.4		9																				Arthropoda	Crustacea			8	120	9	Crustacea
Bathynectes	**14**	0	0.4		9																			a decapod	Arthropoda	Malacostraca	Decapoda	Portunidae	9	218	9	Bathynectes
Munida	**14**	0	0.4		8				1															a decapod	Arthropoda	Malacostraca	Decapoda	Galatheidae	10	221	8	Munida
Nucula	**14**	1	0.5		8							1	1											Near Nut Shell	Mollusca	Bivalvia	Nuculoida	Nuculidae	11	208	8	Nucula
Octopoda	**14**	0	0.5		4																			Octopus Uncl	Mollusca	Cephalopoda		Octopodidae	12	225	4	Octopoda
Ctenodiscus	**14**	0	0.6		4																			Mud Star	Echinodermata	Asteroidea	Paxillosida	Goniopectinidae	13	17	4	Ctenodiscus
Copepoda	**14**	0	0.6		4							1												Copepod Uncl	Arthropoda	Crustacea			14	174	4	Copepoda
Aphroditidae	**14**	0	0.6		4																				Annelida	Polychaeta		Aphroditidae	15	184	4	Aphroditidae
Edotea	**14**	0	0.6		4																			Edotea Sp	Arthropoda		Isopoda	Idoteidae	16	236	4	Edotea
Oweniidae	**14**	0	0.7		3								1			1								Bamboo Worm (Oweniid)	Annelida	Polychaeta		Oweniidae	17	194	3	Oweniidae
Calliostoma	**14**	0	0.7		4																				Mollusca	Gastropoda	Archaeogastropoda	Calliostomatidae	18	219	4	Calliostoma
Pleurobranchaea	**14**	0	0.7		4																			Sea Gooseberry	Mollusca	Gastropoda	Notaspidea	Pleurobranchidae	19	222	4	Pleurobranchaea
Strongylocentrot	**14**	0	0.7		4																			Green Sea Urchin	Echinodermata	Echinoidea	Echinoida	Strongylocentrotidae	20	223	4	Strongylocentrotus
Pleoticus	**14**	0	0.7		4																			Royal Red Shrimp	Arthropoda	Malacostraca	Decapoda	Solenoceridae	21	226	4	Pleoticus
Homarus	**14**	0	0.7		4																			American Lobster	Arthropoda	Malacostraca	Decapoda	Nephropidae	22	237	4	Homarus
Sepioidea	**14**	0	0.8		4																				Mollusca	Cephalopoda	Sepiolida	Sepiolidae	23	109	4	Sepioidea
Crucibulum	**14**	0	0.8		2					2														Striate Cup-And-Saucer	Mollusca	Gastropoda	Neotaenioglossa	Calyptraeidae	24	142	2	Crucibulum
Pitar	**14**	0	0.9		3						2													False Quahog	Mollusca	Bivalvia	Veneroida	Veneridae	25	54	3	Pitar
Hyas	**14**	0	0.9		2			1				1												Toad Crab	Arthropoda	Malacostraca	Decapoda	Oregoniidae	26	145	2	Hyas
Decapoda	**14**	1	1.0		4					2	3						2							Decapod Uncl	Arthropoda	Malacostraca	Decapoda		27	234	4	Decapoda
Ovalipes	**16**	1	0.2			10																		Lady Crab	Arthropoda	Malacostraca	Decapoda	Portunidae	28	107	10	Ovalipes
Oxyurostylis	**16**	1	0.2			17									1					3				Sharp-tailed Cumacean	Arthropoda	Malacostraca	Cumacea	Diastylidae	29	108	17	Oxyurostylis
Crangonidae	**16**	1	0.3	3		20								3										Sand shrimp	Arthropoda		Decapoda	Crangonidae	30	220	20	Crangonidae
Euphausiacea	**22**	5	0.1				97																	Krill	Arthropoda	Malacostraca	Euphausiacea		31	216	97	Euphausiacea
Spionidae	**42**	2	0.1					26		6	3	1								1				Palped polychaeta*	Annelida	Polychaeta	Canalipalpata		33	10	26	Spionidae
Hippomedon	**42**	1	0.1					6		3	1														Arthropoda	Malacostraca	Lysianassidae		34	104	6	Hippomedon
Cirolana	**42**	1	0.1					9		8		1				1								Greedy Isopods	Arthropoda	Malacostraca	Isopoda	Cirolanidae	35	155	9	Cirolana
Corophiidae	**42**	1	0.3					13		4				1										Amphidod	Arthropoda	Malacostraca	Amphipoda	Corophiidae	36	103	13	Corophiidae
Phyllodocidae	**42**	0	0.8					4			1													Paddle worm	Annelida	Polychaeta	Aciculata	Phyllodocidae	37	139	4	Phyllodocidae
Isopoda	**44**	1	0.1	1				2	9	2				1	3		3							Isopod					38	99	9	Isopoda
Marphysa	**44**	0	0.2						8															Marphysa Worm	Annelida	Polychaeta	Aciculata	Eunicidae	39	50	8	Marphysa
Mytilidae	**44**	0	0.2						8															Mussel Uncl					40	207	8	Mytilidae
Bowmaniella	**44**	0	0.5						5																				41	59	5	Bowmaniella
Cistenides	**44**	0	0.6						4													4		Trumpet Worm	Annelida	Polychaeta	Canalipalpata	Pectinariidae	42	62	4	Cistenides
Cerapus	**44**	0	0.6						5																Arthropoda	Malacostraca	Amphipoda		43	186	5	Cerapus
Lyonsia	**44**	0	0.7						3	1										2				Glassy Lyonsia	Mollusca	Bivalvia	Pholadomyoida	Lyonsiidae	44	38	3	Lyonsia
Philine	**44**	0	0.7						3	1															Mollusca	Gastropoda	Cephalaspidea	Philinidae	45	53	3	Philine
Scaphander	**44**	0	0.7						5																Mollusca	Gastropoda	Cephalaspidea	Cylichnidae	46	94	5	Scaphander
Cylichna	**44**	0	0.7						4			1	1												Mollusca	Gastropoda	Cephalaspidea	Cylichnidae	47	214	4	Cylichna
Cribrilina	**44**	0	0.8						5															beaked crusts	Ectoprocta	Gymnolaemata	Cheilostomata	Cribrilinidae	48	16	5	Cribrilina
Electra	**44**	0	0.8						5															lacy crusts	Ectoprocta	Gymnolaemata	Cheilostomata	Electridae	49	19	5	Electra
Hippodiplosia	**44**	0	0.8						5															a bryzoan	Ectoprocta	Gymnolaemata	Cheilostomata	Schizoporellidae	50	23	5	Hippodiplosia
Mulinia	**44**	0	0.8						3								1			2		1		Little Surf Clam	Mollusca	Bivalvia	Veneroida	Mactridae	51	79	3	Mulinia
Pectinidae	**44**	0	0.9						3	1	1													Scallop Uncl					52	52	3	Pectinidae
Elasmopus	**44**	0	0.9						5																				53	67	5	Elasmopus
Neopanope	**44**	0	0.9						5																Arthropoda	Malacostraca	Decapoda	Panopeidae	54	81	5	Neopanope
Cyclocardia	**45**	2	0.1	1				1		30	9													Cardita	Mollusca	Bivalvia	Veneroida	Carditidae	55	1	30	Cyclocardia
Scalibregmidae	**45**	3	0.1					3		47	3		1		1										Annelida	Polychaeta	Ophiliida	Scalibregmidae	56	4	47	Scalibregmidae
Astarte	**45**	2	0.1					4		28	1													Chestnut Astarte	Mollusca	Bivalvia	Veneroida	Astartidae	57	5	28	Astarte
Unciola	**45**	4	0.1					7	1	56	14														Arthropoda	Malacostraca	Amphipoda	Unciolidae	58	8	56	Unciola
Cerastoderma	**45**	2	0.1						5	27	1			1	3									Little Cockle	Mollusca	Bivalvia	Veneroida	Cardiidae	59	15	27	Cerastoderma
Phoxocephalidae	**45**	1	0.1					4		12	1													gamarid amphidop	Arthropoda	Malacostraca	Amphipoda	PHOXOCEPHALIDAE	60	30	12	Phoxocephalidae
Sabellidae	**45**	1	0.1					1		22	4											2		feather duster worm	Annelida	Polychaeta	Canalipalpata	Sabellidae	61	39	22	Sabellidae

