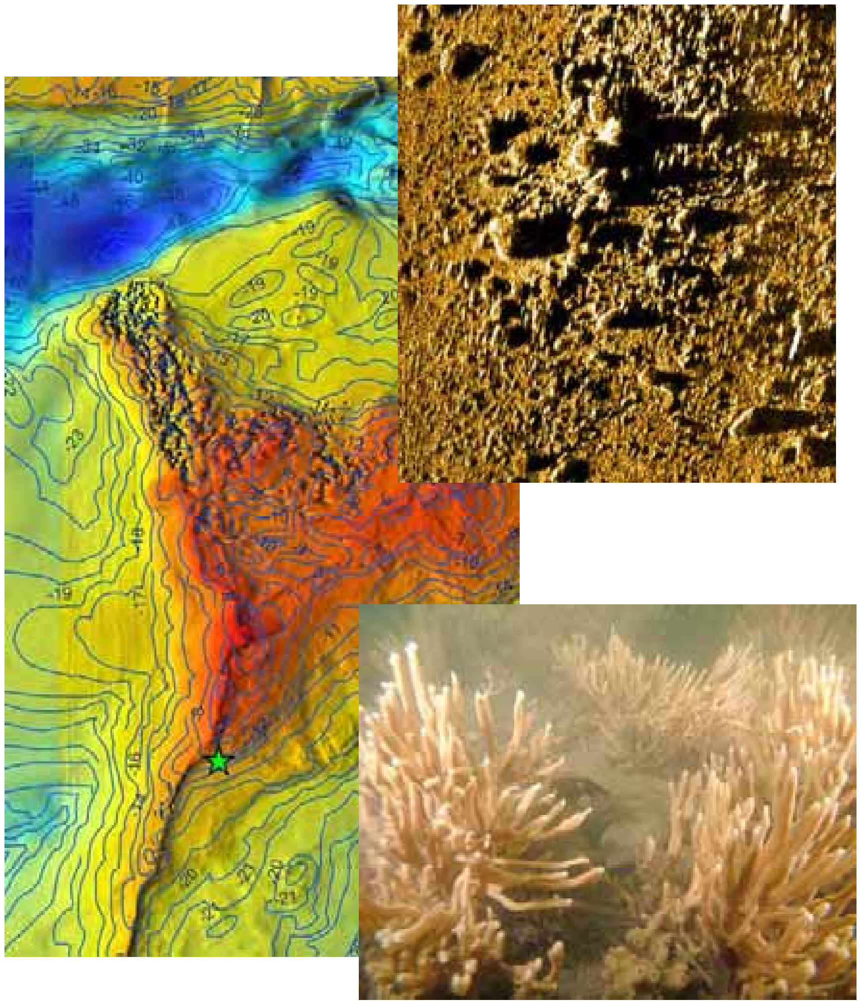
A Habitat Classification Scheme for The Long Island Sound Region



Long Island Sound Study Technical Report

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Cover Images: Left: Shaded relief multibeam sonar map with high resolution bathymetric overlay of the Stratford Shoal region (NOAA/USGS). Upper right: Sidescan sonar of boulder reef habitat along the southern crest of the shoal. Lower right: Frame grab from video of sponge dominated community associated with boulder reef habitat.

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Introduction

Habitat maps illustrate, in a geo-spatial context, attributes of the environment as they relate directly or indirectly to the distribution and abundance of a diversity of living marine resources. Such maps enable a social process that clarifies and perhaps expands the range of options available to decision-makers and the public when faced with evaluating the actual or potential environmental impacts and trade-offs of proposed and ongoing projects.

Peters and Cross (1991) define habitat as "the structural component of the environment that attracts organisms and serves as a center of biological activity". They note that there has been great difficulty in determining at what scale environmental factors effect the distribution and abundance of organisms (i.e., what factors at which scales does an organism respond to in determining its activities and range). Any structural component in the environment occurs within a "patch" (e.g., sand wave field, kelp forest, seagrass meadow), which is typically considered to be homogeneous internally and discrete from adjacent patches (Pickett and White 1985). Patches are generally defined in some convenient manner in relation to the organisms studied and the questions of interest. For example, grain size is often correlated with distribution of a species at a particular life history stage (e.g., the distribution of juvenile American lobster *Homarus americanus* is correlated with the distribution of cobble).

A problem for those attempting to produce "habitat" maps is choosing which attributes of the environment to represent in a spatial context. Such maps require an answer to the question: habitats for what? For example, the important habitat attributes for a particular species of fish (e.g., physical structure such as sponges and boulders for shelter, flow rate that is correlated with encounter rates of zooplankton prey) are different than those attributes important for another species (e.g., grain size and organic carbon content that are correlated with particular infaunal prey species, sediment cohesion that mediates the distribution of burrowing megafauna). Further, benthic communities (habitat components that are used for cover or for prey) can be dynamic over time. While blue mussels *Mytilus edulis* may be a widespread habitat (or biotope) in eastern Long Island Sound during one particular period (e.g., important habitat for economically important species such as American lobster and juvenile tautog *Tautoga onitis*), the effects of senescence and predation mortality on mussel populations can result in widespread disappearance on the time scale of years and expose underlying fine grain sedimentary habitats (Langton et al. 1995). Changes in community composition over time can also be the result of introduced species. Habitats that were once dominated by diverse species of erect fauna (e.g., porifera, hydrozoans, bryozoans) can shift to spatially extensive monospecific colonies of the introduced *Didemnum* sp. (Bullard et al. 2007). The answer to the question of what to map may be to map enduring features as a foundation and map associated attributes at time scales relevant to their dynamics in order to better assess status, distribution and change.

A habitat classification scheme defines the attributes of the environment used to characterize habitats and provides a common lexicon for identifying and mapping features at multiple scales and assessing dynamics overtime. Perhaps most importantly, use of a common habitat classification scheme serves as a foundation to communicate about resources and issues between multiple stakeholders and management groups in a common language. There are at least six existing habitat classification schemes that could be applicable in the Long Island Sound region (Cowardin et al. 1979, Dethier 1992, Greene et al. 1999, Allee et al. 2000, Connor et al. 2004, Valentine et al. 2005) from a total of at least 23 schemes developed globally (listed in Madden et al. 2004). In addition, Madden et al. (2004) has developed a draft "Coastal/Marine

Ecological Classification" system that integrates details from the range of existing schemes. However, the units for classification at fine scale levels of the hierarchy are not yet complete and units in the "biotope" level are absent. This is approximately the level (and below) at which "habitat types" in the coastal region of the northeast United States have been defined and found to be useful for managers and stakeholders (e.g., Langton et al 1995, Auster et al. 1998, Auster and Langton 1999).

Here we describe a flexible seafloor habitat classification scheme developed for implementation in the Long Island Sound (hereafter LIS) region but applicable for other coastal environments as well. The approach we took was to explicitly link the development of the habitat classification scheme to those who will implement and use the scheme to derive map products. That is, our approach was to insure that the scheme is both user-friendly and user-useful (Cowling 2005, Pierce et al. 2005).

Properties of a Habitat Classification Scheme

All habitat classification approaches exhibit some form of nestedness, whether based on a linear hierarchy of habitat classes or based on sets of orthogonal contrasts of habitat types at particular classification levels. Many approaches have been developed with a particular geographic focus (e.g., Dethier 1992 for coastal Washington; Valentine et al. 2005 for the Gulf of Maine region; Greene et al. 1999 for seafloor habitats off California; Auster et al. 2005 for North Atlantic seamounts) but discuss global applicability. The challenge for implementing any individual approach is to develop the set of "habitat classes" that are appropriate and applicable for a given region, then to integrate these classes into a particular classification scheme. This later step requires at least two critical decisions. The first is whether the scheme allows data aggregation within and between classification levels to meet the goals of users. The second is whether the classification scheme, if applied locally to LIS, needs to be integrated to a regional or national classification and mapping effort. These decisions will dictate which classification scheme is used and the structure of the resulting scheme for local application.

An ideal habitat classification scheme for LIS should have the following characteristics (modified from Madden et al. 2004):

1. **Set geographical boundaries.** The classification should have geographical boundaries that are based on oceanographic and community characteristics. LIS has a diverse range of habitats that extend across gradients of depth, salinity, grain size, and productivity and communities of organisms respond to changes across these gradients. Major boundaries could be identified (e.g., intertidal, subtidal, shallow, offshore, western, central, eastern basins) within which finer scale habitat types are nested.

2. **Link to terrestrial and freshwater (aquatic) classification schemes.** The classification scheme needs to have clear linkages to existing terrestrial and aquatic habitat classifications in Connecticut and New York (e.g., Regional Planning Authority, Southern New England GAP, NatureServe, The Nature Conservancy, CT and NY State Agencies, and other schemes). These linkages minimally require common geographic boundaries and, in the case of overlap, clearly articulated commonalities and differences in classification approaches.

3. **Exhibit a nested hierarchy.** The classification scheme should allow for geospatial data at lower (finer) levels in the scheme to be easily aggregated into higher (coarser) levels.

4. **Link habitats to organisms and communities.** Habitats should serve as proxies for patterns in the distribution of organisms and communities. While it is not necessary for all species or community types to respond to habitat boundaries at all levels of the classification scheme, there should be some demonstrable change in organismal distribution across boundaries at all spatial scales (i.e., empirical or inferential based on literature).

5. **Link physical processes to habitat distributions.** The classification scheme should link historic and extant physical processes (oceanographic, meteorological, geologic) to distribution of habitats (e.g., glacial processes to distribution of hard rock substrates, tidal flow patterns to sand wave habitats).

6. **Unique and repeatable classification units at all levels.** The units at each level of the classification scheme should be unique and unambiguous to insure clear derivations of habitat type. Uniqueness at each level will insure repeatability based on sampling over time.

7. **A clearly defined nomenclature.** The nomenclature used in the classification scheme should be exacting and clearly constrain the meaning of terms. An initial glossary of terms should be agreed upon and implemented by users.

8. **Accommodate diverse sources of data.** Geospatial habitat data can take many forms such as grain size and infaunal community data from grab samples; reflectance as a function of sediment type and texture from sidescan or multibeam sonar; and surficial sediment type, texture, and epifaunal community data from seafloor imaging. A classification scheme should be robust and allow classification at many levels based on a diversity of data sources.

9. **Accommodate modification.** The classification scheme should be adaptive to accommodate changes in structure, habitat units, and nomenclature. The evolving nature of habitat mapping, ecology, governance, and the needs of stakeholders will dictate when such change is required. Some forum will be needed to discuss, evaluate and institutionalize such changes.

10. **Link to regional and national classification and mapping efforts.** While not required, it would be of useful to link habitat classification and mapping efforts in LIS to regional and national approaches. LIS is not isolated from the wider Virginian biogeographic province and evaluating environmental problems at local scales (e.g., invasive species, fisheries, impacts of development) might benefit from the ability to link local to regional scale data.

Habitat Attributes Identified by Users

We conducted a web-based user survey of local, state, and federal managers, environmental policy-makers, researchers, environmental engineers, fishers, coastal developers, and those involved in energy infrastructure to ascertain the range of habitat attributes and resolution that they consider relevant to their work in LIS. The survey was conducted in January 2007 and resulted in 108 responses (28.6% of 377 invited participants) to some or all of 17 questions (a detailed summary of the summary is provided in Appendix 1). This survey allowed us to identify habitat attributes and associated levels of resolution that are required across user groups (Table 1). Interestingly, there was no clear delineation of disparate types of information sought by particular user groups, reinforcing the diverse nature of the habitat classification requirements for useful map products. In aggregate, everyone wanted everything.

Table 1. Summary of habitat attributes across multiple scales identified in the user survey.

Major Attribute	Scale or Approach	Example of Descriptor or Modifier
Geoform features		
	Large-scale features	sand dune, bedrock outcrop, steep slope, deltaic fans
	Small-scale features	sand waves, depressions, ripples, [slope]
	Man-made features	dock, cable
Sedimentary Features		
	Linear classification	Wentworth scale, i.e. mud, sandy mud, muddy-sand, fine sand, coarse sand, gravel
	Orthogonal classification	Schlee (1973) or USDA system, e.g. percent of mud, sand, gravel
	Transition areas	Between sediment types or geomorphic features
Biologic Features		
	Organic carbon content	Measure of eutrophication and benthic-pelagic coupling
	Habitat forming species	eelgrass *Zostera marina*, blue mussels *Mytilus edulis*
	Dominant species	based on biomass or density
	Dominant species groups	Seagrass, sponges, bivalves, polychaetes
	Community types	based on species composition
	Key species	selected based on societal value; both managed and non-managed
	Key managed species	American oyster, blue mussel, eelgrass
Boundaries		
	Intertidal – subtidal	Threshold depth for subtidal chosen as either mean low water, mean lower low water, etc.
	Shallow – deep	Threshold depth based on legal or practical map product requirements
Integrative Attributes		
	Disturbance regime	Mean annual tidal current velocity at seafloor, maximum annual tidal current velocity, delineation of mobile and immobile sediments, % time current exceeds critical value, extent of specific episodic events conditions

Survey results identified sets of habitat attributes that are important to map product users and should be utilized in any nested classification scheme for LIS. For a simple example of a nested classification, coarse-scale features can be identified as major physical elements (e.g., shoal, ledge, channel), with the range of sediment types that the feature is composed of nested within each element (e.g., mud, sandy mud, muddy sand, sand, gravelly sand, sandy gravel, gravel). Variation in associated biological attributes linked to each sediment type (e.g., seagrass, American oyster, blue mussel dominated communities) can be used as a fine scale classification element or a modifier of grain size. Some users required only coarse resolution of sediment types (coarse resolution within a classification level) while others required finer scale resolution and details of associated biological communities (relational data across classification levels).

The utility of map products produced at 1:20,000 scale was the most common response. More detailed products at both 1:5,000 and 1:10,000 were also identified to be of utility, especially for use in aiding local management decisions such as evaluating permit requests for structures. The importance of defining boundaries between intertidal and subtidal regions was identified as a major issue related to regulatory and permitting needs.

Identification of Applicable Habitat Classification Schemes

Three habitat classification schemes were selected for detailed evaluation based on an initial qualitative assessment of the compatibility of six schemes for integrating habitat attributes identified in the user survey (Table 2). The classification schemes of Greene et al. (1999), Valentine et al. (2005), and the European Nature Information System (EUNIS; marine elements based on Connor et al. 2004) all were designed in a way to accommodate user defined attributes. While each of these schemes was designed to classify coastal and marine habitats, they differed in organization, level of detail, and intended application. However, these schemes allow use of data derived from a broad range of sample technologies including acoustic and video imaging. The objective of this component of the project was to determine the potential for use of an existing classification scheme for application in LIS. Here we briefly describe the characteristics of each scheme.