Ninoe	**45**	1	0.1					17	1											4	Lumbrinerid Thread Worms	Annelida	Polychaeta	Aciculata	Lumbrineridae	62	51	17	Ninoe
Lumbrineridae	**45**	3	0.1			5	3	20	12	2			3	9				2		8	Lumbrinerid Thread Worms	Annelida	Polychaeta	Aciculata	Lumbrineridae	63	157	20	Lumbrineridae
Cancer	**45**	1	0.1		7	1		9				7	1								Jonah Crab	Arthropoda	Malacostraca	Decapoda	Cancridae	64	235	9	Cancer
Maldanidae	**45**	2	0.2			2		13	3	1	1	1	1	9				6		1	Bamboo Worm Uncl	Annelida	Polychaeta	Scolecida	Maldanidae	65	166	13	Maldanidae
Arctica	**45**	1	0.3		1			13	8												Black Clam	Mollusca	Bivalvia	Veneroida	Arcticidae	66	2	13	Arctica
Placopecten	**45**	1	0.3		2	1		11				1									Deep-Sea Scallop	Mollusca	Bivalvia	Ostreoida	Pectinidae	67	12	11	Placopecten
Goniadidae	**45**	1	0.3			4		7					1	3				4			Chevronworms					68	34	7	Goniadidae
Ericthonius	**45**	0	0.3				1	6	2																	69	45	6	Ericthonius
Annelida	**45**	4	0.3			4	3	36	8	15		1	4	4				5	2	7		Annelida				70	156	36	Annelida
Lunatia	**45**	0	0.4					7													Northern Moon Shell	Mollusca	Gastropoda	Neotaenioglossa	Naticidae	71	25	7	Lunatia
Trochidae	**45**	0	0.4					7													Topsnail Uncl					72	33	7	Trochidae
Photis	**45**	0	0.4					4	2																	73	86	4	Photis
Ophelina	**45**	0	0.4					7	1	1											Opheliid Worm	Annelida	Polychaeta	Canalipalpata	Opheliidae	74	148	7	Ophelina
Terebellidae	**45**	1	0.4					5		2				4	1					1						75	170	5	Terebellidae
Crenella	**45**	0	0.5					4							2					3	Bean Mussell	Mollusca	Bivalvia	Mytiloida	Mytilidae	76	35	4	Crenella
Melita	**45**	0	0.6					7																		77	26	7	Melita
Glyceridae	**45**	1	0.6				1	7	2				5							1	Bloodworms					78	43	7	Glyceridae
Nereis	**45**	0	0.8					3													Clam Worm	Annelida	Polychaeta	Aciculata	Nereididae	79	27	3	Nereis
Odostomia	**45**	0	0.8					3													Pyramid Shells	Mollusca	Gastropoda	Heterostropha	Pyramidellidae	80	28	3	Odostomia
Brada	**45**	0	0.9					3														Annelida	Polychaeta	Canalipalpata	Flabelligeridae	81	14	3	Brada
Polydora	**45**	0	0.9			1		3													Mud Worms	Annelida	Polychaeta	Canalipalpata	Spionidae	82	31	3	Polydora
Solenidae	**45**	0	0.9					3													Razor And Jackknife Clam Uncl					83	32	3	Solenidae
Echinoidea	**45**	0	0.9				2	3	1				1								Sea Urchin And Sand Dollar Uncl					84	42	3	Echinoidea
Salpa	**45**	0	0.9					3													Salp	Chordata	Thaliacea	Salpida	Salpidae	85	93	3	Salpa
Maera	**45**	0	1.0					3																		86	76	3	Maera
Potamilla	**45**	0	1.0					3													Fan Worms	Annelida	Polychaeta	Canalipalpata	Sabellidae	87	90	3	Potamilla
Byblis	**48**	3	0.1			1		2	57												4-Eyed Amphipods	Arthropoda	Malacostraca	Amphipoda	Ampeliscidae	88	7	57	Byblis
Cumacea	**48**	1	0.1					1	20						2						amphipod	Arthropoda	Malacostraca	Cumacea	Cucumariidae	89	9	20	Cumacea
Spiophanes	**48**	1	0.1					2	27												bristleworm	Annelida	Polychaeta	Canalipalpata	Spionidae	90	11	27	Spiophanes
Diastylis	**48**	2	0.1				2	13	16											3	diastylis	Arthropoda	Malacostraca	Cumacea	Diastylidae	91	36	16	Diastylis
Cupuladria	**48**	2	0.1						49												a bryzoan	Ectoprocta	Gymnolaemata			92	100	49	Cupuladria
Rhepoxynius	**48**	3	0.1			11		6	21			8	7					1		1	an amphipod	Arthropoda	Malacostraca	Amphipoda	PHOXOCEPHALIDAE	93	101	21	Rhepoxynius
Amphipoda	**48**	3	0.1				1	11	40			1	1	1						1	Amphidod Unid					94	147	40	Amphipoda
Orbiniidae	**48**	1	0.1				1		9				3	1							a polychaete	Annelida	Polychaeta	Scolecida	Orbibiidae	95	158	9	Orbiniidae
Nephtyidae	**48**	2	0.2			2		6	11	3			1	3		1	1			8	Red-Lined Worms	Annelida	Polychaeta	Phyllodocida	Nephtyidae	96	6	11	Nephtyidae
Leptocheirus	**48**	1	0.2			1		2	11	1											Other Tube Makers	Arthropoda		Amphipoda	Aoridae	97	37	11	Leptocheirus
Tectonatica	**48**	1	0.2						10	1			7		1		2				Miniature Moonsnail	Mollusca	Gastropoda	Neotaenioglossa	Naticidae	98	116	10	Tectonatica
Naticidae	**48**	0	0.4		1				6												Moon Snail, Shark Eye, And Baby-Ear Uncl					99	138	6	Naticidae
Nereidae	**48**	0	0.5						7					2												100	176	7	Nereidae
Eriopisa	**48**	0	0.6						4																	101	68	4	Eriopisa
Edotia	**48**	0	0.7						4																	102	18	4	Edotia
Eobrolgus	**48**	0	0.7						3											3						103	20	3	Eobrolgus
Pandora	**48**	0	0.7						4												Gould'S Pandora	Mollusca	Bivalvia	Pholadomyoida	Pandoridae	104	29	4	Pandora
Mactridae	**48**	0	0.7						4												Surfclam, Duckclam, And Gaper Uncl					105	75	4	Mactridae
Amphiblestrum	**48**	0	0.8						4																	106	13	4	Amphiblestrum
Abra	**48**	0	0.8						4																	107	55	4	Abra
Liljeborgiidae	**48**	0	0.8						4																	108	73	4	Liljeborgiidae
Ischyrocerus	**48**	0	0.9						4																	109	24	4	Ischyrocerus
Neverita	**48**	0	0.9						4												Shark Eye	Mollusca	Gastropoda	Neotaenioglossa	Naticidae	110	82	4	Neverita
Eudorella	**48**	0	1.0					2	2													Arthropoda	Malacostraca	Cumacea	Leuconidae	111	21	2	Eudorella
Scoloplos	**48**	0	1.0			1	1		2			1										Annelida	Polychaeta	Canalipalpata	Orbiniidae	112	44	2	Scoloplos
Mellita	**48**	0	1.0						4																	113	127	4	Mellita
Macoma	**51**	1	0.1							12											Baltic Macoma	Mollusca	Bivalvia	Veneroida	Tellinidae	114	74	12	Macoma
Ensis	**51**	1	0.2			1		2	2	15								3			Common Razor Clam	Mollusca	Bivalvia	Veneroida	Pharidae	115	98	15	Ensis
Spisula	**51**	1	0.2			2				14		1									Surf Clam	Mollusca	Bivalvia	Veneroida	Mactridae	116	136	14	Spisula
Amphinomidae	**51**	1	0.2							10				1							Fireworm Uncl					117	180	10	Amphinomidae
Travisia	**51**	0	0.4					1		4											Opheliid Worms	Annelida	Polychaeta	Canalipalpata	Opheliidae	118	165	4	Travisia
Flabelligeridae	**51**	1	0.4							5				1				5				Annelida	Polychaeta	Canalipalpata	Flabelligeridae	119	190	5	Flabelligeridae
Chaetopterus	**51**	0	0.4							3																120	198	3	Chaetopterus
Nematoda	**51**	0	0.8						1	4	1										Round Worm Uncl					121	175	4	Nematoda

Sipuncula	**51**	0	0.8					1		3	1							Sipunculan Uncl					122	177	3	Sipuncula
Membranipora	**51**	0	1.0							3								Lacy Crusts	Ectoprocta	Gymnolaemata	Cheilostomata	Membraniporidae	123	78	3	Membranipora
Parvilucina	**51**	0	1.0							3													124	84	3	Parvilucina
Schizaster	**51**	0	1.0							3									Echinodermata	Echinoidea	Spatangoida	Schizasteridae	125	95	3	Schizaster
Anomia	**51**	0	1.0	1						2								Jingle Shell	Mollusca	Bivalvia	Ostreoida	Anomiidae	126	117	2	Anomia
Pecten	**51**	0	1.0							3									Mollusca	Bivalvia	Ostreoida	Pectinidae	127	131	3	Pecten
Solariella	**51**	0	1.0					2		2									Mollusca	Gastropoda	Archaeogastropoda	Trochidae	128	178	2	Solariella
Amphiuridae	**51**	0	1.0							3													129	181	3	Amphiuridae
Cuspidariidae	**51**	0	1.0							2	2			1									130	188	2	Cuspidariidae
Sphaerodoridae	**51**	0	1.0							3													131	195	3	Sphaerodoridae
Alvania	**63**	1	0.1							1	16			1			5	Alvania	Mollusca	Gastropoda	Neotaenioglossa	Rissoidae	132	179	16	Alvania
Limopsidae	**63**	1	0.1								11							Mollusc related to ark clams	Mollusca	Bivalvia	Pteriomorphia	Limopsidae	133	200	11	Limopsidae
Golfingia	**63**	0	0.3							1	5					4		a sipuculid worm	Sipuncula	Pararotatoria	Seisonacea	Golfingiidae	134	199	5	Golfingia
Sipunculus	**63**	0	0.4								5							a tube worm	Sipuncula	Pararotatoria	Seisonacea	Sipunculidae	135	206	5	Sipunculus
Anachis	**63**	0	0.5								5							Dove Shell	Mollusca	Gastropoda	Neogastropoda	Columbellidae	136	182	5	Anachis
Modiolus	**63**	0	0.5								5							Ribbed Mussel	Mollusca	Bivalvia	Mytiloida	Mytilidae	137	192	5	Modiolus
Cephalopoda	**63**	0	0.7							1	3							Squid, Cuttlefish, And Octopod Uncl	Mollusca	Cephalopoda	?	?	138	185	3	Cephalopoda
Chaetopteridae	**63**	0	1.0								5							a sipuculid worm	Sipuncula	Pararotatoria			139	60	5	Chaetopteridae
Sigalion	**74**	1	0.1			1			1			16	1					Burrowing Scale Worms	Annelida	Polychaeta	Aciculata	Sigalionidae	140	102	16	Sigalion
Echinarachnius	**74**	2	0.1	10		1		1				36						Common Sand Dollar, Sand Dollar	Echinodermata	Echinoidea	Clypeasteroida	Echinarachniidae	141	111	36	Echinarachnius
Leptasterias	**74**	0	0.5									5			1			Sea Star	Echinodermata	Asteroidea	Forcipulatida	Asteriidae	142	125	5	Leptasterias
Sigalionidae	**74**	1	0.5	1		1		2	2			4	3					a scale worm	Annelida	Polychaeta	Aciculata	Sigalionidae	143	135	4	Sigalionidae
Hippolytidae	**74**	0	0.6									5						a cleaner shrimp	Arthropoda	Crustacea	Decapoda	Hippolytidae	144	124	5	Hippolytidae
Idoteidae	**74**	0	0.7			2						3											145	112	3	Idoteidae
Nassarius	**74**	0	0.9	1								4	1		2			Dog Welk	Mollusca	Gastropoda	Neogastropoda	Nassariidae	146	115	4	Nassarius
Pseudunciola	**77**	1	0.1					1				1	13					a gamarid amphipod	Arthropoda	Malacostraca	Amphipoda	Pseudunciola	147	133	13	Pseudunciola
Bryozoa	**77**	3	0.1			1	1		2			1	58		5			Bryozoan	Ectoprocta	Gymnolaemata			148	146	58	Bryozoa
Diopatra	**77**	1	0.2										10					Plumed Worms	Annelida	Polychaeta	Aciculata	Onuphidae	149	66	10	Diopatra
Lembos	**77**	1	0.2										10					a gamarid amphipod	Arthropoda	Malacostraca	Amphipoda		150	72	10	Lembos
Pinnixa	**77**	1	0.2										10					small commensal crabs	Arthropoda	Malacostraca	Decapoda	Pinnotheridae	151	87	10	Pinnixa
Echinocardium	**77**	1	0.2							2			14					heart urchin	Echinodermata	Echinoidea	Spatangoida		152	114	14	Echinocardium
Exogone	**77**	1	0.4										10					Syllid Worm	Annelida	Polychaeta	Aciculata	Syllidae	153	22	10	Exogone
Syllidae	**77**	0	0.4						1				9										154	40	9	Syllidae
Caprellidae	**77**	1	0.4				4	2					6										155	113	6	Caprellidae
Bathyporeia	**77**	1	0.5										10										156	118	10	Bathyporeia
Paguridae	**77**	0	0.6						1			4	5					Right-Handed Hermit Crab Uncl					157	110	5	Paguridae
Euspira	**77**	0	0.6							1		2	4					Northern Moonsnail	Mollusca	Gastropoda	Neotaenioglossa	Naticidae	158	122	4	Euspira
Aeginina	**77**	0	0.6				3	1					3						Arthropoda	Malacostraca	Amphipoda	Caprellidae	159	140	3	Aeginina
Malletia	**77**	1	0.6								3		4			3			Mollusca	Bivalvia	Nuculoida	Malletiidae	160	201	4	Malletia
Pseudoleptocuma	**77**	0	0.8						4			1	4					Ncn	Arthropoda	Malacostraca	Cumacea	Bodotriidae	161	132	4	Pseudoleptocuma
Holothuroidea	**87**	1	0.1											16		4		Sea Cucumber Uncl	Echinodermata	Echinoidea	Holothuroidea		162	168	16	Holothuroidea
Antalis	**87**	5	0.1								1			90		1		Occidental Tuskshell	Mollusca	Scaphopoda	Dentaliida	Dentaliidae	163	183	90	Antalis
Ceratocephale	**87**	1	0.1											29				Clamworms	Annelida	Polychaeta	Aciculata	Nereididae	164	187	29	Ceratocephale
Hyalinoecia	**87**	1	0.1							2				27				Plumed Worms	Annelida	Polychaeta	Aciculata	Onuphidae	165	191	27	Hyalinoecia
Pogonophora	**87**	2	0.1								3			30				beardworms	Annelida	Polychaeta	Canalipalpata	Siboglinidae	166	203	30	Pogonophora
Siboglinum	**87**	2	0.1								4			42				beardworms	Annelida	Polychaeta	Canalipalpata	Siboglinidae	167	205	42	Siboglinum
Ampharetidae	**87**	1	0.1							1				22				a polychaete	Annelida	Polychaeta	Canalipalpata		168	210	22	Ampharetidae
Thyasira	**87**	2	0.1											28		1	9	Hatchet shell	Mollusca	Bivalvia	Veneroida	Thyasiridae	169	213	28	Thyasira
Havelockia	**87**	1	0.1							1				16	1			Hairy Sea Cucmber	Echinodermata	Holothuroidea	Dendrochirotida	Phyllophoridae	170	215	16	Havelockia
Phascolion	**87**	1	0.2				4							7				tube worm	Sipuncula	Pararotatoria	Seisonacea	Golfingiidae	171	167	7	Phascolion
Sternaspis	**87**	0	0.3											7				bristleworm	Annelida	Polychaeta	Canalipalpata	Sternaspidae	172	96	7	Sternaspis
Opheliidae	**87**	1	0.3					5						8			1	a worm	Annelida	Polychaeta	Scolecida		173	154	8	Opheliidae
Oligobrachia	**87**	0	0.4											7				a worm	Annelida	Pogonophora	Oligobrachidae		174	193	7	Oligobrachia
Amphineura	**87**	0	0.4								3			3				chiton-like	Mollusca	Plolyplacophora			175	196	3	Amphineura
Melinna	**87**	0	0.4					2						5				Ampharitid Worms	Annelida	Polychaeta	Canalipalpata	Ampharetidae	176	211	5	Melinna
Ophiura	**87**	0	0.5											7				a brittlestar	Echinodermata	Ophiuroidea	Ophiurida	Ophiuridae	177	83	7	Ophiura
Dentalium	**87**	0	0.5											7				tusk shell	Mollusca	Scaphopoda	Dentaliida	Dentaliidae	178	189	7	Dentalium
Saturnia	**87**	0	0.7								3			4				a mollusk	Mollusca	Bivalvia	Nuculoida	Malletiidae	179	204	4	Saturnia
Gastropoda	**95**	2	0.1						6				2	4	36	1		Snail Uncl					180	161	36	Gastropoda
Mitrella	**95**	1	0.1					1					1		12			Dove Shell	Mollusca	Gastropoda	Neogastropoda	Columbellidae	181	172	12	Mitrella
Kurtziella	**95**	1	0.2												10			Cone snail	Mollusca	Gastropoda	Neogastropoda	Conidae	182	71	10	Kurtziella

Ophiocten	**95**	1	0.2														10							Brittle Star	Echinodermata	Ophiuroidea	Ophiurida	Ophiuridae	183	130	10	Ophiocten
Stereoderma	**95**	1	0.2														10							Sea cucumber	Echinodermata	Holothuroidea	Dendrochirotida	Cucumariidae	184	137	10	Stereoderma
Cyclopecten	**95**	0	0.3					1									9							a bivalve	Mollusca	Bivalvia	Ostreoida	Propeamussidae	185	65	9	Cyclopecten
Marginella	**95**	1	0.3														10							margin shells	Mollusca	Gastropoda	Neogastropoda	Marginellidae	186	77	10	Marginella
Retusa	**95**	0	0.3														7						2	Solitary Glassy Bubble	Mollusca	Gastropoda	Cephalaspidea	Retusidae	187	92	7	Retusa
Tanaidae	**95**	0	0.3								1						7												188	143	7	Tanaidae
Crassinella	**95**	1	0.4														10							Lunate Crassinella	Mollusca	Bivalvia	Veneroida	Crassatellidae	189	119	10	Crassinella
Ervilia	**95**	1	0.4														10												190	121	10	Ervilia
Granulina	**95**	0	0.5											2			8								Mollusca	Gastropoda	Neogastropoda	Cystiscidae	191	141	8	Granulina
Turbonilla	**95**	0	0.8	1							1						3							Pyramid Shells	Mollusca	Gastropoda	Heterostropha	Pyramidellidae	192	97	3	Turbonilla
Sergestes	**111**	1	0.1		4													11						a prawn	Arthropoda	Malacostraca	Decapoda	Sergestidae	193	217	11	Sergestes
Illex	**111**	2	0.1	14														19						Boreal Squid	Mollusca	Cephalopoda	Teuthida	Ommastrephidae	194	224	19	Illex
Astropectinidae	**111**	2	0.1	6														38						Sea star	Echinodermata	Asteroidea	Paxillosida	Astropectinidae	195	227	38	Astropectinidae
Pandalidae	**111**	1	0.2	11														17						Boreal Red Shrimps	Arthropoda	Malacostraca	Decapoda	Pandalidae	196	230	17	Pandalidae
Dichelopandalus	**111**	0	0.6	3								1						4						Boreal Red Shrimp (Pandalus)	Arthropoda	Malacostraca	Decapoda	Pandalidae	197	229	4	Dichelopandalus
Haustoriidae	**141**	3	0.1			4			11			10	16			22								an amphipod	Arthropoda	Malacostraca	Amphipoda	Haustoriidae	198	123	22	Haustoriidae
Magelonidae	**141**	1	0.2													14								a worm	Annelida	Polychaeta	Canalipalpata	Magelonidae	199	126	14	Magelonidae
Oedicerotidae	**141**	0	0.4									1	3			5								an amphipod	Arthropoda	Malacostraca	Amphipoda	Oedicerotidae	200	129	5	Oedicerotidae
Cirripedia	**141**	0	0.6						1	2			1	1		3								a barnacle	Arthropoda	Maxillopoda			201	61	3	Cirripedia
Corbulidae	**144**	1	0.1																20					a bivalve	Mollusca	Bivalvia	Myoida	Corbulidae	202	63	20	Corbulidae
Gemma	**144**	1	0.1																20					Gem Shell	Mollusca	Bivalvia	Veneroida	Veneridae	203	70	20	Gemma
Periploma	**144**	1	0.1																19					Lea's Spoon Shell	Mollusca	Bivalvia	Pholadomyoida	Periplomatidae	204	85	19	Periploma
Neomysis	**144**	1	0.1										2			4			12					mysid shrimp	Arthropoda	Malacostraca	Mysida	Mysidae	205	128	12	Neomysis
Tellinidae	**144**	2	0.1	1					1	4			1						32					Tellin clams	Mollusca	Bivalvia	Veneroida	Tellinidae	206	144	32	Tellinidae
Capitellidae	**144**	1	0.1																13	12				a worm	Annelida	Polychaeta	Scolecida	Cappitellidae	207	149	13	Capitellidae
Nuculanidae	**144**	1	0.1											2					15					a bivalve	Mollusca	Bivalvia	Nuculoida	Nuculandidae	208	150	15	Nuculanidae
Lucinoma	**144**	2	0.1																35	2				a bivalve	Mollusca	Bivalvia	Veneroida	Lucinidae	209	151	35	Lucinoma
Bivalvia	**144**	5	0.1																97					a bivalve	Mollusca	Bivalvia	?	?	210	159	97	Bivalvia
Amphioplus	**144**	1	0.1																19					Burrowing Brittlestar	Echinodermata	Ophiuroidea	Ophiurida	Amphiuridae	211	162	19	Amphioplus
Ophiuroidea	**144**	1	0.1																15	2		2		Brittle Star And Basket Star Uncl	Echinodermata	Ophiuroidea	Ophiurida	Ophiuroidea	212	163	15	Ophiuroidea
Mendicula	**144**	1	0.1									11			1				16					Rusty Axinopsid	Mollusca	Bivalvia	Veneroida	Thyasiridae	213	202	16	Mendicula
Aglaophamus	**144**	1	0.2								1								17					Red-Lined Worms	Annelida	Polychaeta	Aciculata	Nephtyidae	214	46	17	Aglaophamus
Yoldia	**144**	1	0.2								1		2	2					9					File Yoldia	Mollusca	Bivalvia	Nuculoida	Yoldiidae	215	209	9	Yoldia
Arabellidae	**144**	1	0.3		1					2	3								5					Red Irridescent Burrowing Worms					216	152	5	Arabellidae
Cadulus	**144**	1	0.3							1	2		1	1			2		5					Tusk Shell	Mollusca	Scaphopoda	Gadilida	Gadilidae	217	171	5	Cadulus
Polynoidae	**144**	1	0.4									3	1			2			6										218	89	6	Polynoidae
Anoplodactylus	**145**	0	0.3																	6				Lentil Sea Spider	Arthropoda	Pycnogonida	Pantopoda	Phoxichilidiidae	219	56	6	Anoplodactylus
Pycnogonida	**145**	0	0.3																	6				Sea Spider Uncl	Arthropoda	Pycnogonida	Pantopoda		220	91	6	Pycnogonida
Plectodon	**145**	0	0.6																	6				a bivale	Mollusca	Bivalvia	Pholadomyoida		221	88	6	Plectodon
Crepidula	**145**	0	0.9							2										4				Slipper Shell	Mollusca	Gastropoda	Neotaenioglossa	Calyptraeidae	222	64	4	Crepidula
Thraciidae	**152**	1	0.1								1	1									13			a bivalve	Mollusca	Bivalvia	Pholadomyoida	Thraciidae	223	41	13	Thraciidae
Ampeliscidae	**152**	3	0.1								5	22							1		27			an amphipod	Arthropoda	Malacostraca	Amphipoda	Ampeliscidae	224	47	27	Ampeliscidae
Arca	**152**	1	0.1																		18			a bivalve	Mollusca	Bivalvia	Arcoida	Arcidae	225	48	18	Arca
Cirratulidae	**152**	1	0.1				1	1			2		2			4					11			Fringed Worm	Annelida	Polychaeta	Canalipalpata	Cirratulidae	226	153	11	Cirratulidae
Onuphidae	**152**	2	0.1										3			1	1		1	1	27			Plumed Worms	Annelida	Polychaeta	Aciculata	Onuphidae	227	173	27	Onuphidae
Arcidae	**152**	0	0.3																		9			ark clam	Mollusca	Bivalvia	Arcoida		228	57	9	Arcidae
Aricidea	**152**	0	0.3										1							1	7			Paraonid Worms	Annelida	Polychaeta	Canalipalpata	Paraonidae	229	58	7	Aricidea
Harpinia	**152**	0	0.4								4										4			an amphipod	Arthropoda	Malacostraca	Amphipoda	PHOXOCEPHALIDAE	230	49	4	Harpinia
Eunicidae	**152**	0	0.5							2											4			a worm	Annelida	Polychaeta	Eunicida	Eunicidae	231	69	4	Eunicidae
Drilonereis	**152**	0	0.5								1				3						4			a worm	Annelida	Polychaeta	Aciculata	Oenonidae	232	169	4	Drilonereis
Scaphopoda	**152**	0	0.6											2	2						3			Tuskshell And Toothshell Uncl	Mollusca	Scaphopoda	?	?	233	212	3	Scaphopoda
Diplodonta	**152**	0	0.9										2								4	4		a bivalve	Mollusca	Bivalvia	Veneroida	Ungulinidae	234	164	4	Diplodonta
Balcis	**213**	1	0.1																			11		small sea snail	Mollusca	Gastropoda	Neotaenioglossa	Eulimidae	235	197	11	Balcis
Mya	**213**	1	0.2																			11		Softshell Clam	Mollusca	Bivalvia	Myoida	Myidae	236	80	11	Mya
Ascidiacea	**213**	1	0.4								7	1	1					1			5	8		Sea Squirt Uncl	Chordata	Ascidiacea			237	3	8	Ascidiacea