Table 2. Characteristics and initial evaluation of classification schemes.

	Habitat Classification Schemes					
	Cowardin et al. 1979	**Dethier 1992**	**Greene et al. 1999**	**Allee et al. 2000**	**Connor et al. 2004**	**Valentine et al. 2005**
Type	Hierarchical	Hierarchical	Hierarchical	Hierarchical	Hierarchical	Hierarchical within themes
Number Levels	5	6	5	13	6	4
Goal	Impose boundaries on natural ecosystems for the inventory, evaluation, and management of wetland and deepwater habitats	Identify and describe marine and estuarine communities covering the full array of near-shore benthic habitat types	Understand and predict spatial distributions of rockfish (Sebastes) assemblages in deep water	Identify essential fish habitat and define marine protected areas	Classify benthic communities of invertebrates and seaweeds for scientific application, and management and conservation of marine habitats	Characterize the sublittoral via topographic, geologic, biologic, and oceanographic attributes; and natural and anthropogenic processes

Intent	Arrange ecological taxa, define concepts and terms consistently, identify map units	Framework for existing data and future inventory, selection and ranking of marine preserves, provide ecologically-based mapping units for intertidal and shallow subtidal	A standard classification scheme that accurately and efficiently interprets and compares habitats and associated assemblages across geographic regions	Framework for interpretation of ecological function, and a consistent terminology, including a glossary of terms	Consistent description of habitat types, assessment of geographical distribution and extent of habitats	Serve as a template for a database that will provide a basis for organizing and comparing habitat information and for recognizing regional habitat types
Target Audience	Coastal resource management community	Land-use planners, resource managers, regulators, and agency personnel	Fisheries scientists and managers	Local, regional, and national coastal resource managers	Environmental managers, marine scientists, and field surveyors working at local, national, international levels	Scientists and managers of fisheries and the environment
Focus	Wetland and deepwater habitats of the US; emphasizes wetland habitats,	Marine and estuarine communities of Washington State/Pacific Northwest	Marine benthic deepwater habitats along the west coast of North America	Coastal marine systems of the U.S. coast	Shores and seabeds around Britain and Ireland	Marine sublittoral zone of the Northeastern North America Region
Data	Hydro-dynamic, substratum, soil quality, biological, and modifier data	Geophysical and geologic data, energy data, and biological data	Geophysical data collected via remote systems and in situ biological and geologic observations	Seafloor or water column, depth, wave/wind energy, hydro-geomorphic, hydrodynamic, light, topography, substratum, and modifiers; should accommodate any available data	Substratum, wave exposure, depth surveyed, sample type, location, and species present	Multibeam and sidescan sonar surveys, photographic and video transects, and sediment and biological sampling

Evaluation	Focus on nearshore areas and no hierarchy to accommodate fine scale details of habitats in deeper water.	Alternative to Cowardin et al. system but classi-fication of energy elements requires time series observations and no explicit hierarchy for structural elements.	Developed to address variation found in marine deepwater habitats.	This scheme is the framework supporting Madden et al. 2004. Scheme was draft and not in final form.	Developed to address variation found in marine deepwater habitats.	Developed to address variation found in marine deepwater habitats.
Status	Reject	Reject	Evaluate	Reject	Evaluate	Evaluate

Greene et al. 1999 A Classification Scheme for Deep Seafloor Habitats

This classification scheme was initially developed to characterize habitats at 30-300 m depth for demersal fishes along the Pacific coast of North America. Habitats were classified in a hierarchy of decreasing spatial scales from kms (i.e., megahabitat) to cm or smaller (i.e., microhabitat). Figure 1 illustrates the relationship between elements of the scheme across multiple spatial scales and includes how habitat attributes identified in the user survey fit within this scheme. Megahabitats are large features that have dimensions greater than one kilometer. Long Island Sound could be characterized as a single megahabitat or multiple megahabitats if divided by depth boundaries or basins. Mesohabitats are 10s of meters to a kilometer in dimension and can include shoals, sills, reefs, moraines, and sediment fields. Macrohabitats range in size from 1 – 10 m and microhabitats include features or materials up to 1 m (e.g., boulders, shell deposits, biogenic strctures). This classification scheme is highly linear and has been applied in mapping and management arenas for U.S. west coast fisheries and marine protected area management (i.e. Alaska, Harney et al. 2006; Washington, Intelmann and Cochrane 2006; California, Cochrane and Lafferty 2002).

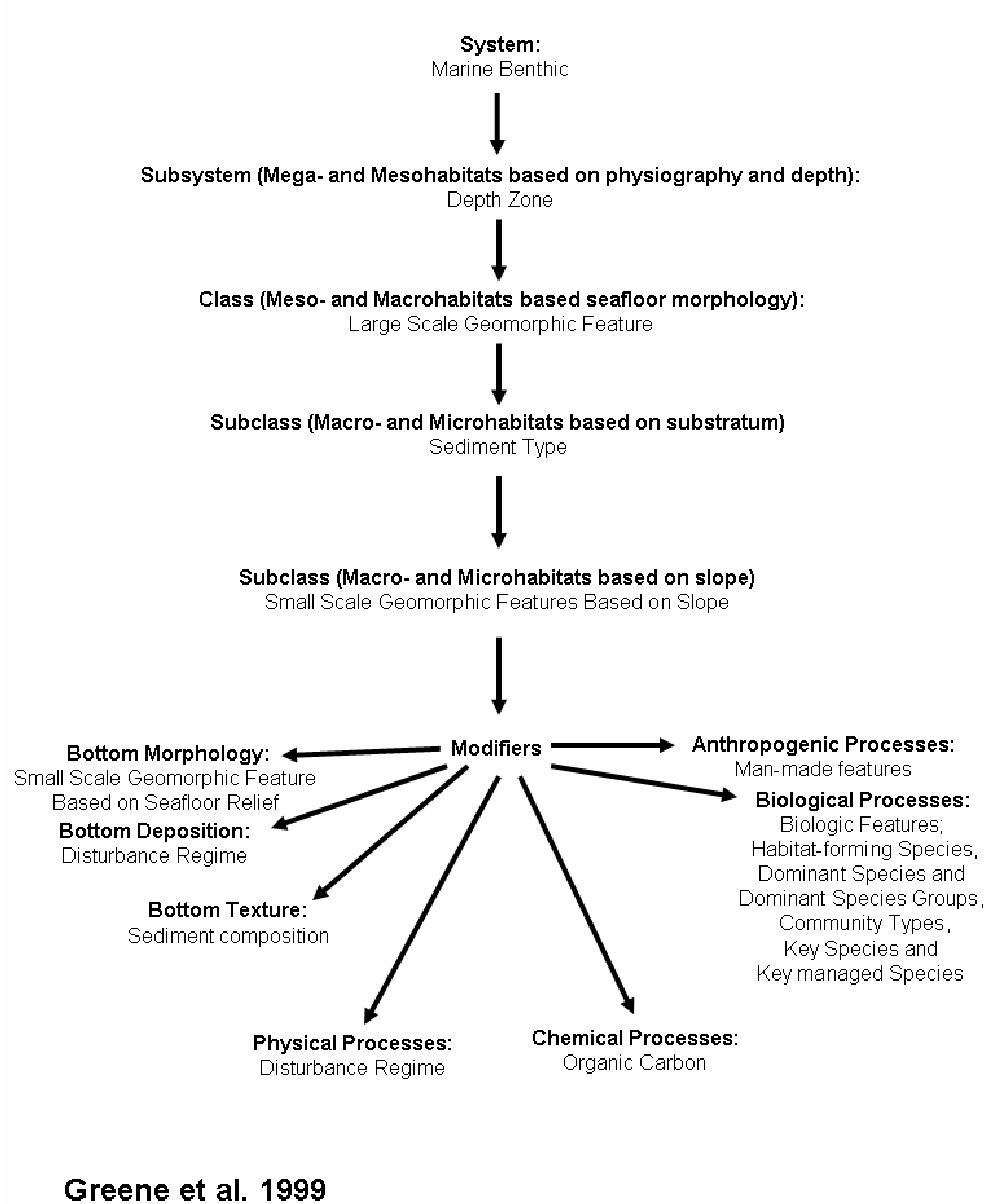


Figure 1. Schematic representation of the Greene et al. hierarchy depicting the classification levels and habitat attributes (identified by the user survey) associated with each level. Size scales include: Megahabitats > 1 km, mesohabitats = 10m – 1km, macrohabitats = 1 – 10m, and microhabitats <1m.

Valentine et al. 2005 Classification of Marine Sublittoral Habitats, with Application to the Northeastern North America Region

This classification scheme was initially developed to characterize marine sublittoral habitats off northeastern North America, but modification for habitat classification needs in other regions was an explicit goal (Valentine et al. 2005). As in Greene et al. (1999), habitats were classified in hierarchies (i.e. classes, subclasses, categories, and attributes) nested with eight major themes (Figure 2). However, the overarching themes are independent. Themes 1- 5 represent broad scale habitat types that range in size from 10s of km to10s of m (i.e., topographical setting, seabed dynamics and currents, seabed texture, grain size, and seabed roughness). Themes 6 - 8 represent fine scale habitat types that are less than 10 m in dimension (i.e., attributes related to associated fauna and flora, patterns of habitat association and usage, as well as rates or patterns of habitat recovery from disturbance such as fish burrows and attached epifauna). This scheme is currently being evaluated for implementation (as well as Greene et al. 1999 and others) by Massachusetts Office of Coastal Zone Management and is being tested in a collaborative project between the U.S. Geological Survey and the Geological Survey of Canada.

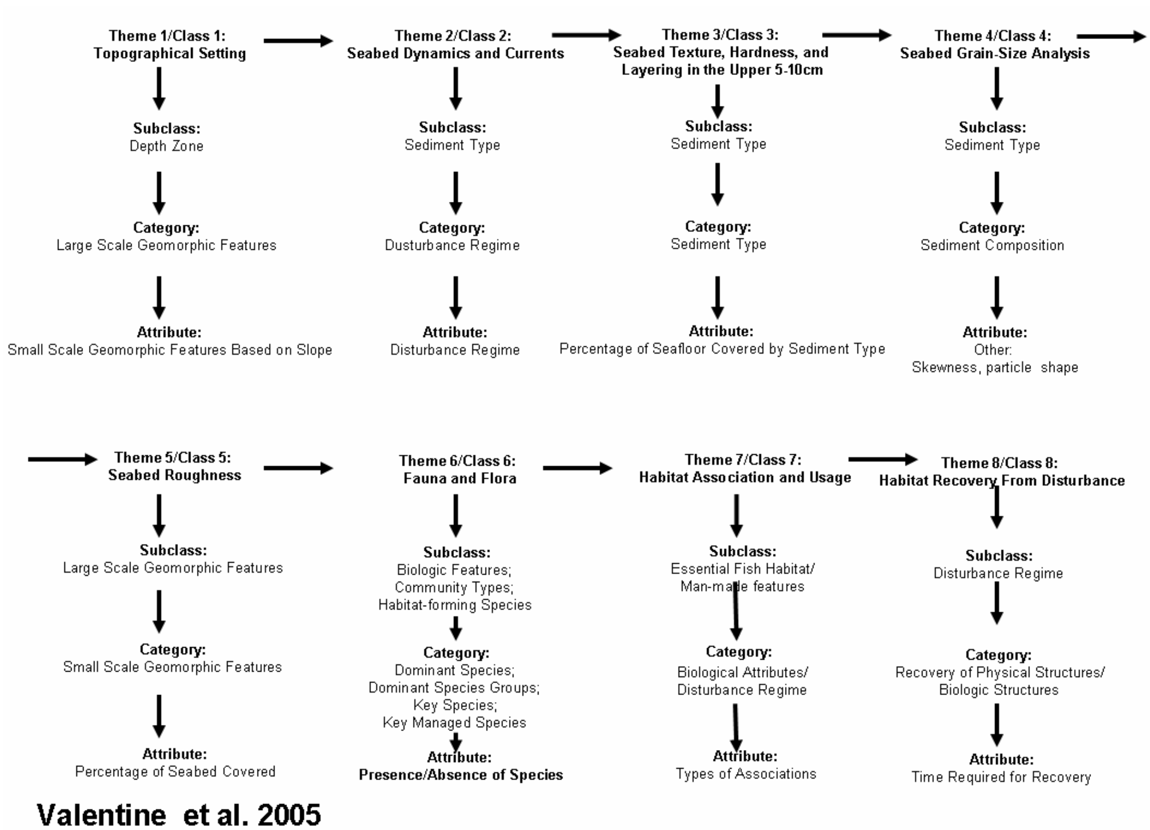


Figure 2. Schematic representation of the Valentine et al. classification scheme. Themes 1-5 represent broad scale habitat types (10m - ≤100 km). Themes 6-8 represent fine scale habitats (≤10 m). Habitat attributes identified by the user survey were linked to the corresponding hierarchies under each theme.

EUNIS (European Nature Information System)

EUNIS is a classification scheme implemented in the form of a web application http://www.jncc.gov.uk/marine/biotopes/BiotopeSearch.aspx that was developed to aid in the management and conservation of habitats across Europe. The marine and coastal components are only part of a larger classification scheme that has eight main levels including terrestrial habitats. The classification scheme contains a hierarchy consisting of environment, broad habitat type, habitat complex, biotope complex, biotope and sub-biotope (Figure 3). The environment was classified as marine by definition. Broad-scale habitat categories are based largely on their physical character at multiple scales (i.e., gravel or fine-grain sediment habitats, and intertidal, subtidal, or deep ocean). These broad habitat divisions were then divided as main habitats/habitat complexes based on sediment type (e.g. gravel, mud) and different degrees of wave exposure. The main habitats were subdivided further as fine scale biotope complexes (i.e., one or more biotopes based on biotic and abiotic factors). Biotope complexes were divided again into individual biotopes based on dominant species and dominant species groups, with biotopes comprised of subbiotopes (i.e. other species in the community). This scheme is widely applied for conservation and monitoring of habitats and rare species through the European Environment Agency and the Joint Nature Conservation Committee.

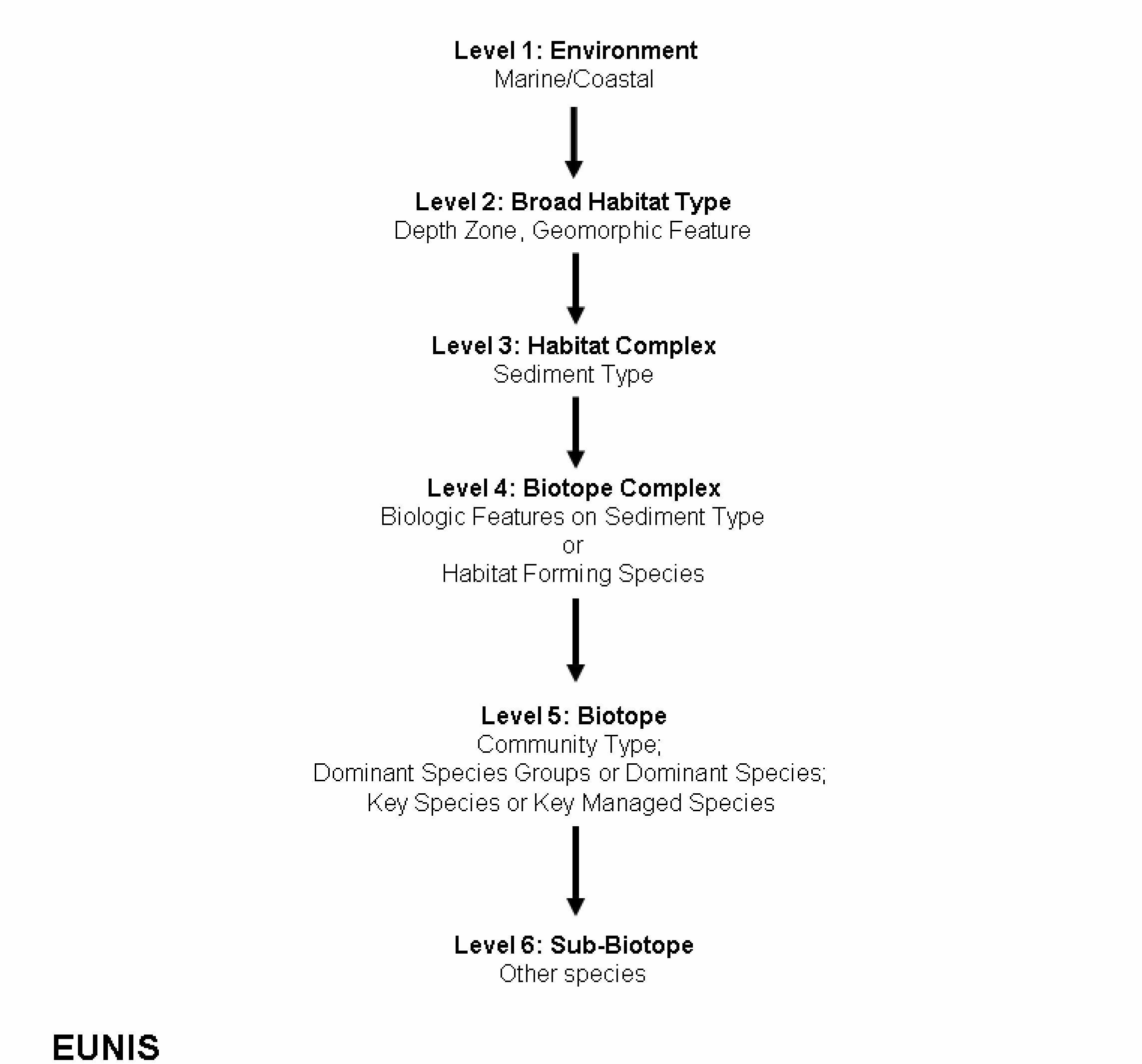


Figure 3. Schematic representation of the European Nature Information System (EUNIS) depicting classification levels of the hierarchy (large scale = broad and main habitats, and fine scale = biotope complex – subbiotopes) and associated habitat attributes as identified by the user survey.

The fundamental approach to classifying seafloor habitat in all three schemes was to use seafloor topography and substrate type as primary habitat attributes. The diversity of habitats classified in the test sites was dependent upon the physical and biological heterogeneity of the seafloor, as well as the organization and definition of the levels within each scheme. The same sites were classified differently across schemes based on the definitions of habitat descriptors. For example, Greene et al. (1999) defines a site as a shallow subtidal habitat based on depth while Valentine et al. (2005) defines the same site as a deep aphotic habitat based on the absence of macrophytic algae. In addition to differences among definitions of habitat descriptors, each scheme incorporated the capacity to characterize habitat attributes that others do not. For example, Greene et al. (1999) contains modifiers to describe chemical processes, while Valentine et al. (2005) and EUNIS do not characterize any attributes related to chemical processes, whether naturally occurring or from anthropogenic impacts. Likewise, Greene et al. (1999) and Valentine et al. (2005) incorporate anthropogenic processes and impacts, while EUNIS ignores such effects on seafloor habitats.

Comparisons of each of the approaches for classifying the biological characteristics of habitat such as community composition, benthic species diversity, taxon specific distributions, and physical characteristics such as sedimentary environment, sediment types, and grain size distribution were conducted using available data sets although most biological data sets were spatially limited within test sites (a detailed description of the evaluation approach and fullresults are presented in Appendix II). As a result, such tests could not be conducted for all operant levels of each scheme at every site. Despite this caveat, results indicated of the utility of each approach.

The Greene et al. (1999) scheme was the most effective in providing a clear hierarchy for organizing and visualizing both large- and fine-scale habitat classes, but lacked sufficient detail in bottom texture attributes at the finer scale. If adopted, this scheme would need to be modified to encompass the detail required to differentiate habitats at relevant levels. The Valentine et al. (2005) scheme is the most complex, with a relatively large number and variety of independent themes. Multiple themes utilize the same data sets at different levels hence providing more than one way to classify habitats based on available data. However, this complexity requires different survey approaches to produce map products based on each theme. In contrast to Green et al. (1999) that classifies biological attributes in a top down manner (i.e., entering the hierarchy at the system level), Valentine et al. (2005) employs what can be considered as a bottom-up approach whereby the biological data are first described in a distinct theme and results are placed in a broader context of major seabed features. The EUNIS scheme places a great deal of emphasis on sediment type and little on large-scale features. This approach is complex and is not inclusive of all habitats that are found in LIS and at particular levels, does not include any habitats that are in LIS. Such caveats result in multiple levels within the hierarchy being classified in the same exact way, i.e. Level 2 (broad habitat type) and Level 3 (habitat complex) are both classified as sublittoral sediment (Figure 12). While the scheme does provide some level of detail for biological communities, it reflects those from the Northeastern Atlantic to the Mediterranean and not the Northwest Atlantic. If adopted this scheme would need to be altered to represent the LIS region. As it is designed, it is not easily adaptable for application outside of the current region of use and does not include attributes that have been identified as relevant by users.

Proposed Habitat Classification Scheme for the Long Island Sound Region

The range of issues identified during the evaluation of the three existing classification schemes suggested a tailored hierarchy for use in LIS would best serve the needs of users. Here we propose a scheme that is based on the linear and nested hierarchy of classes detailed in Greene et al. (1999), is inclusive of attributes identified in the user survey, and eliminates redundancy of use of data at multiple scales (Figure 4). Of most significance is this scheme uses enduring features as a foundation (higher level attributes) for all modifiers that are dynamic at ecologically relevant time scales.

The system level (i.e., highest level of the hierarchy) is defined by seascapes. If the results of the ecological analyses contained in this report are implemented, there is a single LIS seascape. However, decisions based on the objectives of management requirements could produce multiple seascape units and such delineations are made at this level of the classification. Major basins of LIS may be a functional seascape unit given that such designations are used both in predictive modeling exercises and operational management arenas (Figures 5). Transition zones between basins, rather than simple linear boundaries across topographic highs, may be useful for separating these major features although explicit decision rules for delineating such zones will need to be applied (Appendix 3).

The sub-system level is defined by the division of inter-tidal and sub-tidal. The sub-tidal can be further divided by shallow and deep zones (Figures 6a-b), attributes identified in the user survey but with highly variable boundary criteria (Appendix 1). In order to maintain a level of consistency, the definitions for intertidal and subtidal, as well as shallow and deep were taken from EPA Long Island Sound Study web site (http://www.longislandsoundstudy.net). Habitat classes are based on broad-scale geomorphic features such as banks, sills and basins while sub-classes are defined by sediment type. A secondary sub-class can be utilized to define small-scale seafloor morphology (e.g., mounds, depressions, ripples, reefs). Separation of seafloor features at two scales as well as grain size characterization within the hierarchy is in part based on the range of user survey responses and the approaches required for collecting such data. Broad-scale geomorphic features can be delineated using acoustic methods such as single or multibeam sonar while grain size classification will require collection of physical samples. Small-scale morphological features of the seafloor can be characterized using side-scan sonar as well underwater imaging (still or video). Separating the types of classification schemes by logical divisions based on the technological approaches used to collect requisite data can insure that specific levels of classification within the hierarchy can be completed using particular approaches in the field.

Modifiers are linked to the hierarchy at the lowest level and are parallel (i.e., not nested). Since each category or type of modifier requires a unique sample acquisition or analytical approach, the position in the hierarchy essentially makes each type of attribute independent of the others, although multiple attributes can be correlated in a geographic framework among modifiers. The outcome of such placement of modifiers within the hierarchy allows survey data to be used to complete map coverages independent of other modifiers. Further, data from localized surveys can be joined to other coverages of the same attribute assuming use of the same measurement approaches and dimensions (or an approach to normalize disparate data types).
It is important to note that the underlying geologic framework provides the foundation for a range of modifiers that describe biologic and chemical attributes of seafloor habitats as well as the physical and anthropogenic processes that mediate seafloor features (using a diversity of suggested proxies).

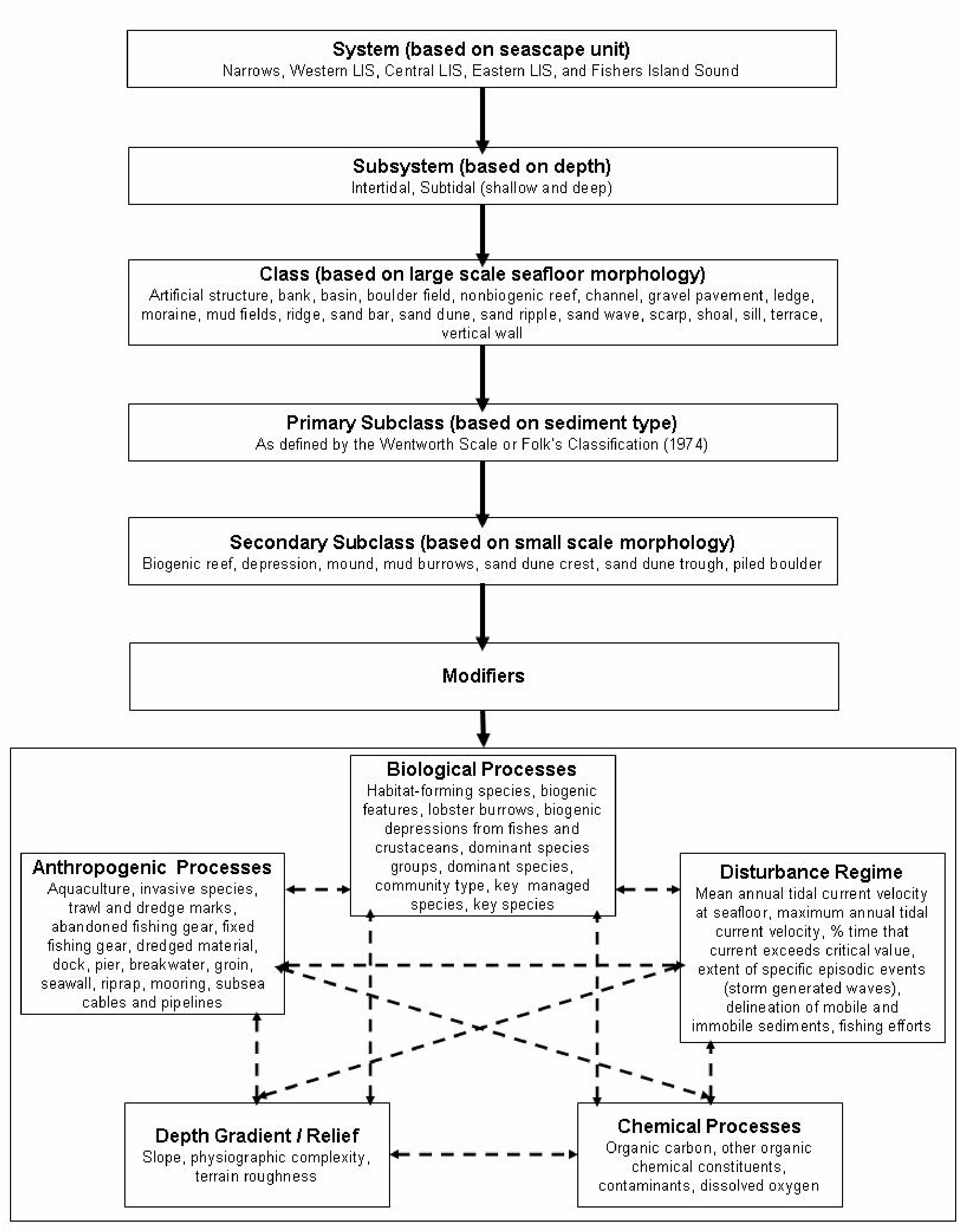


Figure 4. Proposed habitat classification scheme for the LIS region. Note that all types of modifiers can be linked, in order to facilitate visualization and analysis of relationships.