Sequence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Identifier	1	14	16	22	42	44	45	48	51	63	74	77	87	95	111	141	144	145	152	213
# of items	18	23	10	7	27	22	29	24	32	19	19	10	14	10	6	7	5	16	11	9

Appendix 2. Physical Factors Profiles for the Organism Groups

MID ATLANTIC BIGHT

Table MAB1. Thresholds for bathymetry and bathymetry profiles for each organism group. Group numbers correspond with the organism group identification number in text. Thresholds correspond to the optimum threshold points. Numbers and bars indicate the number of samples taken from each zone. Chi-squared tests for the significance of each distribution compared to a random distribution are given in the lowermost table along with the depth class where each organism group is most likely to be found (ns = not significant).

	ORGANISM GROUPS											
Depth (meters)	**14**	**22**	**42**	**44**	**45**	**48**	**51**	**63**	**74**	**77**	**87**	**95**
1: 0-17	0	0	0	6	0	2	12	0	1	0	0	4
2: 17- 31	1	0	5	5	0	9	9	0	13	6	0	3
3: 31-85	9	0	20	7	27	13	2	0	5	3	0	1
4: 85-102	0	0	1	1	2	0	0	0	0	0	0	0
5: 102- 280	11	7	1	2	0	0	2	0	0	0	0	1
6: 280 – 996	0	0	0	0	0	0	4	4	0	0	14	0
7: 996+	1	0	0	0	0	0	2	15	0	1	0	0

	ORGANISM GROUPS					
Depth (meters)	**111**	**141**	**144**	**145**	**152**	**213**
1: 0-17	0	4	1	9	4	1
2: 17- 31	0	3	1	0	1	0
3: 31-85	1	0	1	1	0	0
4: 85-102	1	0	0	0	3	0
5: 102- 280	4	0	2	3	2	0
6: 280 – 996	0	0	0	0	1	0
7: 996+	0	0	0	2	0	6

	14	22	42	44	45	48	51	63	74	77	87	95	111	141	144	145	152	213
CHISQR	**0.00**	**0.00**	**0.00**	**0.19**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.02**	**0.00**	**0.26**	**0.00**	**0.11**	**0.01**	**0.00**	**0.00**	**0.01**
Most likely Depth	**5**	**5**	**3**	**ns**	**3**	**2,3**	**1,2**	**7**	**2**	**2**	**6**	**ns**	**5**	**ns**	**5**	**1**	**4,5**	**7**

Table MAB2: Grain size thresholds and grain size profiles for each organism group. Group numbers correspond with the organism group identification number in text. Thresholds correspond to the optimum thresholds. Numbers and bars indicate the number of samples taken from each zone. Chi-squared tests for the significance of each distribution compared to a random distribution is given in the lowermost table along with the grain-size class where each organism group is most likely to be found (ns = not significant).

ORGANISM GROUPS

Grain Size in mm	**14 14**	**22 22**	**42 42**	**44 44**	**45 45**	**48 48**	**51 51**	**63 63**	**74 74**	**77 77**
1: 0.00 to 0.08 cla y and silt	2	0	1	2	1	1	8	14	0	1
2: 0.08 to 0.21 very fine sand	11	3	4	6	2	4	10	5	0	0
3: 0.21 to 0.24 fine sand	0	4	0	0	2	1	0	0	0	1
4: 0.24 to 0.26 fine sand	0	0	3	2	0	0	0	0	2	2
5: 0.26 to 0.52 sand	6	0	15	3	22	14	10	0	10	4
6: > 0.52 coarse sand	3	0	4	8	2	4	3	0	7	2

ORGANISM GROUPS

Grain Size in mm	**87**	**95**	**111**	**141**	**144**	**145**	**152**	**213**
1: 0.00 to 0.08 cla y and silt	7	0	0	0	2	7	3	5
2: 0.08 to 0.21 very fine sand	5	4	3	1	0	2	5	2
3: 0.21 to 0.24 fine sand	0	0	0	0	1	0	2	0
4: 0.24 to 0.26 fine sand	0	0	1	0	2	0	0	0
5: 0.26 to 0.52 sand	2	2	2	2	0	6	0	0
6: > 0.52 coarse sand	0	3	0	4	0	0	1	0

Group	**14**	**22**	**42**	**44**	**45**	**48**	**51**	**63**	**74**	**77**	**87**	**95**	**111**	**141**	**144**	**145**	**152**	**213**
CHI_SQR	0.020	0.000	0.001	0.003	0.000	0.045	0.475	0.000	0.000	0.007	0.138	0.154	0.083	0.041	0.000	0.311	0.026	0.116
Most Likely Grain Size class	**2**	**3**	**5**	**6**	**5**	**5**	**ns(2)**	**1**	**5,6**	**4**	**1,2**	**ns(2,6)**	**2**	**6**	**4**	**ns(1)**	**2,3**	**ns (1)**

Table MAB3. Landform profiles for the organism groups. Group numbers correspond with the organism group identification number in text. Numbers and bars indicate the number of samples taken from each zone. Chi-squared tests for the significance of each distribution compared to a random distribution is given in the lowermost table along with the seabed form where each organism group is most likely to be found (ns = not significant).

Seabed form	**14**	**22**	**42**	**44**	**45**	**48**	**51**	**63**	**74**	**77**
1 Depression	2	0	3	2	10	3	5	0	2	3
2 high sloping flat	7	1	7	9	10	12	11	0	10	2
3 low sloping flat	4	2	16	9	9	9	10	2	7	3
4 high sideslope	5	4	1	1	0	0	0	4	0	0
5 low sideslope	2	0	0	0	0	0	1	3	0	0
6 canyon/steepslope	2	0	0	0	0	0	4	10	0	2

Seabed form	**87**	**95**	**111**	**141**	**144**	**145**	**152**	**213**
1 Depression	0	4	1	0	0	1	1	0
2 low sloping flat	1	2	1	3	2	6	3	2
3 high sloping flat	0	3	3	4	0	4	4	1
4 high sidelope	1	0	1	0	2	1	1	2
5 low sidelslope	0	0	0	0	0	0	0	0
6 canyon/steepslope	12	0	0	0	1	3	2	2

Group	**14**	**22**	**42**	**44**	**45**	**48**	**51**	**63**	**74**	**77**	**87**	**95**	**111**	**141**	**144**	**145**	**152**	**213**
Chi_Sqr	0.00	0.00	0.00	0.10	0.03	0.06	0.73	0.00	0.11	0.76	0.00	0.34	0.50	0.38	0.00	0.49	0.84	0.01
Most Likely Seabed form	4	4	3	3(2)	1	2(3)	ns	6	ns(2,3)	ns	6	ns(1)	ns	ns(2)	4	ns(3)	ns(6)	4(6)

SOUTHERN NEW ENGLAND

Table SNE1. Thresholds for bathymetry and bathymetry profiles for each organism group. Group numbers correspond with the organism group identification number in text. Thresholds correspond to the optimum threshold points. Numbers and bars indicate the number of samples taken from each zone.