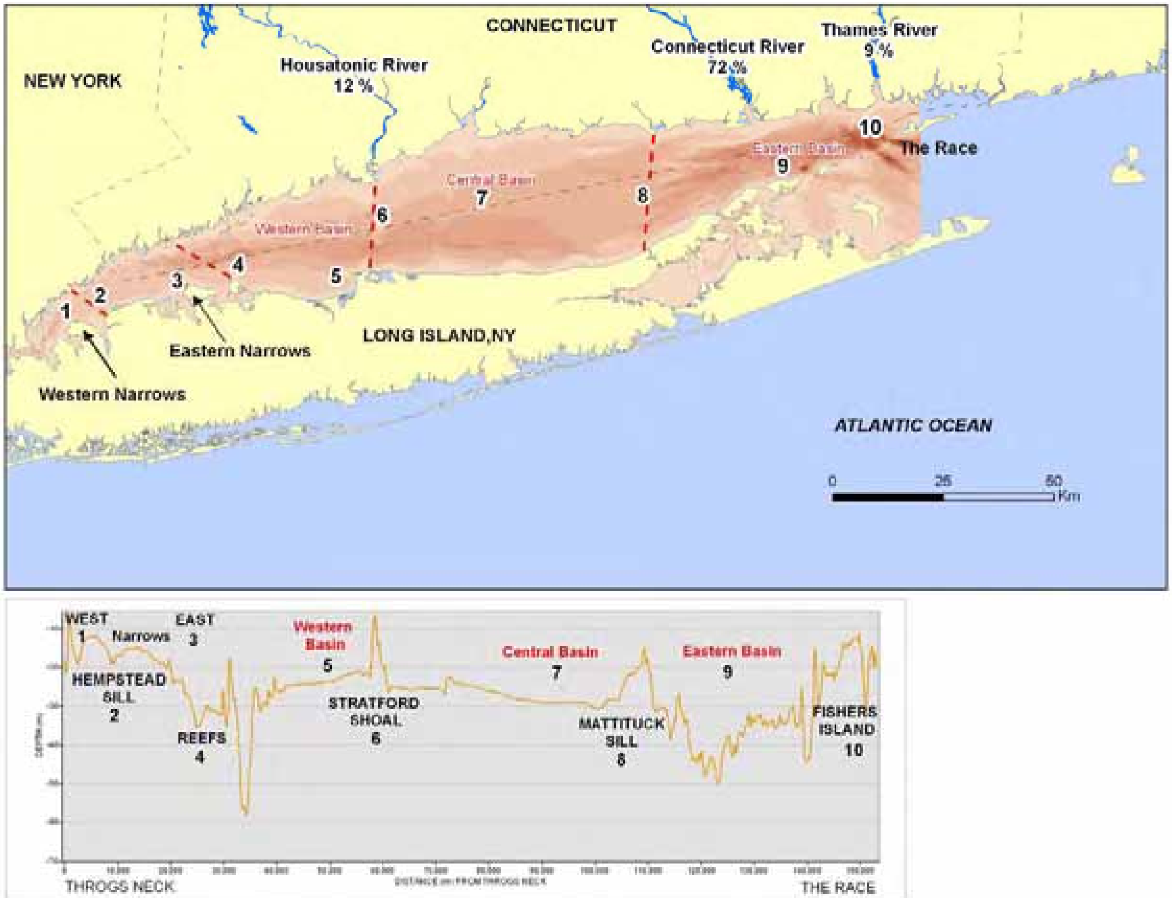
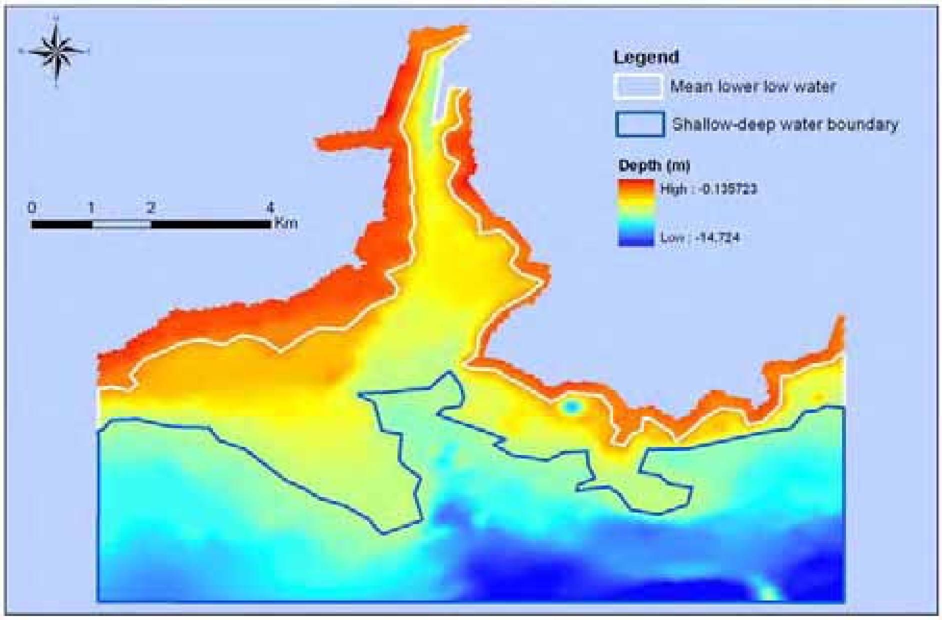
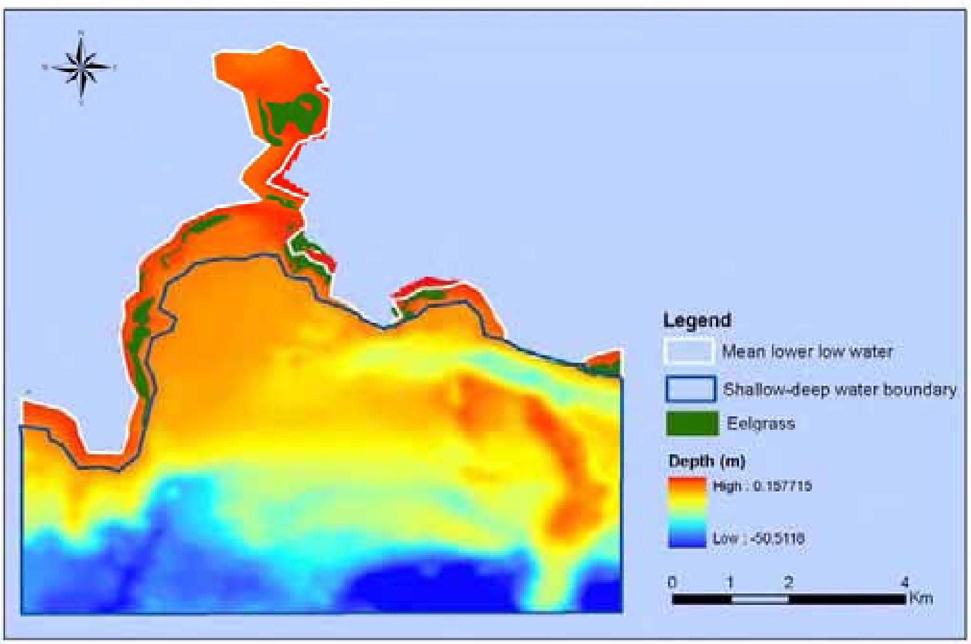


Figure 5. Major features dividing basins and geomorphic regions of Long Island Sound.



A) New Haven



B) Niantic

Figure 6. Examples of delineations of intertidal as well as shallow and deep subtidal regions using a coastal bathymetric coverage rectified to mean high tide.

Draft Nomenclature of Feature Terms

The nomenclature used to classify or describe habitat units at each level of the scheme should be unique and unambiguous to insure proper classification and delineation of boundaries for each habitat type. A draft lexicon of terms is provided in Table 3. Note this list is only an example of the types of descriptors and definitions useful to characterize habitats based on the selected attributes. The metric and resolution required to describe each modifier must also be determined.

Table 3. Draft definitions of modifiers across levels of the classification hierarchy.

Modifer	Definition
Subsystem	
Intertidal	area that falls between extreme high and low tides
Subtidal	area that falls below the extreme low tide
Shallow	water lying less than or equal to 4m below the mean low water mark
Deep	water lying greater than 4m below the mean low water mark
Large Scale Seafloor Morphology	
Artificial Structure	man-made reefs, docks and pilings, dredge material disposal mounds
Bank	a broad elevation of the sea floor around which the water is relatively shallow
Basin	a large, bowl-shaped depression in the surface of the sea floor
Boulder Field	boulder-strewn area not located on a topographic high
Non-biogenic Reef	exposed rock outcrops or boulders on a topographic high, i.e. boulder reefs
Channel	a trench, furrow, or groove in the sea floor; the deeper part of a river or harbor
Gravel Pavement	forms as a residual deposit where strong tidal and storm currents winnow sand from coarse glacial sediment
Ledge	a reef, ridge, or line of rocks in the sea or other body of water
Moraine	a ridge, mound, or irregular mass of unstratified glacial drift, chiefly boulders, gravel, sand, and clay
Mud Fields	expanse area of relatively flat mud
Ridge	a long, narrow elevation on the sea floor
Sand Bar	a bar of sand formed in a sea by the action of tides or currents
Sand Dunes	hills of sand formed under the action of current flow
Sand Ripples	relatively small, low, and rounded features formed by the most recent and effective currents
Sand Waves	a large, ridgelike primary structure resembling a water wave on the upper surface of a sedimentary bed that is formed by high-velocity water currents
Scarp	a long steep slope or cliff at the edge of a plateau or ridge; usually formed by erosion or the faulting of the earth's crust

Shoal	a sandy elevation of the bottom of a body of water
Sill	a flat (usually horizontal) mass of igneous rock between two layers of older sedimentary rock
Terrace	a nearly level strip of land with a more or less abrupt descent along the margin of the sea, a lake, or a river
Vertical Wall	a continuous upright (60-90º) rock structure
Subclass (Sediment Type)	
Organic Debris	consisting of plant or animal material
Mud	size classifications will be based on the method proposed by Wentworth (1929), the inclusive graphic statistical method of Folk (1974), and the nomenclature proposed by Shepard (1954)
Sand	as above
Pebble	as above
Cobble	as above
Boulder	as above
Gravel	as above
Mixed Sediments	as above
Bedrock	native unconsolidated rock underlying the surface of the seafloor
Subclass (Small Scale Morphology)	
Biogenic Reef	reefs constructed by animals (e.g. bivalves)
Depression	an area that is sunk below the surrounding seafloor
Mound	a heap or elevation of seafloor sediments
Mud Burrows	a hole or tunnel in the mud as excavated by animals
Sand Dune Crest	the top or highest point of a sand dune
Sand Dune Trough	a long narrow depression between sand dunes
Piled Boulder	large boulder-sized rocks lying on top of one another that form deep crevices
Chemical Processes	
Organic Carbon	carbon bound in organic compounds used as an indicator of water quality
Other Organic Chemical Constituents	organic phosphorous and nitrogen
Contaminants	element or compound of an extraneous nature, e.g. heavy metal contamination from mercury
Dissolved Oxygen	oxygen freely available in water

Biological Processes	
Habitat Forming Species	increase spatial complexity and alter local environmental conditions, facilitating an assemblage of fauna and flora
Lobster burrow	hole or tunnel in mud as excavated and /or occupied by a lobster
Biogenic depression from fishes and crustaceans	bowl-shaped area of the seafloor that has sunk due to excavation or movement by fishes (i.e. flounder) or crustaceans (i.e. crabs)
Dominant Species Groups	groups of species (e.g. worms) that exceed the abundance of other species groups
Dominant Species	species that when cumulatively totaled exceed the dominance measure or majority
Community Type	an ecological unit composed of a group of organisms or a population of different species occupying a particular area, usually interacting with each other and their environment.
Key Managed Species	As below, but managed to conserve its significance, i.e., American oyster, blue mussel, eelgrass, channeled whelk, American lobster, and winter flounder
Key Species	a species that has ecological, economic, conservation, and social significance
Anthropogenic Processes	
Aquaculture	the cultivation of aquatic animals and plants in natural or controlled marine, estuarine, and freshwater environments
Invasive Species	nonindigenous species that cause ecologically, environmentally, or economically adverse effects to the area into which they are introduced
Trawl/dredge marks	furrows on the seafloor resulting from the trawl or dredge being dragged across the bottom
Abandoned Fishing Gear	Crab or lobster pots, fish traps and nets, fishing line, etc. that has been lost or discarded into the sea
Fixed Fishing Gear	active crab or lobster pots, gill nets, and long lines set on the bottom with floats to the surface
Dredged Material	bottom sediments excavated and deposited from other areas
Dock	the area of water between two piers or along side a pier that receives a ship
Pier	a platform extending from a shore over water and supported by piles or floats, used to secure, protect, and provide access to ships or boats
Breakwater	a barrier made of stone or concrete that protects the shore from the full impact of waves; aids in prevention of erosion
Groin	a small jetty extending from a shore to protect a beach against erosion or to trap shifting sands
Seawall	an embankment to prevent erosion of the shoreline
Riprap	a loose assemblage of broken stones erected in water as a foundation

Mooring	a holdfast (for a vessel) by means of cables, anchors, or lines
Sub-sea cables and pipelines	outfall pipes for effluent, liquified natural gas terminals, lines of communication
Disturbance Regime	
Mean Annual Tidal Current Velocity at Seafloor	Speed and direction of the horizontal movement of water due to tides at the seafloor, averaged over a 365 day period
Maximum Annual Tidal Current Velocity	Highest value of speed and direction of tidal currents identified from a 365 day period
Percent time that current exceeds critical value	The percent of time, in a given area of the seafloor, that the current velocity is greater than the threshold value required to move a particle of sediment. Note: The current velocity required to move a particle of sediment varies with grain size.
Extent of specific episodic events (storm generated waves)	The speed and depth of occurrence of wave orbitals due to wind events.
Delineation of mobile and immobile sediments	Sediments advected by natural currents versus consolidated sediments that remain stable in natural currents
Fishing effort (mobile and fixed gear)	measure of the amount of fishing; an index is usually used such as the number of hooks on a long line, the number of permit holders, the area that has been trawled or dredged
Depth/Gradient Relief	
Slope	inclination of the seafloor; the property possessed by seafloor surface that departs from the horizontal, i.e. "a five-degree gradient"
Physiographic Complexity	the degree of complexity of landscape arrangement and spatial dimension
Terrain Roughness	the irregularity or smoothness of the sea floor

Implementation Issues

There are a number of issues that need to be addressed in order to implement this or similar schemes for classifying seafloor habitats in a comprehensive and coordinated manner. The list of ideal properties of a classification system outlined at the beginning of this document

Table 4. Attributes of a classification system and relationship to development of a classification scheme versus issues for implementation of the scheme.

Attribute	Scheme Development	Scheme Implementation
1. Set geographical boundaries		X
2. Link to terrestrial and freshwater (aquatic) classification schemes		X
3. Exhibit a nested hierarchy	X	
4. Link habitats to organisms and communities	X	
5. Link physical processes to habitat distributions	X	
6. Unique and repeatable classification units at all levels	X	
7. A clearly defined nomenclature	X	
8. Accommodate diverse sources of data	X	
9. Accommodate modification	X	
10. Link to regional and national classification and mapping efforts		X

contained several elements that must be addressed by decision-makers who will implement this system (summarized in Table 4). Additional issues arose from the user survey and the analysis presented here. These issues are, in no particular order:

1. Seascapes. A decision regarding designation of seascape units at the scale of basins or other logical geomorphological features or at political boundaries is required.

2. Shallow versus deep water. Delineation of a depth threshold separating “shallow” from “deep” water and determination of scale, resolution, and habitat attributes that separate these otherwise arbitrary designations in terms of classification and mapping is required.

3. Sediment classification. Selection of a sediment classification approach is needed to insure consistency between surveys, i.e. Shepard (1954) versus Folk (1974).

4. Scale of map products. Selection of the scale(s) of published map products and required resolution of features for use by managers and stakeholders is needed. The user survey indicated that 1:20,000, 1:5000 and 1:10,000 scale maps are commonly used. However, 1: 1,200, 1:2,000, 1:12,000 scale maps facilitate linkages to subaqueous soil surveys and coastal zone mapping in the Little Naragansett Bay area. Variations in the scale of map products for shallow versus deep

regions may facilitate diverse uses (e.g., permitting of structures in shallow water versus siting cables and pipelines offshore).

5. A process to vet new terminology of habitat descriptors to insure unambiguous use will be required. The metric and resolution for each must also be determined. A web-based lexicon that can be continuously updated is suggested to accommodate multiple users.

6. Choices of sampling technologies as well as protocols for use and analysis will be needed to insure compatibility between surveys and projects over time (e.g., sonar frequencies, transducer configuration, path width, overlap, optical resolution for still-video systems, sediment processing protocols, faunal processing protocols, approach to community analysis, and taxonomic resolution and authorities). Sampling approaches should be linked explicitly to the attributes in the classification scheme at appropriate scales.

7. Methods and standards of interpolation for extrapolating point data to continuous coverage need to be determined.

8. Methods and standards for predictive habitat suitability modeling (or ecological niche modeling) need to be determined.

9. Linking map products explicitly to use as decision-support tools for particular management needs should be examined (example in Appendix 4).

Management Implications

A habitat classification scheme can provide a common currency for diverse user groups to study, understand, and discuss the trade-offs in managing the common property resources of Long Island Sound. However, government agencies at local, state and federal levels with responsibilities for Long Island Sound will need to mandate the implementation of the classification scheme in order to insure the widest level of use. Developing a centralized repository for geospatial data and map products would enhance the utility of having a common scheme and make map products available to the widest population of potential users.

The unique aspect of this proposed classification scheme is the iterative nature of the process used for developing the scheme. This process should result in wide acceptance of the utility of the approach and result in map products that transcend traditional disciplinary and agency boundaries.

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Appendix 1. Detailed Results of User Survey

The user survey instrument was implemented as a secure web page and database. Respondents were invited to participate in the survey via an email message that provided an anonymous link to the web site (i.e., the electronic address of the respondents were not recorded). One hundred eight respondents (28.6% of 377 invited participants) completed some or all of the survey. Below is the text and format of the survey instrument. Following this are detailed summaries of the responses to each of the questions.

User Survey Instrument

Thank you for agreeing to participate in our survey of seafloor habitat classification needs for Long Island Sound. Below are questions designed to elicit responses that will aid us in determining the range of important habitat attributes that should be included in a habitat classification protocol. Most questions simply require selection of a choice from a list of answers. However, if you think the response does not fully encompass your requirements for a particular type of habitat attribute, please explain further in the "additional comments" section provided under each question.

1. What general types of habitat features are useful to delineate for your application of seafloor maps? Note that details of each will be addressed later in the survey. Check all that apply:

☐ Geomorphic features (e.g., sand dunes, ripples, piled boulders, ridges, basins)
☐ Sediment types (e.g., mud, sand, gravel)
☐ Biological features (e.g., seagrass, oysters, sponges)

Additional comments:____

2. What types of geomorphic features should be identified?

☐ Large scale features only (e.g., sand dunes, bedrock outcrops, steep slopes)
☐ Small scale features only (e.g., sand waves, ripples)
☐ Both
☐ Not relevant

Additional comments:____

3. What types of sediment classification systems do you use?

☐ Linear hierarchy (i.e., Wentworth scale = mud, sandy mud, muddy-sand, fine sand, coarse sand, gravel)
☐ Relational classification (ie., percent of mud, sand, gravel)
☐ Both
☐ Not relevant
Additional comments:____

4. Are measures of organic carbon content relevant? (Name other types of relevant organic materials in comment section.)

☐ Yes
☐ No

Additional comments:

5. What types of biological attributes of seafloor habitats are relevant for your map product needs? Check all that apply:

☐ Habitat forming species (e.g., eelgrass *Zostera marina*, blue mussels *Mytilus edulis*)
☐ Dominant species (i.e., based on biomass or density)
☐ Dominant species groups (e.g., seagrass, sponges, bivalves)
☐ Community types (i.e., based on species composition)
☐ Key species (i.e., selected based on societal value; both managed and non-managed)
☐ Key managed species (e.g., American oyster, blue mussel, eelgrass)
☐ Other (please note in comments section)
☐ Not relevant

Additional comments:

6. Do you have a requirement to separate intertidal from subtidal habitat (e.g., separating intertidal sand from subtidal sand)?

☐ Yes
☐ No

Additional comments:

7. Do you have a requirement for delineating "shallow" from "deep" habitats of the same type in a classification system?

☐ Yes
☐ No

Additional comments:

8. If you answered yes to question 7, what is the depth threshold separating shallow from deep? Provide answer in comment window below.

Additional comments:

9. Is it useful to classify habitats by a measure of natural disturbance regime?

☐ Yes
☐ No

Additional comments:____

10. If you answered yes to question 9 above, what attribute or proxy would be useful for mapping "disturbance" regime in a spatial context? Check all that apply:

☐ Mean annual tidal current velocity
☐ Maximum annual tidal current velocity
☐ Delineation of mobile and immobile sediments
☐ Other (please note in comment section)
☐ Don't know but a proxy would be useful

Additional comments:____

11. What type of sampling technologies do you use in your mapping activities? Check all that apply:

☐ Core
☐ Grab
☐ Acoustic seabed classification
☐ Aerial imagery
☐ Sidescan sonar
☐ Multi-beam sonar
☐ LIDAR
☐ Other (please note in comment section)
☐ Not relevant

Additional comments:____

12. What sample resolution/density is required for your mapping activities?

☐ Continuous coverage over mapped area (e.g., from sidescan or multibeam)
☐ Grid sampling (e.g., interpolated seafloor characteristics from grab samples, video, etc.)
☐ Adaptive sampling based on related survey (e.g., grab sampling to groundtruth sidescan or multibeam)

Additional comments:____

13. What is the approximate spatial scale of map products that you commonly utilize? Check all that apply:

☐ 1:5,000
☐ 1:10,000
☐ 1:20,000
☐ 1:50,000
☐ 1:100,000
☐ Larger than previous choices
☐ Smaller than previous choices

Additional comments:____

14. What are your applications of map products? Check all that apply:

☐ Permitting activities (on adjacent land)
☐ Permitting activities (shallow in-water activities from high tide line to 5 m)
☐ Permitting activities (in-water activities 5 m and deeper)
☐ Municipal planning or project evaluation
☐ State planning or project evaluation
☐ Federal planning or project evaluation
☐ Living marine resource assessment
☐ Living marine resource research
☐ Geological resource assessment
☐ Geological resource research
☐ Environmental quality assessment
☐ Environmental quality research
☐ Research (please specify in comments section below)
☐ Education use
☐ Environmental impact studies
☐ Marine protected area planning
☐ Utility corridors/infrastructure

Additional comments:____

15. What type of organization do you currently work for?

☐ Federal natural resource agency
☐ State natural resource agency
☐ Municipal government
☐ Fishing industry
☐ Shipping industry
☐ Energy/utilities industry
☐ Real estate development industry
☐ Academia
☐ Environmental NGO
☐ Industry NGO
☐ Other (please specify in comments section below)

Additional comments:______________________________

16. What is your professional role in development or use of map products?

☐ Planner-regulator, municipal
☐ Planner-regulator, state
☐ Planner-regulator, federal
☐ Regional planning agency
☐ State natural resource agency
☐ Federal natural resource agency
☐ Commercial fishing industry
☐ Recreational fishing industry (e.g., charter boat)
☐ Recreational fisher
☐ Recreational boating industry
☐ Recreational boater
☐ Shipping industry
☐ Real estate development
☐ Coastal construction and engineering
☐ Energy transmission/provider
☐ Academic
☐ Other (please specify in comments section)

Additional comments:______________________________

17. Do you produce or use seafloor map products?

☐ Produce maps
☐ Map user
☐ Both

Additional comments:______________________________

18. Please provide additional comments that will help clarify your requirements for a useful seafloor habitat classification system.

Additional comments:____

Detailed summaries of responses to survey questions

1**. What general types of habitat features are useful to delineate for your application of seafloor maps?**

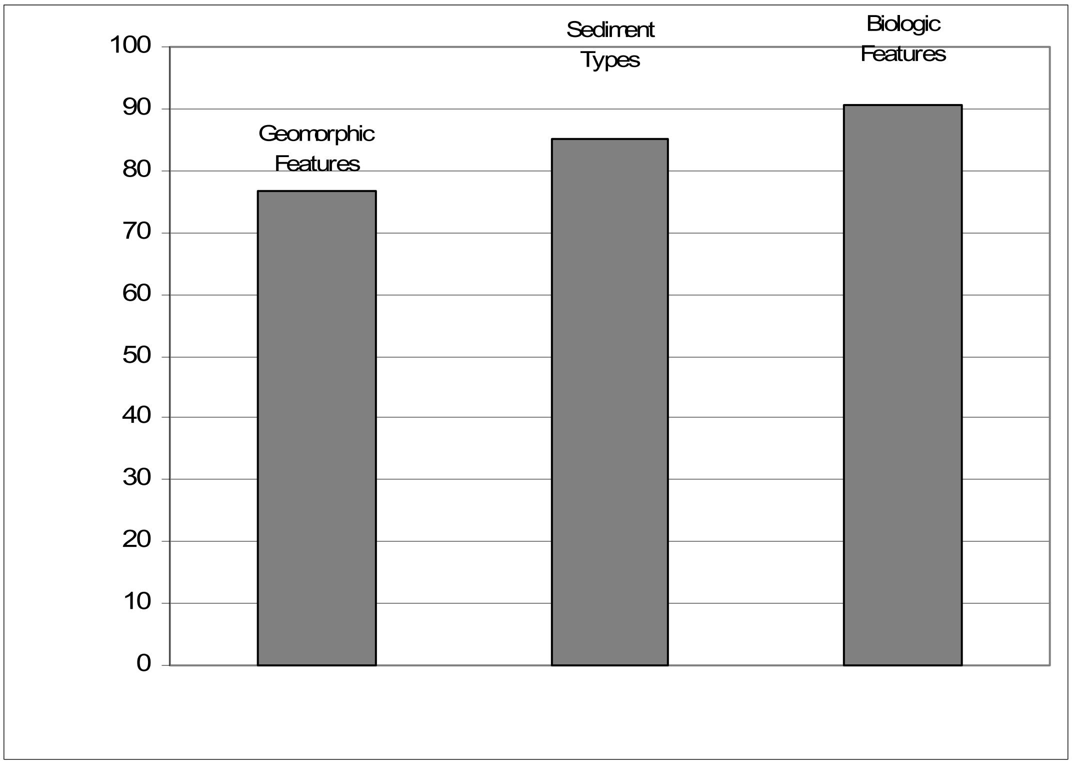


Figure 1.1. Percentage of Respondents by Habitat Feature

All respondents (n = 108) answered the query. The majority of respondents indicated that all three types of habitat features were useful for their application of seafloor habitat map products. (Geologic = 77%, Sedimentary = 85%, Biologic = 91%).

Comments:

Respondents noted the transience of biologic features, both subtidal and intertidal (e.g., marsh boundaries, intertidal communities) but identified the need to link geomorphic features to biotopes. Delineating regions of the seafloor exposed to hypoxia or anoxia on a regular (annual) basis as well as identifying manmade features (e.g., shipwrecks, cable trenches, channels, disposal mounds, built structures, areas used for mariculture) was suggested. A number of respondents identified the need to link seafloor features to natural resource species and their habitats (e.g., economically important finfish, crustaceans, and molluscs). Differences in habitat classification approaches were also mentioned in terms of using soil versus sediment classification systems. Finally, identification of broad classes of depositional versus erosional environments was identified as an important geospatial "feature".

2. What types of geomorphic features should be identified?

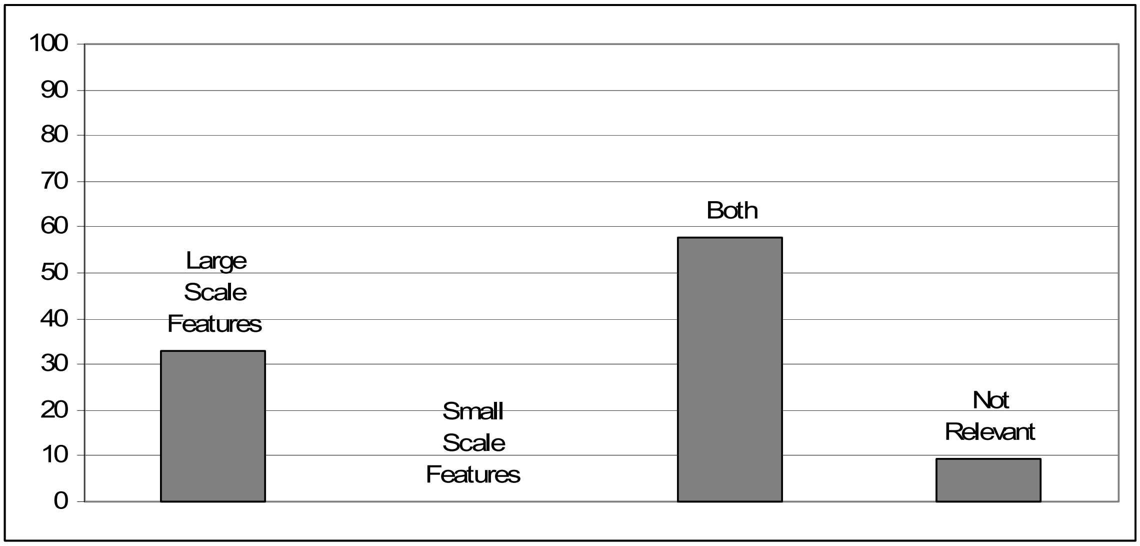


Figure 1.2. Percentage of respondents by geomorphic features

Ninety-eight percent of respondents answered this question. The majority (58%) indicated that both small and large scale features should be identified. Thirty-three percent indicated that only large scale features should be identified while 9% indicated that neither small nor large scale features were relevant.