Increasing DEPTH (meters)	ORGANISM GROUPS 1 1	1.1 1.1	5 5	44 44	45 45	47 47	69 69	85 85	86 86	90 90	94 94	98 98
0-6.9 meter	35	9	11	0	0	0	1	0	0	0	0	0
6.9 – 26 meters	14	2	3	0	0	0	2	1	5	4	9	9
26 – 72 meters	31	2	3	10	11	3	35	43	32	4	18	25
72 – 108 meters	10	0	1	15	4	3	1	9	0	0	0	14
108-331 meters	14	0	0	30	8	19	0	2	8	0	0	1
331+ meter	29	0	0	1	0	0	0	0	3	12	0	0

Increasing DEPTH (meters)	ORGANISM GROUPS 112 112	115 115	121 121	136 136	157 157	458 458	476 476	480 480	483 483
0-6.9 meter	0	1	0	0	0	1	0	0	0
6.9 – 26 meters	0	12	0	0	0	3	0	0	0
26 – 72 meters	0	14	0	15	1	2	13	10	2
72 – 108 meters	12	1	25	0	9	0	1	6	1
108-331 meters	19	10	15	0	3	0	11	11	7
331+ meter	3	8	0	0	0	15	0	1	0

Table SNE2: Grain size thresholds and grain size profiles for each organism group. Group numbers correspond with the organism group identification number in text. Thresholds correspond to the optimum thresholds. Numbers and bars indicate the number of samples taken from each zone.

	ORGANISM GROUPS																							
Increasing GRAIN SIZE (mm)	**1**	**1**	**1.1**	**1.1**	**5**	**5**	**44**	**44**	**45**	**45**	**47**	**47**	**69**	**69**	**85**	**85**	**86**	**86**	**90**	**90**
0-0.027 fine silt	13		0		0		5		2		3		0		4		0		5	
0.027 – 0.117 very fine sand	45		0		0		38		12		15		12		22		26		7	
0.117-0.99 sand & coarse sand	44		5		6		7		6		3		23		27		17		4	
0.99 – 3.1 very coarse sand	30		6		12		2		3		1		4		2		3		1	
3.1 – 10.7 very fine pebbles to fine pebbles	0		2		0		1		0		0		0		0		1		3	
>10.7 medium pebbles	1		0		0		3		0		3		0		0		1		0	

	ORGANISM GROUPS																							
Increasing GRAIN SIZE (mm)	**94**	**94**	**98**	**98**	**112**	**112**	**115**	**115**	**121**	**121**	**136**	**136**	**157**	**157**	**458**	**458**	**476**	**476**	**480**	**480**	**483**	**483**
0-0.027 fine silt	0		2		10		0		18		0		5		10		1		2		0	
0.027 – 0.117 very fine sand	5		24		21		24		21		3		7		9		11		15		6	
0.117-0.99 sand & coarse sand	20		23		3		16		1		12		1		1		10		6		3	
0.99 – 3.1 very coarse sand	1		0		0		0		0		0		0		0		3		4		1	
3.1 – 10.7 very fine pebbles to fine pebbles	0		0		0		5		0		0		0		1		0		0		0	
>10.7 medium pebbles	1		0		0		1		0		0		0		0		0		1		0	

Table SNE3. Landform profiles for the organism groups. Group numbers correspond with the organism group identification number in text. Numbers and bars indicate the number of samples taken from each zone.

Seabed Forms	ORGANISM GROUPS																							
	1	1	1.1	1.1	5	5	44	44	45	45	47	47	69	69	85	85	86	86	90	90	94	94
Level Flat	4		1		1		3		1		1		8		5		5		0		1	
Flat	11		0		1		6		2		2		8		15		10		0		6	
Gentle-slope Flat	76		10		16		32		14		12		23		35		28		9		20	
Side slope	24		0		0		15		6		9		0		0		2		4		0	
Steep slope	14		2		0		0		0		1		0		0		1		3		0	
Cliff/canyon	4		0		0		0		0		0		0		0		2		4		0	

Seabed Forms	ORGANISM GROUPS																					
	98	98	112	112	115	115	121	121	136	136	157	157	458	458	476	476	480	480	483	483
Level Flat	4		6		3		2		4		1		1		3		0		1	
Flat	10		5		4		13		3		3		0		3		3		0	
Gentle-slope Flat	33		16		22		23		8		9		6		13		19		8	
Side slope	1		7		9		2		0		0		5		6		4		1	
Steep slope	1		0		6		0		0		0		7		0		2		0	
Cliff/canyon	0		0		2		0		0		0		2		0		0		0	

GULF OF MAINE

Table GOM1. Thresholds for bathymetry and bathymetry profiles for each organism group. Group numbers correspond with the organism group identification number in text. Thresholds correspond to the optimum threshold points. Numbers and bars indicate the number of samples taken from each zone.

Increasing DEPTH (Meters)	ORGANISM GROUPS 1	1	2	2	7	7	8	8	10	10	11	11	16	16	24	24	31	31	34	34
1: 0-45	3		26		0		1		11		4		0		0		0		12	
2: 45-53	3		5		0		0		1		4		0		0		0		2	
3: 53-97	9		41		7		4		15		12		1		0		10		5	
4: 97-126	9		6		8		3		3		1		2		4		6		6	
5: 126-368	97		55		53		20		1		6		12		26		11		19	
6: 368+	1		3		0		0		6		1		0		0		0		4	

Increasing DEPTH (Meters)	ORGANISM GROUPS 43	43	153	153	178	178	183	183	185	185	266	266	291	291	423	423	526	526	549	549
1: 0-45	0		0		2		0		0		10		6		0		0		1	
2: 45-53	1		0		3		1		0		4		17		0		0		2	
3: 53-97	8		10		23		14		44		9		16		2		23		6	
4: 97-126	1		12		2		0		1		11		0		2		2		0	
5: 126-368	37		56		16		0		0		10		0		22		0		0	
6: 368+	0		0		0		0		0		5		0		0		0		0	

Table GOM2: Grain size thresholds and grain size profiles for each organism group. Group numbers correspond with the organism group identification number in text. Thresholds correspond to the optimum thresholds. Numbers and bars indicate the number of samples taken from each zone.

	ORGANISM GROUPS																							
Increasing GRAIN SIZE (mm)	**1**	**1**	**2**	**2**	**7**	**7**	**8**	**8**	**10**	**10**	**11**	**11**	**16**	**16**	**24**	**24**	**31**	**31**	**34**	**34**	**43**	**43**
1: 0 -0.03 clay and silt	42		10		10		2		0		1		2		7		3		4		3	
2: 0.03 – 0.05 coarse silt	9		1		5		3		2		2		1		0		1		5		5	
3: 0.05 – 0.1 very fine sand	5		4		8		4		3		2		0		8		0		0		3	
4: 0.1 – 0.4 fine to med sand	2		39		8		7		12		14		5		2		6		2		5	
5: 0.4 – 1.7 coarse to vc sand	34		48		15		6		8		6		3		6		8		25		12	
6: 1.7+ pebbles	30		34		22		6		12		3		4		7		9		12		19	

	ORGANISM GROUPS																			
Increasing GRAIN SIZE (mm)	**43**	**43**	**153**	**153**	**178**	**178**	**183**	**183**	**185**	**185**	**266**	**266**	**291**	**291**	**423**	**423**	**526**	**526**	**549**	**549**
1: 0 -0.03 clay and silt	3		25		2		0		0		2		0		4		0		0	
2: 0.03 – 0.05 coarse silt	5		4		1		0		0		1		3		2		0		0	
3: 0.05 – 0.1 very fine sand	3		1		2		2		7		1		0		1		4		0	
4: 0.1 – 0.4 fine to med sand	5		5		19		7		22		13		27		3		8		6	
5: 0.4 – 1.7 coarse to vc sand	12		21		13		5		12		22		9		5		12		2	
6: 1.7+ pebbles	19		22		9		1		4		10		0		11		1		1	

Table GOM3. Landform profiles for the organism groups. Group numbers correspond with the organism group identification number in text. Numbers and bars indicate the number of samples taken from each zone.

ORGANISM GROUPS

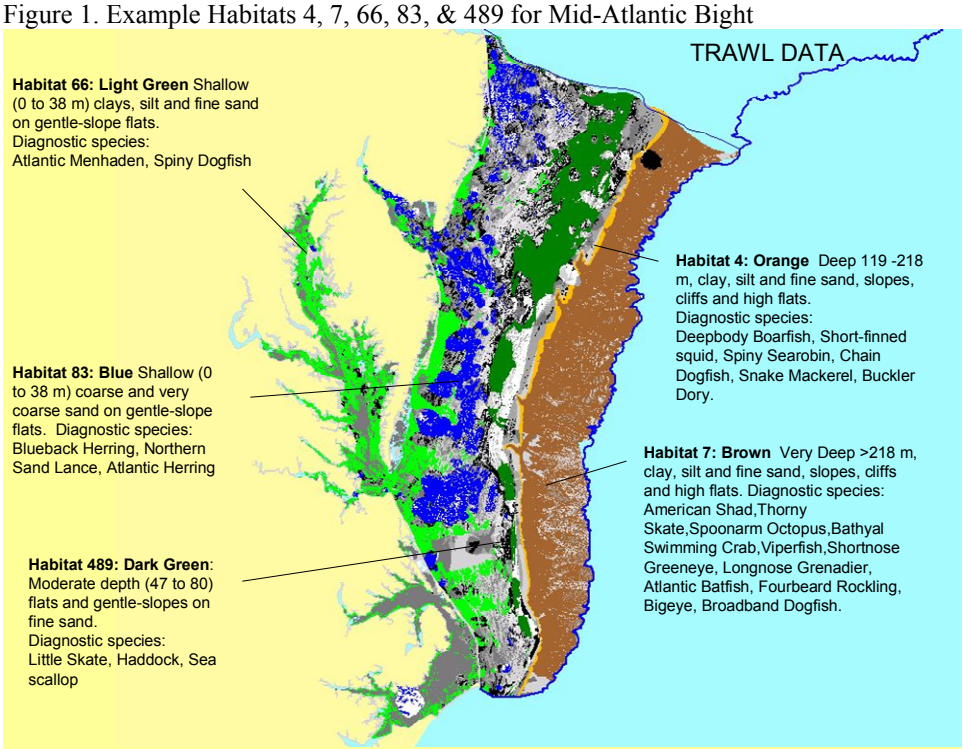
Seabed Forms	**1**	**2**	**7**	**8**	**10**	**11**	**16**	**24**	**31**	**34**
Level Flat	0	5	4	0	0	2	0	1	1	1
Flat	4	10	1	0	0	6	1	0	1	3
Gentle-slope Flat	93	92	44	22	25	16	9	24	18	27
Side slope	22	23	19	6	3	2	5	5	7	11
Steep slope	2	5	0	0	8	2	0	0	0	4
Cliff/canyon	1	1	0	0	1	0	0	0	0	2

ORGANISM GROUPS

Seabed Forms	**43**	**153**	**178**	**183**	**185**	**266**	**291**	**423**	**526**	**549**
Level Flat	3	2	4	1	3	2	2	0	3	1
Flat	3	3	3	3	8	6	12	1	3	2
Gentle-slope Flat	34	56	33	10	33	25	25	19	19	6
Side slope	7	14	6	1	1	10	0	5	0	0
Steep slope	0	3	0	0	0	3	0	1	0	0
Cliff/canyon	0	0	0	0	0	3	0	0	0	0

Appendix 3. Test of demersal fish habitat mapping based on 2005 bottom trawl data

Figure 1. Example Habitats 4, 7, 66, 83, & 489 for Mid-Atlantic Bight



Mid Atlantic Bight

Habitat 1: Shallow to moderate (0 to 80 m) depths, any substrate mostly fine sand, depressions and flats. Diagnostic species:

- Alewife *(Alosa pseudoharengus)*
- Smallmouth Flounder *(Etropus microstomus)*
- Winter Skate *(Leucoraja ocellata)*
- Striped Bass *(Morone saxatilis)*
- Atlantic Mackerel *(Scomber scombrus)*
- Searobin *(Triglidae)*

Habitat 4: Deep 119 -218 m, clay, silt and fine sand, slopes, cliffs and high flats. Diagnostic species:

- Deepbody Boarfish *(Antigonia capros)*
- Short-finned squid *(Illex illecebrosus)*
- Spiny Searobin *(Prionotus alatus)*
- Chain Dogfish *(Scyliorhinus retifer)*
- Snake Mackerel *(Trichiuridae)*
- Buckler Dory *(Zenopsis conchifera)*

Habitat 7: Very Deep >218 m, clay, silt and fine sand, slopes, cliffs and high flats.
Diagnostic species:

- American Shad *(Alosa sapidissima)*
- Thorny Skate *(Amblyraja radiata)*
- Spoonarm Octopus *(Bathypolypus arcticus)*
- Bathyal Swimming Crab *(Bathynectes longispina)*
- Viperfish *(Chauliodus sloani)*
- Shortnose Greeneye *(Chlorophthalmus agassizi)*
- Longnose Grenadier *(Coelorhynchus carminatus)*
- Atlantic Batfish *(Dibranchus atlanticus)*
- Fourbeard Rockling *(Enchelyopus cimbrius)*
- Bigeye *(Epigonus pandionis)*
- Broadband Dogfish *(Etmopterus gracilispinis)*
- Beardless Codling *(Gadella imberbis)*
- Galatheid Uncl *(Galatheidae galatheidae)*
- Red deep sea crab *(Geryon quinquedens)*
- Witch Flounder *(Glyptocephalus cynoglossus)*
- Blackbelly Rosefish *(Helicolenus dactylopterus)*
- American Lobster *(Homarus americanus)*
- Slimehead *(Hoplostethus occidentalis)*
- Goosefish *(Lophius americanus)*
- Grenadier Uncl *(Macrouridae macrouridae)*
- Western Softhead Grenadier *(Malacocephalus occidentalis)*
- Smooth Skate *(Malacoraja senta)*
- Weitzmans Pearlsides *(Maurolicus weitzmani)*
- Offshore Hake *(Merluccius albidus)*
- Silver Hake *(Merluccius bilinearis)*
- Lanternfish Uncl *(Myctophidae myctophidae)*
- Atlantic Hagfish *(Myxine glutinosa)*
- Slender Snipe Eel *(Nemichthys scolopaceus)*
- Common Octopus *(Octopus vulgaris)*
- Longnose Greeneye *(Parasudis truculenta)*
- Barracudina Uncl *(Paralepidae paralepidae)*
- Shrimp *(Penaeus sp)*
- Sea Lamprey *(Petromyzon marinus)*
- Royal red shrimp *(Pleoticus robustus)*
- Polymetme *(Polymetme thaeocoryla)*
- Hatchetfish Uncl *(Sternoptychidae)*
- Boa Dragonfish *(Stomias boa)*
- Tonguefish *(Symphurus sp)*
- Blackmouth Bass *(Synagrops bellus)*
- Longfin Hake *(Urophycis chesteri)*

Habitat 10: Mostly shallow (0 to 24 m) but ranges up to 80 m, Flats and gentle-slope flats, fine sand to coarse sand. No diagnostic species but red porgy *(Pagrus sedecim)* and Sandbar Shark *(Carcharhinus plumbeus)* are typical.

Habitat 11: Moderately deep (80 to 119) clay and fine sand on slopes and high position gentle-slope flats. Diagnostic species :

- Black Sea Bass *(Centropristis striata)*
- Rosette Skate *(Leucoraja garmani)*
- Longfin inshore squid *(Loligo pealeii)*
- Summer Flounder *(Paralichthys dentatus)*
- Butterfish *(Peprilus triacanthus)*
- Northern Searobin *(Prionotus carolinus)*
- Striped Searobin *(Prionotus evolans)*
- Clearnose Skate *(Raja eglanteria)*

Habitat 66: Shallow (0 to 38 m) clays, silt and fine sand on gentle-slope flats. Diagnostic species:

- Atlantic Menhaden *(Brevoortia tyrannus)*
- Spiny Dogfish *(Squalus acanthias)*

Habitat 83: Shallow (0 to 38 m) coarse and very coarse sand on gentle-slope flats. Diagnostic species:

- Blueback Herring *(Alosa aestivalis)*
- Northern Sand Lance *(Ammodytes dubius)*
- Atlantic Herring *(Clupea harengus)*

Habitat 120: Shallow (24 to 38 m) clay to coarse sand on gentle-slope flats. Diagnostic species:

- Atlantic Silverside *(Menidia menidia)*

Habitat 175: Shallow (24 to 80 m) fine sand on gentle-slope flats. Diagnostic species:

- Northern Stargazer *(Astroscopus guttatus)*
- Mackerel Scad *(Decapterus macarellus)*
- Lady crab *(Ovalipes ocellatus)*
- Swimming Crab *(Portunidae)*
- Brown Rock Shrimp *(Sicyonia brevirostris)*

Habitat 176: Very Shallow (0 to 38 m) coarse sand and very coarse sand on flats and gentle-slope flats. Diagnostic species:

- Northern Moonsnail *(Euspira heros)*
- Atlantic Surfclam *(Spisula solidissima)*

Habitat 177: Very shallow (0-38) very coarse sand, flats and gentle-slopes. No diagnostic species: Stargazer (*Uranoscopidae)* is typical.

Habitat 179: Various depths (0-119) and grainsized (clay to coarse sand) flats and gentle-slopes. One diagnostic species: Polka-Dot Cusk-Eel *(Otophidium omostigmum).* This group may not hold up as its own type

Habitat 182: Shallow to moderate depths (0-80) fine sand to very coarse sand, mid position gentle-slopes. One diagnostic species: Atlantic Rock Crab *(Cancer irroratus)*

Habitat 193: Shallow (0-38 m) clay/silt to fine sand, Flats and mid position gentle-slopes. One diagnostic species:

- Southern Quahog *(Mercenaria campechiensis)*

Habitat 196a & b: Shallow to moderate depths (0-80 m) any grain size but mostly fine sand, Flats and gentle-slopes. Many samples Diagnostic species:

a. Very shallow (0-47) subtype 196

- Ocean Quahog *(Arctica islandica)*

b. Shallow (47-80*)* subtype 233

- Smooth Astarte *(Astarte castanea)*
- Common Whelk *(Buccinum undatum)*
- False Quahog *(Pitar morrhuanus)*
- Razor And Jackknife Clam *(Solenidae))*

Habitat 202: Shallow (24-38 m) clay/silt to fine sand, Mid position gentle-slopes. Diagnostic species:

- Channeled Whelk *(Busycon canaliculatum)*
- Knobbed whelk *(Busycon carica)*
- Horseshoe Crab *(Limulus polyphemus)*
- Spider Crab *(Majidae)*
- Shark Eye *(Neverita duplicata)*
- Hermit Crab *(Paguroidea)*

Habitat 489: Moderate depth (47 to 80) flats and gentle-slopes on fine sand. Diagnostic species:

- Little Skate *(Leucoraja erinacea)*
- Haddock *(Melanogrammus aeglefinus)*
- Sea scallop *(Placopecten magellanicus)*

Habitat 490: Moderate depth (47 to 80) flats and gentle-slopes on fine sand. Diagnostic species:

- Northern Sea Star *(Asterias vulgaris)*
- Sea star *(Astropecten astropecten)*
- Cancer Crab *(Cancridae)*
- Gulf Stream Flounder *(Citharichthys arctifrons)*
- Atlantic Cod *(Gadus morhua)*
- Goosefish *(Lophius americanus)*
- Bobtail Uncl *(Sepiolidae sepiolidae)*
- Sea Star, Brittle Star, And Basketstar *(Stelleroidea)*
- Red Hake *(Urophycis chuss)*

Habitat 491: Moderate depth (47 to 80) any substrate but mostly fine sand. Flats and gentle-slopes. Diagnostic species:

- Fawn Cusk-Eel *(Lepophidium profundorum)*
- Fourspot Flounder *(Paralichthys oblongus)*
- Spotted Hake *(Urophycis regia)*