Comments:

Respondents noted the need to define features to insure proper interpretation of the level of homogeneity within a defined area. The transience of some small scale features was noted, suggesting a need to include relevant information related to such features as metadata on map products (e.g., transition areas between sand and gravel). Links between subaqueous soil types and landform features was discussed by one respondent but linking such classifications from shallow to deep waters in Long Island Sound is not obvious. The terminology for any new classification system should insure broad application across a diversity of users. Use of the terms "landform" or "landscape unit" rather than "large scale geomorphic feature" for features such as flood-tidal deltas, wash-over fans, bay floor is common among some user groups.

3. What types of sediment classification systems do you use?

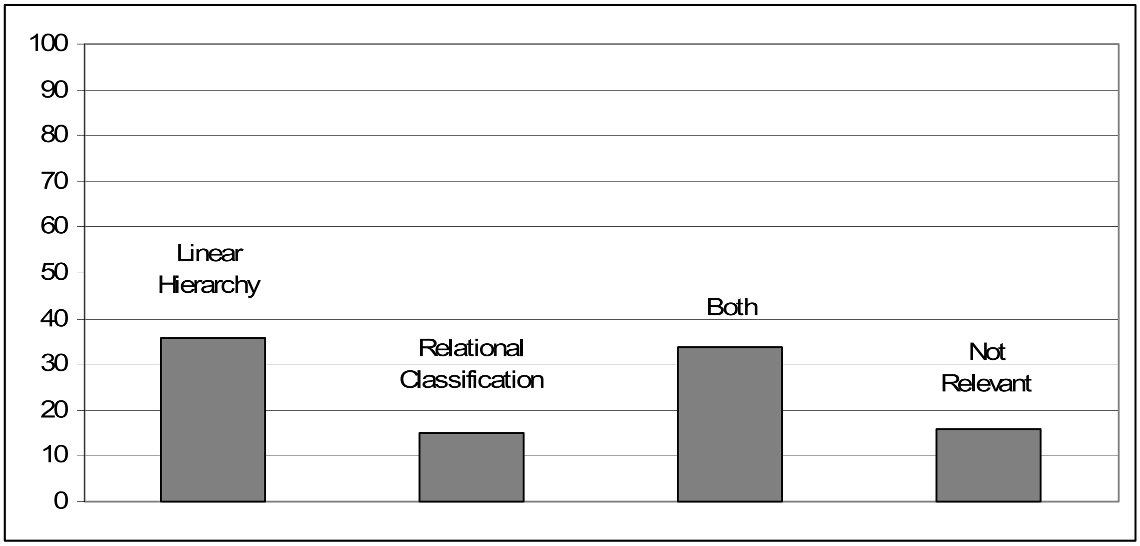


Figure 1.3. Percentage of respondents by sediment classification system.

Ninety-three percent of respondents answered this question. Thirty-five percent identified linear hierarchy and 15% identified relational classification as the types of classification systems they used. Thirty-four percent used both linear hierarchy and relational classification systems, while 16% reported that neither were relevant in their work.

Comments:

Some respondents felt that there should be some flexibility involved in using sediment classification systems, and that it was not critical whether a linear hierarchy or a relational classification was used. Likewise, a number of respondents suggested the use of the USDA textural triangle classification system rather than any of the choices presented here. These respondents noted that the USDA system can be used to map subaqueous soils and landforms, and it can also be linked to grain size distribution (i.e. Wentworth Scale).

4. Are measures of organic carbon content relevant? (Name other types of relevant organic materials in comment section.)

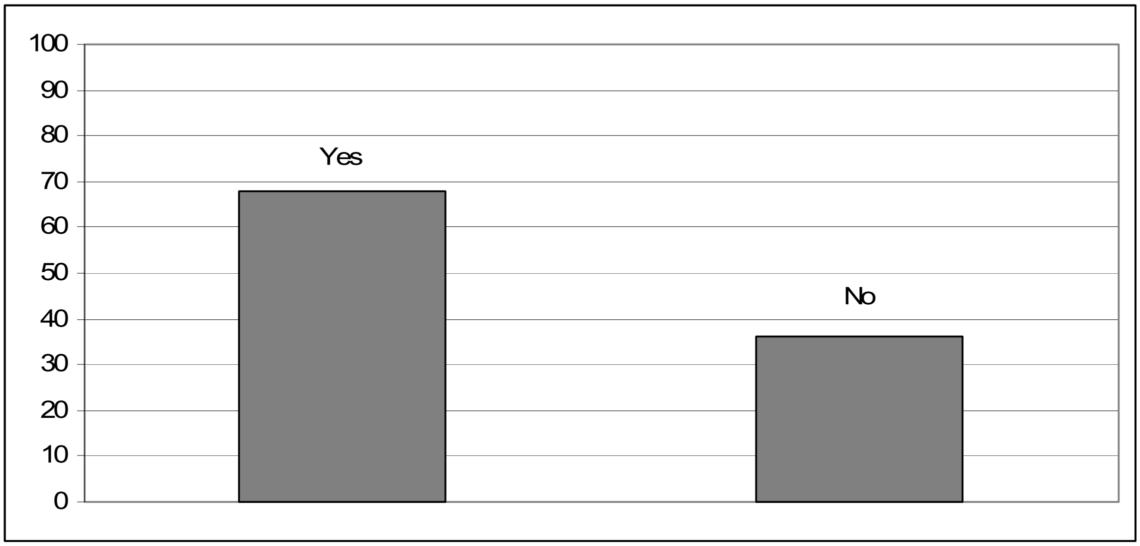


Figure 1.4. Percentage of Respondents by relevancy of organic carbon content

Ninety six percent of the respondents answered the query. The majority (65%) indicated that measures of organic carbon content are relevant.

Comments:

A number of respondents noted the importance of organic carbon concentration as an indicator of eutrophication. The impact of eutrophication on benthic-pelagic coupling is important for user groups dealing with benthic organisms (e.g. lobsters and deposit-feeding assemblages), and submerged aquatic vegetation (SAV; e.g. *Zostera marina*). Many of the same respondents noted that percent organic carbon is also an indicator of organic contaminant concentration, a factor often taken into consideration at sites where sediment resuspension is likely (e.g. dredge and *Mycelium* disposal areas, and trench locations). One respondent also recognized that organic carbon may be more labile and dynamic depending upon the depth at which users sample, and may therefore only be useful in classifying habitats for which organic carbon is measured frequently.

5. What types of biological attributes of seafloor habitats are relevant for your map product needs?

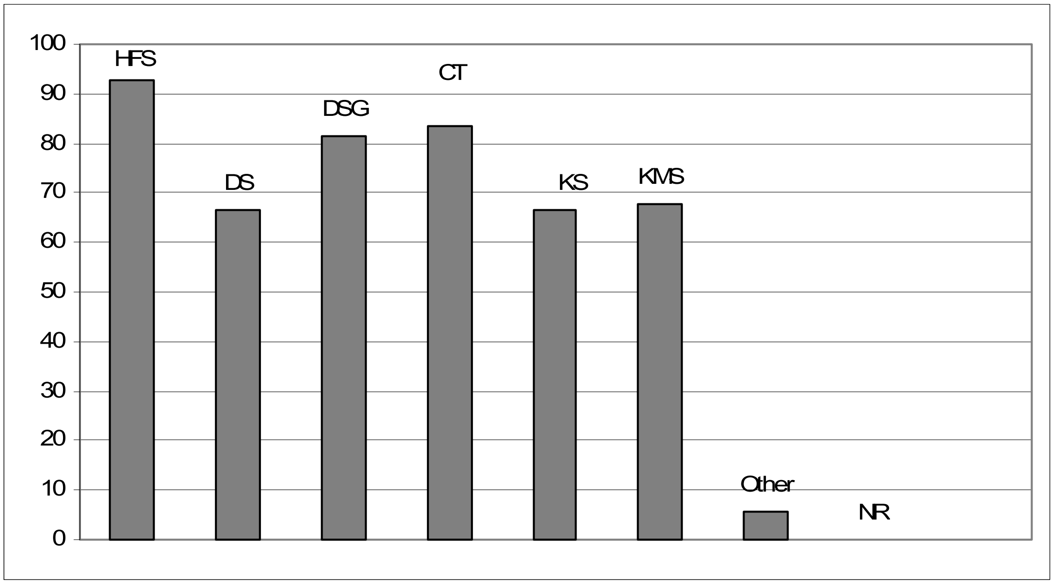


Figure 1.5. Percentage of respondents by relevant biological attributes of seafloor habitats. Categories correspond the to following: HFS = Habitat Forming Species, DS = Dominant Species, DSG = Dominant Species Groups, CT = Community Types, KS = Key Species, KMS = Key Managed Species

One hundred percent of respondents answered the query. The majority (93%) identified habitat forming species as relevant to their map product needs, but a high percentage indicated that all biological attributes were relevant to mapping needs.

Comments:

Respondents noted the general utility of biological attributes that can be linked to attributes in nearby regions (e.g. eelgrass and shellfish beds in Little Narragansett Bay). It was suggested that each of the biological attributes could be incorporated into the 'biotope' level of the EUNIS (European Nature Information System) classification system for Europe. It will be necessary to investigate the use of such attributes at a biotope level in the development of our classification system. Respondents also identified the need for invasive and migratory species as biological attributes of seafloor habitats in map products.

6. Do you have a requirement to separate intertidal from subtidal habitat (e.g., separating intertidal sand from subtidal sand)?

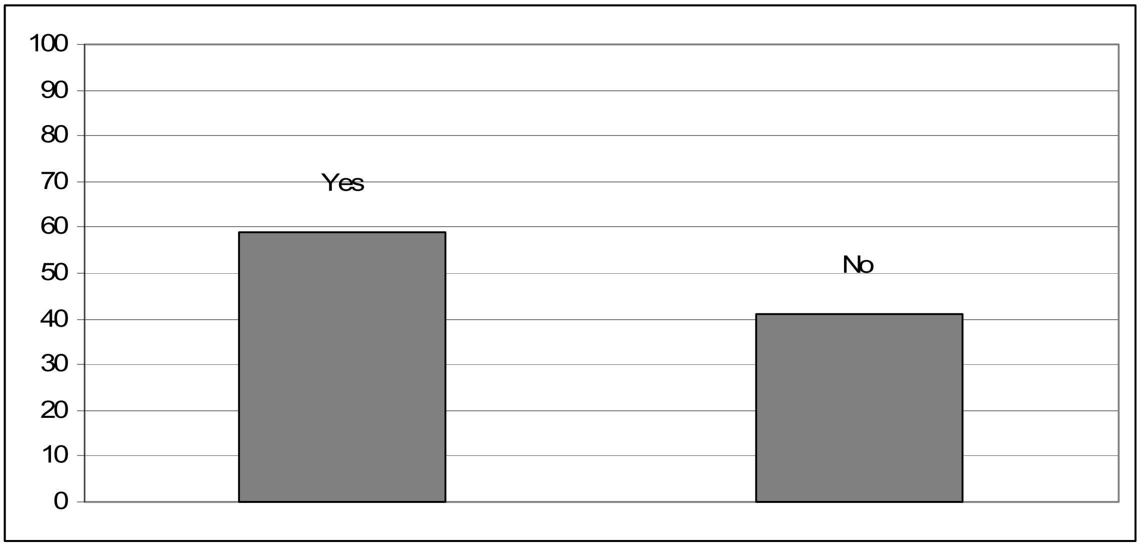


Figure 1.6. Percentage of respondents by requirement for separation of intertidal from subtidal habitat.

Ninety nine percent of respondents answered the query. 59% indicated that they had a requirement for separation of intertidal from subtidal habitats.

Comments:

Respondents noted the importance of separating intertidal from subtidal habitats for both regulatory and non-regulatory uses. These include, but are not limited to assessment of jurisdictional review areas for local municipalities and state natural resource agencies, i.e. issuing dock or bulkhead permits. Respondents also noted the importance of distinguishing between intertidal and subtidal habitats with regards to aquaculture, submerged aquatic vegetation, juvenile fish habitat, and marshes. Several respondents discussed the importance of defining intertidal and subtidal zones in the face of climate change and predicted sea level rise.

7. Do you have a requirement for delineating "shallow" from "deep" habitats of the same type in a classification system?

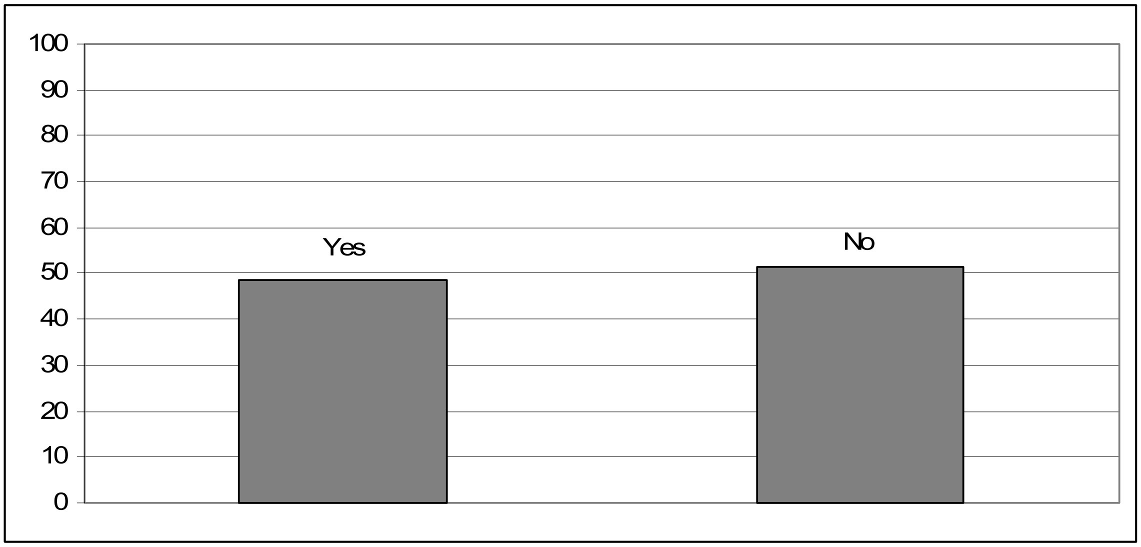


Figure 1.7. Percentage of respondents by requirement for delineating shallow from deep habitats

Ninety nine percent of respondents answered the query. Approximately half of these respondents (49%) indicated a requirement for delineating shallow from deep habitats of the same type in a classification system.

Comments:

Respondents suggested several means by which to delineate shallow from deep habitats. These suggestions included the use of the EPA definition of shallow water of less than 4 m as well as use of the mean depth of 1% surface irradiance (i.e., light level). Others suggested there was no necessity for a specific threshold depth as long as map products included bathymetric contours. Several respondents discussed the fact that habitats at different depths will be delineated by different species, automatically creating a differentiation between “shallow” and “deep”. One respondent noted the importance of delineating shallow from deep habitats in aquaculture (e.g. transfer of oysters from shallow to deep water with an increase in size).

8. If you answered yes to question 7, what is the depth threshold separating shallow from deep?

Comments:

Many respondents defined the depth threshold separating shallow from deep water with a range of numeric values (e.g. 3 ft., 5 ft., 10 ft., 12 ft., 15 ft., 20 ft., 25 ft., 30 ft., 1.7 m, 2.5 – 3 m, 4 m, 5 m, 6 m, 10 m, 15 m, 20 m). While many of these values are arbitrary, some respondents provided specific definitions used to delineate shallow from deep water. For example, some respondents indicated 20 ft as the depth threshold for eelgrass populations, while others defined the eelgrass threshold as 1.7 m. For those working with the USDA soil classification, 2.5 to 3 m is the maximum shallow water depth, and greater than 3 m is defined as deep water. The EPA definition for shallow water is <4m, which is similar to the Rhode Island MapCoast threshold of 5m. These thresholds coincide with an estimated threshold for light penetration, which one respondent defined as 2-3 m. The Coastal and Marine Ecological Classification Standard (CMECS) defines the depth threshold as 15m.

Some respondents suggested operational definitions to delineate shallow and deep habitats (e.g. the 100 yr. storm wave base, the depth at which viable *Zostera* stands cannot be supported, light penetration based on data, pycnocline and diffusive barriers). One respondent noted that being able to delineate shallow from deep habitats may be system-dependent, i.e. shallow water soft-sediment systems are more susceptible to disturbances than deep-water systems, or rock substrate systems. Another respondent added that the Coastal Zone Management Act defines "nearshore waters" rather than shallow habitats (i.e., those waters and their substrates lying between mean high water and a depth approximated by the 10 m contour).

9. Is it useful to classify habitats by a measure of natural disturbance regime?

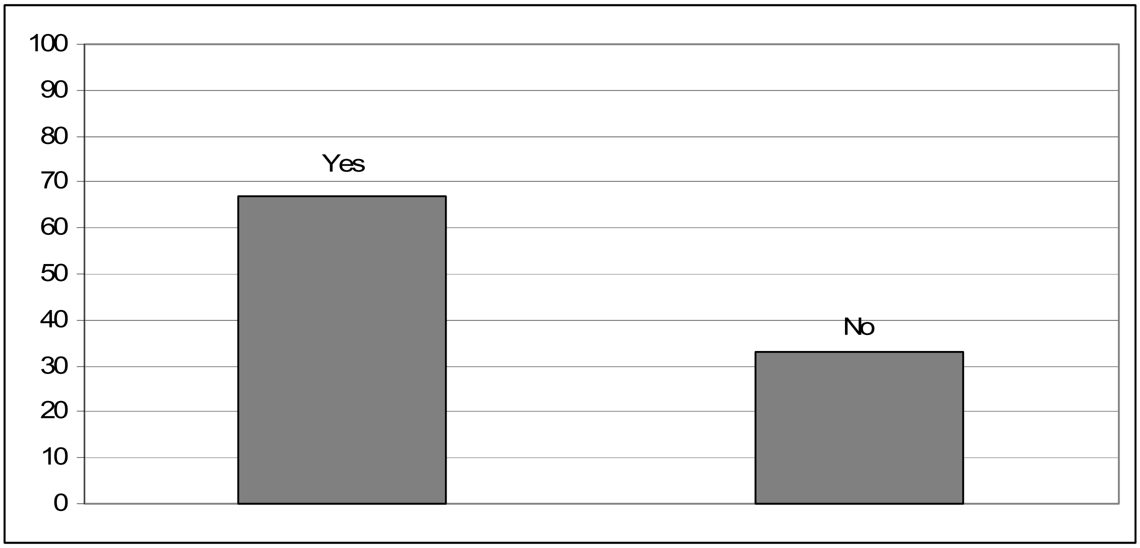


Figure 1.8. Percentage of respondents by utility of natural disturbance regime.

Ninety five percent of the respondents answered the question. The majority of the 103 respondents (67%) indicated that classification of habitats by a measure of natural disturbance regime is useful.

Comments:

While many of the respondents expressed the utility of habitat classification by a measure of natural disturbance routine, they acknowledged the difficulty of quantifying such a measure. Clear definitions of 'natural disturbance regime' will be necessary (e.g. wave action, scour, riverine flow, or episodic events like increased freshwater input, storms,etc.) in identification of potential habitat viability for biologic communities, planning for new developments, or studying shoreline erosion. Another respondent suggested that a disturbance regime might be useful as a descriptor within a classification scheme, rather than a separate level. Likewise, it will be necessary to decide whether to include pipelines/cables, dredge areas, and manmade channels as a natural disturbance regime or separate features.

10. If you answered yes to question 9 above, what attribute or proxy would be useful for mapping "disturbance" regime in a spatial context?

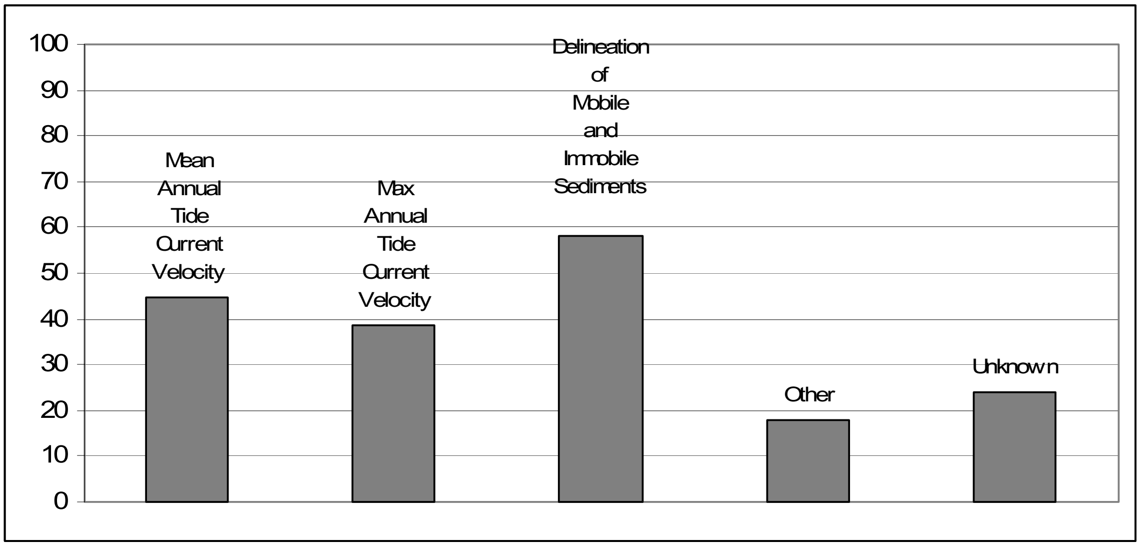


Figure 1.9. Percent of Respondents by Proxy for Mapping "Disturbance" Regime.

Ninety seven percent of the respondents who answered yes to question 9 also answered this query. Of those 67 respondents, 58% indicated that delineation of mobile and immobile sediments is useful for mapping disturbance regime in a spatial context. 45% and 39% of respondents indicated that mean and max annual tide current velocity, respectively, is useful.

Comments:

Many of the respondents indicated that episodic events (e.g. major storms and unusual atmospheric events) are a useful proxy for mapping disturbance regimes. Others suggested wave disturbance, presence/absence of long-lived benthic invertebrates, bioturbation, and presence/absence of sulfidic materials as a measure of the exposure to air as useful proxies. One respondent noted that natural disturbance regimes are included when mapping landforms, or large features.

11. What type of sampling technologies do you use in your mapping activities?

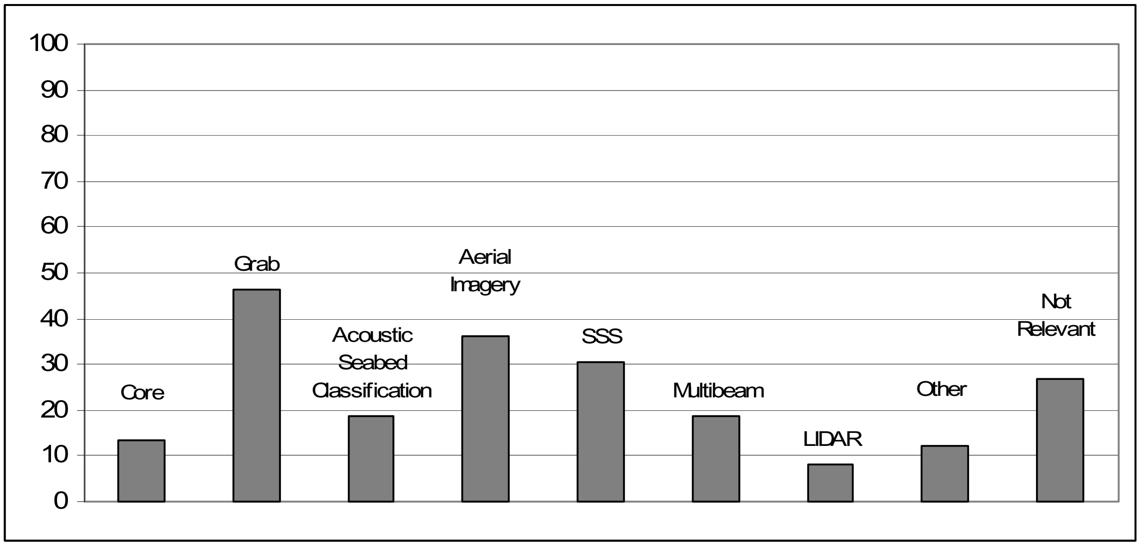


Figure 1.10. Percentage of respondents by sampling technologies.

One hundred percent of respondents answered the query. The majority of respondents (46%) use grabs to sample for mapping activties, followed by 36% who use aerial imagery, and 31% who use side scan sonar.

Comments:

Respondents noted underwater video, visual seagrass observations, sediment profiling, and undersea vehicles as additional types of sampling technologies used in mapping activities. Another respondent suggested sampling to include characteristics of the overlying water, as well as its flow, velocity, and shear stress as the connectivity among habitats is associated with circulation patterns and their variability.

12. What sample resolution/density is required for your mapping activities?

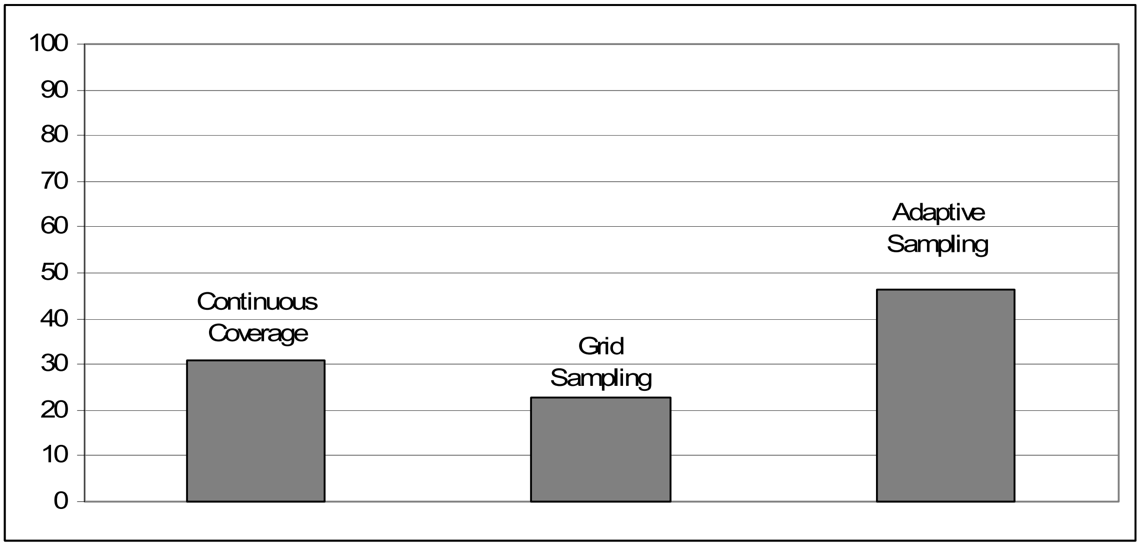


Figure 1.11. Percentage of respondents by sample resolution/density

Seventy eight percent of respondents answered the query. Of these, 31% indicated that continuous coverage is required for their map activities and needs, while 23% indicated grid sampling, and 46% indicated adaptive sampling.

Comments:

Respondents noted that no matter what resolution / density is required for their mapping activities, it is important that their data is verified by cores or grab samples. In addition, it was noted that when using the USDA system, subaqueous soil samples follow a traditional landscape model and the resolution required for mapping is conditional upon how much information is necessary to characterize the representative bedform or submerged feature.