Habitat 658: Moderate depth (47 to 80) fine sand to very coarse sand. High position gentle-slopes. Diagnostic species:

- Witch Flounder *(Glyptocephalus cynoglossus)*
- Sea Raven *(Hemitripterus americanus)*
- Yellowtail Flounder *(Limanda ferruginea)*
- Ocean Pout *(Macrozoarces americanus)*
- Silver Hake *(Merluccius bilinearis)*
- Longhorn Sculpin *(Myoxocephalus octodecemspinosus)*
- Winter Flounder *(Pseudopleuronectes americanus)*
- Skate *(Raja sp)*

Habitat 716: Shallow (0 to 38 m) any substrate. Gentle-slopes. Diagnostic species:
A: Very shallow 0 to 18 (24) m, any substrate, subtype 716

- Striped Anchovy *(Anchoa hepsetus)*
- Bay Anchovy *(Anchoa mitchilli)*
- Blue crab *(Callinectes sapidus)*
- Striped Burrfish *(Chilomycterus schoepfi)*
- Weakfish *(Cynoscion regalis)*
- Bluntnose Stingray *(Dasyatis say)*
- Round Herring *(Etrumeus teres)*
- Smooth Butterfly Ray *(Gymnura micrura)*
- Spot *(Leiostomus xanthurus)*
- Atlantic Brief Squid *(Lolliguncula brevis)*
- Southern Kingfish *(Menticirrhus americanus)*
- Northern Kingfish *(Menticirrhus saxatilis)*
- Atlantic Croaker *(Micropogonias undulatus)*
- White Mullet *(Mugil curema)*
- Smooth Dogfish *(Mustelus canis)*
- Bullnose Ray *(Myliobatis freminvillei)*
- Striped Cusk-Eel *(Ophidion marginatum)*
- Pigfish *(Orthopristis chrysoptera)*
- Black Drum *(Pogonias cromis)*
- Bluefish *(Pomatomus saltatrix)*
- Cownose Ray *(Rhinoptera bonasus)*
- Greater Amberjack *(Seriola dumerili)*
- Northern Puffer *(Sphoeroides maculatus)*
- Rough Scad *(Trachurus lathami)*

B: Shallow, 18 (24) to 38 m, sand and coarse sand subtype 775

- Gray Triggerfish *(Balistes capriscus)*
- Blue Runner *(Caranx crysos)*
- Crevalle Jack *(Caranx hippos)*
- Atlantic Spadefish *(Chaetodipterus faber)*
- Southern Stingray *(Dasyatis americana)*
- Round Scad *(Decapterus punctatus)*
- Silver Jenny *(Eucinostomus gula)*
- Spiny Butterfly Ray *(Gymnura altavela)*
- Banded Drum *(Larimus fasciatus)*
- Planehead Filefish *(Monacanthus hispidus)*

- Atlantic Thread Herring *(Opisthonema oglinum)*
- Harvestfish *(Peprilus alepidotus)*
- Spanish Sardine *(Sardinella aurita)*
- King Mackerel *(Scomberomorus cavalla)*
- Spanish Mackerel *(Scomberomorus maculatus)*
- Bigeye Scad *(Selar crumenophthalmus)*
- Lookdown *(Selene vomer)*
- Lesser Amberjack *(Seriola fasciata)*
- Banded Rudderfish *(Seriola zonata)*
- Scup *(Stenotomus chrysops)*
- Inshore Lizardfish *(Synodus foetens)*
- Atlantic Cutlassfish *(Trichiurus lepturus)*

Appendix 4: GIS methods for physical factor data sets

Abstract: This document details specific methods used to produce the GIS layers that comprise The Nature Conservancy's Ecological Marine Units.

Introduction: National Marine Fisheries Service data were used to find the locations of organisms living at the bottom of the ocean, including those which burrow into the seafloor or swim just above it. Benthic grab samples and epibenthic trawl surveys (NMFS Northeast Fisheries Science Center, http://www.nefsc.noaa.gov/) were used to determine the organisms' habitat preferences by finding the depth, substrate, seafloor temperature and Seabed-form (topographic features) at each location in the following data sources:

1. Bathymetry, compiled by TNC from three sources:
   - USGS Gulf of Maine 15' Bathymetry (http://pubs.usgs.gov/of/1998/of98-801/bathy/index.htm);
   - NOAA Coastal Relief Model (http://www.ngdc.noaa.gov/mgg/coastal/coastal.html);
   - NOAA Bathymetric & Fishing Maps (http://www.ngdc.noaa.gov/mgg/bathymetry/maps/nos_intro.html);
2. Substrate grain-size, interpolated from usSEABED point data (http://walrus.wr.usgs.gov/usseabed/);
3. Seabed-forms, derived from Bathymetry by TNC.

The NMFS biotic data were overlaid in GIS with the above datasets, and analyzed to identify organisms' habitat preferences. Each layer was classified at ecologically meaningful thresholds. The classified layers were merged into a single dataset, maintaining the attributes of the input layers. The result is a model of benthic habitats separated into discrete units according to organisms' habitat preferences.

Methods:

Bathymetry was based on the NOAA/NGDC Coastal Relief Model (CRM), a Digital Elevation Model of the seafloor generally of very high quality. It was necessary to append the CRM in two areas:

- Canadian waters north of the Hague Line into the Bay of Fundy are best covered by USGS' Gulf of Maine 15' Bathymetry (GOM15). This raster was resampled with bilinear interpolation from a cell size of ~350 meters to 82 meters so it could be joined to the CRM. This manipulation of the cell size does not imply increased resolution. A "buffer" around the CRM bathymetry where soundings had been extrapolated up to 9 km beyond the Hague Line was removed.
- The CRM contains distinct, anomalous peaks and valleys distorting its smooth surface. Although we bypassed these features throughout most of the study area with GIS methods detailed below, the complex slopes and canyons of the continental slope are poorly represented in the CRM. We replaced the bathymetry for the continental slope, below 150 meters depth northeast of Hudson Canyon, along with a section of eastern George's Bank, with NOS Bathymetric & Fishing contour maps (BFM). Figure 1 shows the CRM in shaded relief over the BFM maps. Depth survey points appear to pull the

CRM surface ‘up’(lighter to the north & west) or push the surface ‘down’ (lighter to the south & east) into an artificial surface, as opposed to the BFM contour lines portrayal of more natural-looking forms:

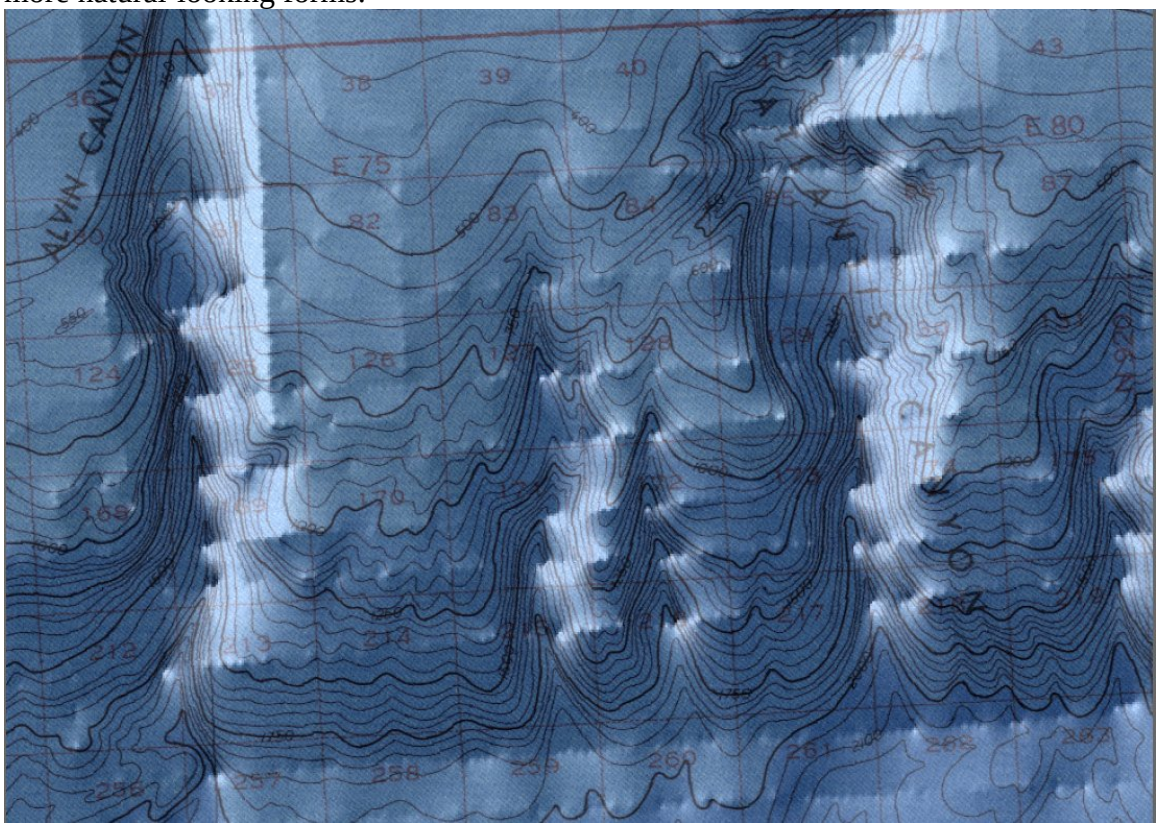


Figure 1: Comparison of CRM bathymetry (shaded relief) with BFM contour maps

Although the scanned BFM maps are available for free download, they are not ready for use in GIS because they have not been georeferenced or vectorized. There were 4 main phases to adjusting the CRM bathymetry:

1. Convert BFM to vector format;
2. Code vectors with corresponding depth values;
3. Add selected CRM vectors so new surface will match existing bathymetry;
4. Interpolate seafloor surface from these vectors and merge with CRM.

1. NOS Bathymetric & Fishing Maps in TIFF format were downloaded via an ArcIMS Map Interface at http://www.ngdc.noaa.gov/mgg/bathymetry/maps/nos_intro.html. Once unzipped, the images were opened in JASC Paint Shop Pro 7 for manipulation such as margin removal or rotation if necessary. Paint Shop Pro’s Color Balance feature was used to differentiate the contour lines from the background.[i]
The images were then converted from color to black & white by decreasing the color depth to two colors.[ii]
These binary images were georeferenced, using ArcMap 9.2’s Georeferencing extension, to a coverage generated along degrees of latitude & longitude. Then the images were converted to vectors in ArcMap’s Vectorization extension. This process involves four steps:

A. Load the edited binary image into ArcMap (if using a color image, load just one band) and symbolize the image in 2 colors (Show: Classified);
B. Start editing an empty shapefile to receive the vectors;
C. Set Vectorization Settings[iii]
D. Generate Features

2. Vectorization extracted usable lines from the images' 50 meter index contours, but the resulting vectors were far from perfect. They contained many superfluous segments, including contour labels straddling the lines and unwanted bleeding between closely-spaced lines, and fragmentation broke the lines into hundreds of thousands of segments. The vectors that best represented contours were selected manually and coded with their proper depth values. Erroneous features were simply not assigned depth values, and deleted. Although this process is easily described, it took over 100 hours to assign depth values to the vectors.

3. Converting contours to a surface can produce edge errors unless input data extend beyond the area of interest. We included six extra 50m BFM contours below our study area's boundary (2500 m). To ensure that our topographic surface would match the CRM's good quality bathymetry above 150 meters depth, we pasted the 150, 140, 130 and 120m isobaths from the CRM into the BFM vectors. In cases where the two datasets overlapped, the CRM was given preference.

4. We used ARC/INFO's Topogrid to build a seafloor surface from the BFM contours. Our 50m contour interval was sufficient to model the steep continental slope and canyons. Where these slopes transition to the flatter abyssal plain, the 50m interval begins to leave artificial terraces that could produce false flat or sloping seabed-forms. Merging the BFM and CRM data along the 150 m isobath produced satisfactory results, and aside from a narrow visible seam, there is a generally smooth transition between the two datasets. The BFM did not contain enough information to fix a distinct flat area in the CRM along the North Carolina shoreline, from 36.2 °N – 36.5 °N, out to 75.1 °W.

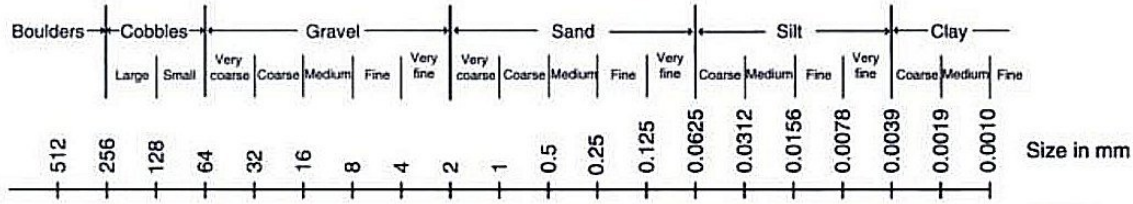
The resulting region-wide bathymetry may be the best available dataset covering this area. Although we consider this product finished, further improvements might include fixing minor seams between BFM tiles, and addressing the "dimpled" nature of the CRM.

Finally, depth was grouped into classes, which varied slightly between the three subregions of our study area to accommodate the various preferences of characteristic organism groups:

Gulf of Maine:	Southern New England:	Mid-Atlantic Bight:
Shallow (0 - -44m)	Surface (0 - -7m)	Surface (0 - -17m)
Lower photic (-44 - -53m)	Shallow (-7 - -26m)	Shallow (-17 - -31m)
Transitional (-53 - -97m)	Lower photic (-26 - -72m)	Lower photic (-31 - -85m)
Medium depth (-97 - -126m)	Transitional (-72 - -108m)	Transitional (-85 - -102m)
Deep (-126 - -368m)	Deep (-108 - -331m)	Deep (-102 - -280m)
Very deep (< -368m)	Very deep (< -331m)	Very deep (-280 - -1000m)
		Abyssal (< -1000m)

Sediment Grain-size. We tried several ways to expand sediment data from point samples to cover the entire study area. The simplest method was to create Thiessen polygons by placing polygon boundaries halfway between sample points. However, this method provided no transition between disparate grain-size found at distant sample points. We also mapped the relative percentage clay, silt, sand and gravel and combined the components in Shepard's scheme following Sarretta et al. (2007)[iv], but again found that variability in the spatial arrangement of sample points tended to suppress isolated features that differed from their neighbors.
usSEABED's averaged grain-size for each sample produced a more robust interpretation of sediment texture, showing local variation as well as large-scale patterns. The point samples were interpolated using the Kriging interpolation method in ArcGIS to create surfaces representing the area between sample points, using the following parameters: ordinary method; spherical semivariogram; variable search radius type using 12 points with no maximum distance; output cell size of 500 meters. Kriging interpolation produced the best overall interpretation of grain-size, although it was unable to provide a smooth transition in the areas mentioned above where samples separated by great distances contained a wide variety of grain-sizes.

We classified grain-size according to organisms' preferences, and assigned names to these classes based on the Wentworth (1922) scheme:



Kondolf, G. M. and H. Piégay. 2003. Tools in Fluvial Geomorphology. P. 348. John Wiley and Sons

To accommodate the various preferences of characteristic organism groups, the classes varied slightly in the three subregions of our study area:

Gulf of Maine:	Southern New England:	Mid-Atlantic Bight:
Clay and silt (0 - 0.03mm)	Clay (0 - 0.03mm)	Clay (0 - 0.08mm)
Coarse silt (0.03 - 0.05mm)	Silt (0.03 - 0.12mm)	Silt (0.08 - 0.21mm)
Very fine sand (0.05 - 0.1mm)	Sand (0.12 - 0.99mm)	Fine sand (0.21 - 0.24mm)
Fine to medium sand (0.1 - 0.39mm)	Very coarse sand (0.99 - 3.1mm)	Fine to medium sand (0.24 - 0.26mm)
Coarse sand (0.39 - 1.7mm)	Fine pebbles (3.1 - 10.7mm)	Medium sand (0.26 - 0.52mm)
Pebbles to boulders (1.7 - 85.5mm)	Coarse pebbles to boulders (10.7 - 85.5mm)	Pebbles to boulders (0.52 - 85.5mm)

There are two additional pertinent substrate datasets that could be used to improve our grain-size coverage. USGS' US East-Coast Sediment Texture database (http://woodshole.er.usgs.gov/openfile/of2005-1001/) contains additional point locations with sediment grain-size, but was not used because of differences in attributes. USGS'

Continental Margin Mapping (CONMAP) Sediments Grainsize Distribution attempted to draw boundaries between Shepard's classes, and although these data "do not accurately depict small-scale sediment distributions or sea-floor variability", they could provide validation for our interpolation methods.

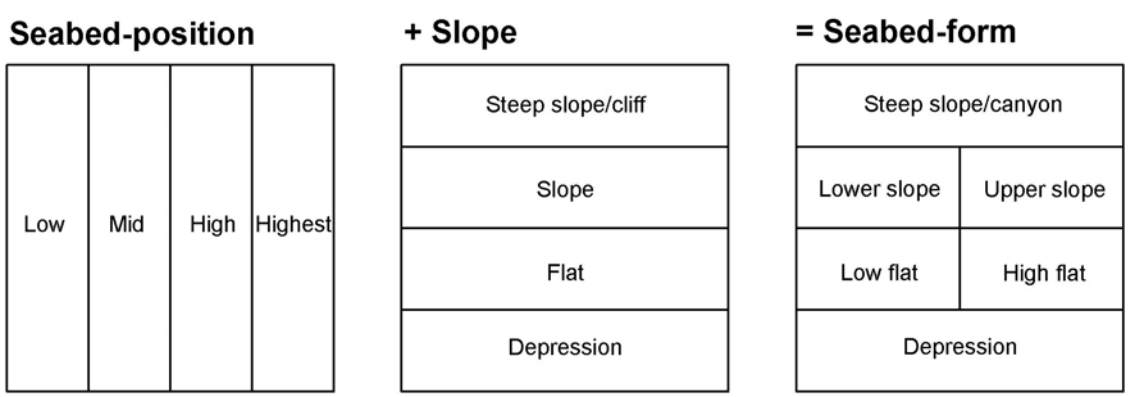
Seabed-forms classify seafloor topography into discrete units. Derived from the digital bathymetry described above, most seabed-forms can be described using just two variables: seabed position and slope. This method uses cell-based raster modeling in ESRI's Workstation Arc/INFO GRID module.

Seabed position (also referred to as topographic position or slope position) describes the topography of the area surrounding a particular cell. We based our land position calculations on Fels and Zobel (1995) although many other methods have been used (e.g. Lynn et al. 1995; Skidmore 1990; Moore, D. M. et al. 1991). Fels' method evaluates the elevation differences between the model 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). Fels and Zobel's (1995) equation is as follows:

$$\text{Land Position} = -\frac{\sum_{1,n} \frac{E_n - E_o}{d}}{n}$$

where E_o = elevation of the model point under evaluation
E_n = elevation of a surrounding model point
d = horizontal distance between the two model points
n = the total number of surrounding points employed in the evaluation

The seabed-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 200 cells after examining the effects of various radii.



Although 8° would not be considered a cliff in the terrestrial world, there are very few locations on the continental shelf with slopes in this category. Even the relatively steep continental slope has large areas with less than 8° slope, so this break point was useful for distinguishing canyons from the slow transition to the continental rise.

Slope was also used to bypass small errors that occur in the bathymetry, by identifying very small-scale variations in depth. Sloped areas with a perimeter less than 2000 meters (representing a maximum of 250,000 meters^2, or 37 grid cells) were removed from our model as by using a mask operation.

DRAFT 10/16/08

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[i] [Colors>Adjust>Color Balance]:

shadows:	-100	0-25	100
midtones:	0	0	0
highlights:	-100	100	100

[ii] [Colors>Decrease Color Depth>2 Colors] (accept defaults)

[iii] Settings:
Intersection Solution: Geometrical
Maximum Line Width: 5
Noise Level: 50
Compression Tolerance: 0.025 (accept default)
Smoothing Weight: 3 (default)
Gap Closure Tolerance: 5
Fan Angle: 20
Hole Size: 4
Do not Resolve Corners

[iv] Sarretta, et al., 2007. Development of algebra algorithms for automated generation of grain-size distribution maps: Earth Surface Processes and Landforms, 32, pp.1116-1127.

Wentworth, **C.K.**, **1922**, A scale of grade class terms for clastic sediments: Journal. of Geology, v. 30, no. 5, p. 377-392