13. What is the approximate spatial scale of map products that you commonly utilize?

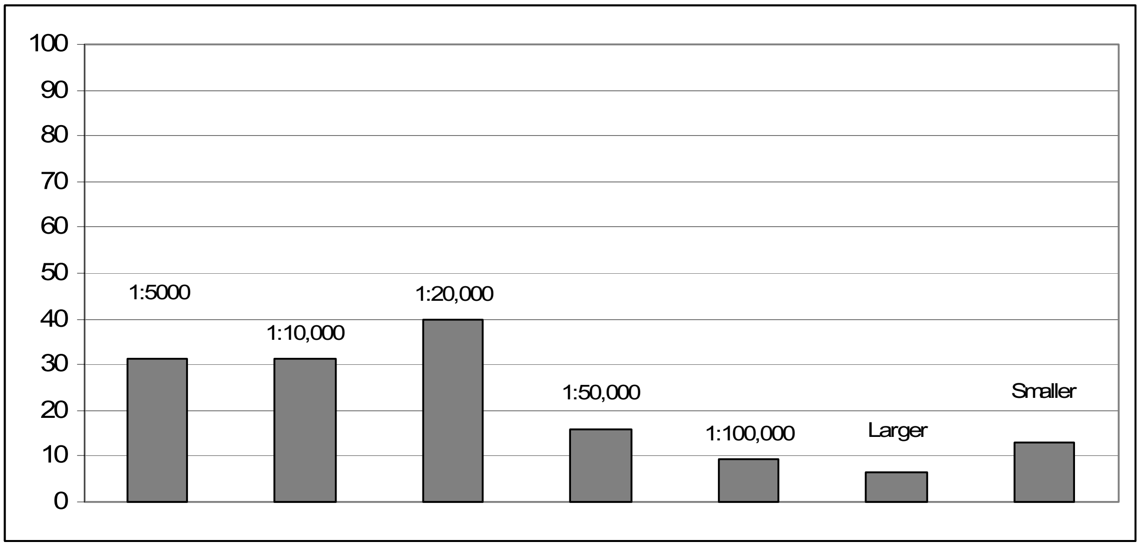


Figure 1.12. Percentage of respondents by spatial scale.

One hundred percent of 108 respondents answered the query, 40% indicated that they commonly utilize a 1:20,000 spatial scale. This was followed by 32% of the respondents that indicated they commonly utilize both the 1:5000 and the 1:10,000 spatial scales.

Comments:

In addition to the choices provided above, respondents identified several spatial scales of commonly utilized map products (e.g. 1: 1200, 1:2000, 1:12,000 to facilitate meshing with subaqueous soil surveys and coastal zone mapping of Little Naragansett Bay, 1"=20' to 1"=100'). Other respondents indicated that spatial scale was solely dependent upon the study area or biological system being addressed.

14. What are your applications of map products? Check all that apply:

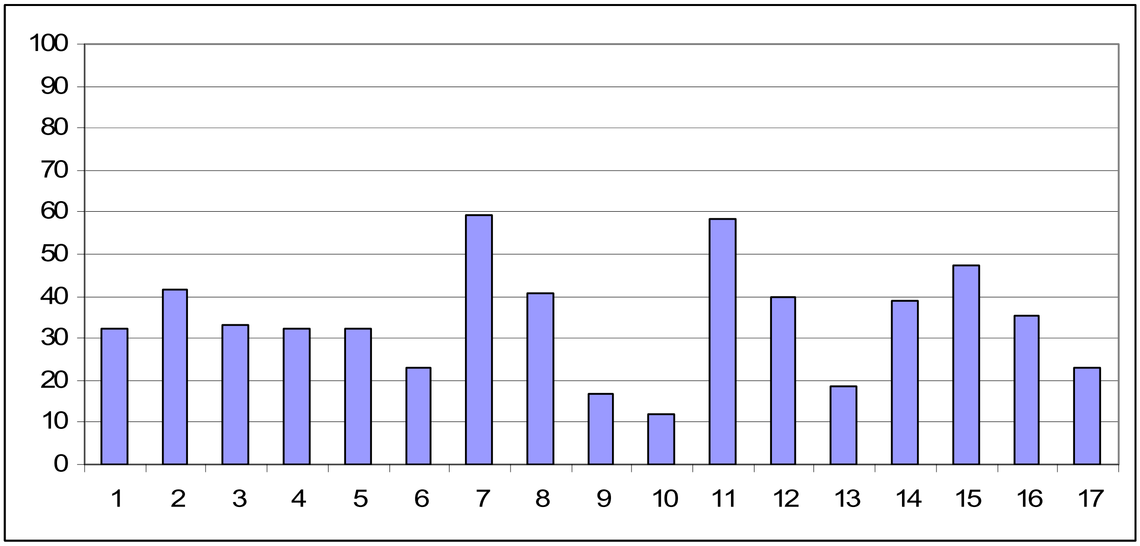


Figure 1.13. Percentage of respondents by application of map products. Categories along x-axis are as follows:

1 = Permitting activities (on adjacent land)

2 = Permitting activities (shallow in-water activities from high tide line to 5 m)

3 = Permitting activities (in-water activities 5 m and deeper)

4 = Municipal planning or project

5 = State planning or project evaluation

6 = Federal planning or project

7 = Living marine resource assessment

8 = Living marine resource research

9 = Geological resource assessment

10 = Geological resource research

11 = Environmental quality assessment

12 = Environmental quality research

13 = Research (please specify in comments section below

14 = Education use

15 = Environmental impact studies

16 = Marine protected area planning

17 = Utility corridors/infrastructure

One hundred percent of respondents answered the query. Fifty nine percent indicated living marine resource assessment as an application of mapping needs, and 58% indicated environmental quality assessment.

Comments:

Many respondents identified additional and/or more specific applications of map products (e.g. examination of hard bottom communities, subaqueous soil interpretations, SAV restoration, shellfish management, tidal marsh protection, navigational channel creation, maritime resources, and the distribution of heavy metal contamination).

15. What type of organization do you currently work for?

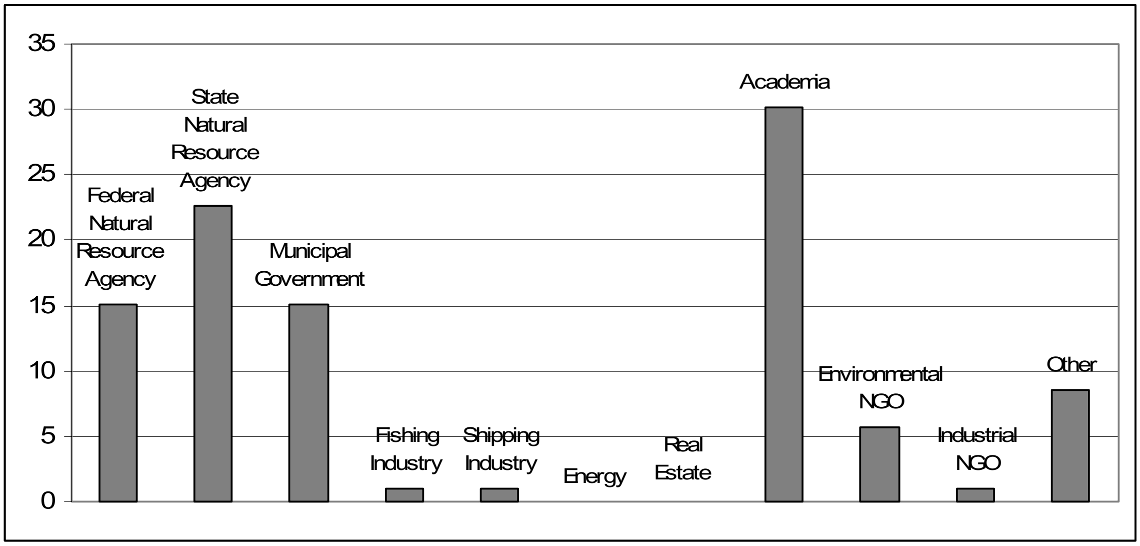


Figure 1.14. Percentage of Survey Respondent by Occupation

Ninety eight percent of the respondents answered the query. Most of the respondents (31%) worked in academia, with the next highest number in state natural resource agencies (24%), followed by federal natural resource agency and municipal government employees (both 16%).

Comments:

Some respondents indicated the specific organization at which they are employed. These organizations included an aquarium, a citizen's advisory committee, an interstate regulatory and environmental agency, a municipal shellfish commission, a state and federal fisheries management group, a federal research/outreach program, a federally funded research program, an interstate water quality agency, the Environmental Resources Section for the United States Army Corps of Engineers, the United States Department of Agriculture Natural Resources Conservation Service, the partnership MapCoast, Sea Grant College Program, and the United States Environmental Protection Agency.

16. What is your professional role in development or use of map products?

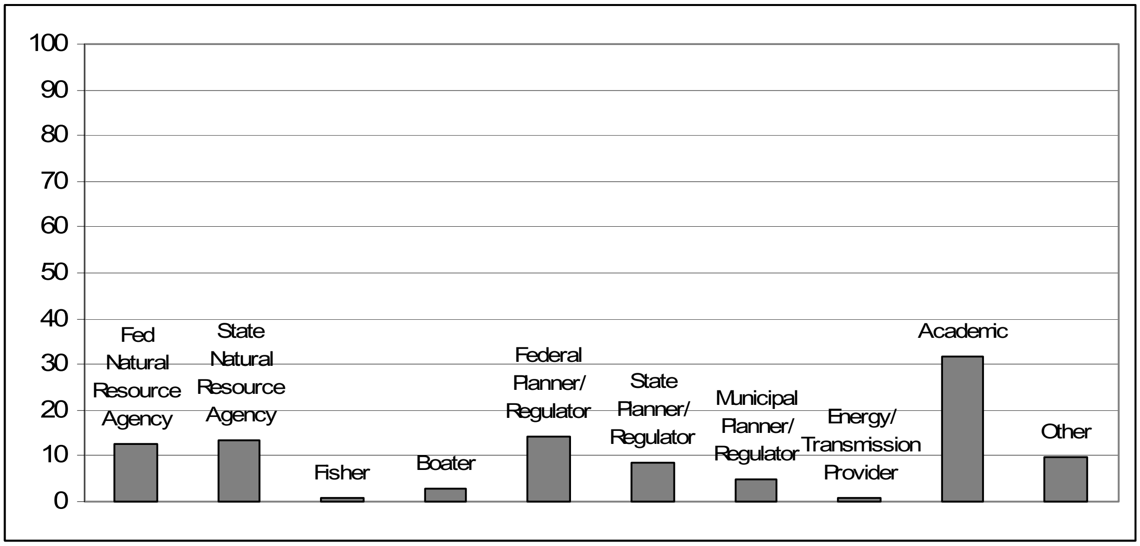


Figure 1.15. Percentage of respondents by professional role

Ninety six percent of respondents answered the query. Most respondents (32%) were academics, 14% were federal planners/regulators, 13% each had roles in federal or state natural resource agencies, followed by "other".

Comments:

Some of the respondents that answered this query provided their specific role in the organization where they are employed. These include a marine conservation scientist, supervisor of a State Agency Division's Geographic Information System Unit, and GIS specialist. Others use map products to evaluate pier and dock permits, inventory tidal wetlands, review potential marine protected areas, influence the actions of municipal decision makers, monitor mariculture facilities, as well as for outreach purposes (e.g. public presentations and teaching environmental education).

17. Do you produce or use seafloor map products?

Figure 1.16. Percentage of respondents by production and/or use of seafloor map products

Ninety one percent of respondents answered this query. Of these, 65% of the respondents use maps and 5% produce maps. Thirty percent of the respondents use and produce maps.

Comments:

Several respondents indicated that they produce and use maps of submerged aquatic vegetation not only to synthesize and communicate data, but in the evaluation of permit activties (e.g. placement of cables and pipelines, proposed aquaculture projects, and dredging projects). Additional maps are also produced (e.g. shellfish beds, sediment type, sidescan sonar, geological and biogeochemical data) by respondents.

18. Please provide additional comments that will help clarify your requirements for a useful seafloor habitat classification system

Additional comments were provided by many of the respondents. These comments focused on individual users' needs for seafloor habitat classification systems. Several respondents noted an interest nearshore areas (e.g. harbors, water less than 30 ft. deep) as it is an area least well mapped, most impacted, and vital to many species. Many respondents indicated an interest in benthic habitats throughout Long Island Sound (e.g. juvenile / fish habitat , algae and the surrounding sediment types, and community types as related to trawl data). Other respondents identified sediment patterns and soil classifications as requirements useful for seafloor habitat classification systems, with reference to the USDA Soil Taxonomy and the need for soil classification greater than 2 m deep. The need for a map product that associates living marine resources with sediment types and hydrodynamic conditions on a temporal scale also seemed to be a common response among user groups. Similarly, one respondent indicated the need to develop a habitat classification scheme that clearly defines the biotope level. Mapping to the biotope level is of tremendous value to environmental regulators, those users that evaluate resources, and marine conservationists so that critical habitat resources can be identified and protected.

One respondent also identified the need to incorporate large natural or manmade structures because they serve as optimal sites for scuba diving and recreational fishing activities.

Other respondents focused on the detail and accuracy of the seafloor habitat classification system, indicating the need to cover the entire Sound at appropriate scales for each map application. With limited funding, it is important to limit the scope and size of this classification system. Therefore, it was suggested that the habitat classification scheme be more accurate at a higher resolution in areas of special concern (e.g. sites of infrastructure projects, high biodiversity, etc.) It was also suggested that once developed, the habitat classification be subject to an outside peer review process in order to validate the tool.

Appendix 2. Detailed Evaluation of Selected Classification Schemes

In order to evaluate the utility of existing schemes for use in LIS, we integrated the habitat attributes identified by the survey responses into the selected schemes. Existing geospatial data sets were used to compare and contrast the utility of each scheme for classifying habitats. Geospatial data sets were integrated into a single Geographic Information System (GIS) project using ESRI's ArcMap software. Coverage included: bathymetry (1 and 5 m contour resolution), shoreline, sedimentary environment (various including sediment class, erosional-depositional environment), USGS sediment sample database, benthos (from Pelligrino & Hubbard, community type, diversity, dominant species, species composition), benthic forams, total organic carbon, contaminant metals, fish community type based on spring and fall trawl survey data, and terrain roughness indices using both multibeam bathymetry from mapped sites and sound-wide 1 m bathymetry. We also used both sidescan and multibeam sonar mosaics (and multibeam backscatter where available) from all survey areas to date including Six-Mile Reef off Old Saybrook. We have received seagrass distribution maps (based on aerial imagery) from USF&WS but these were not used in the current evaluation.

Test sites were chosen based on locations of previous sidescan or multibeam sonar surveys spatially coincident grab sample locations (Figure 2.1). Test sites represent a range of conditions such as dynamic nearshore environments (e.g., Roanoke Point, Branford, and Niantic Bay) and deep relatively stable areas (e.g., Stratford Shoal, Six Mile Reef, and the Race) with heterogeneous seafloor types. We explicitly focused on heterogeneous areas in order to best evaluate the variation between classification schemes.

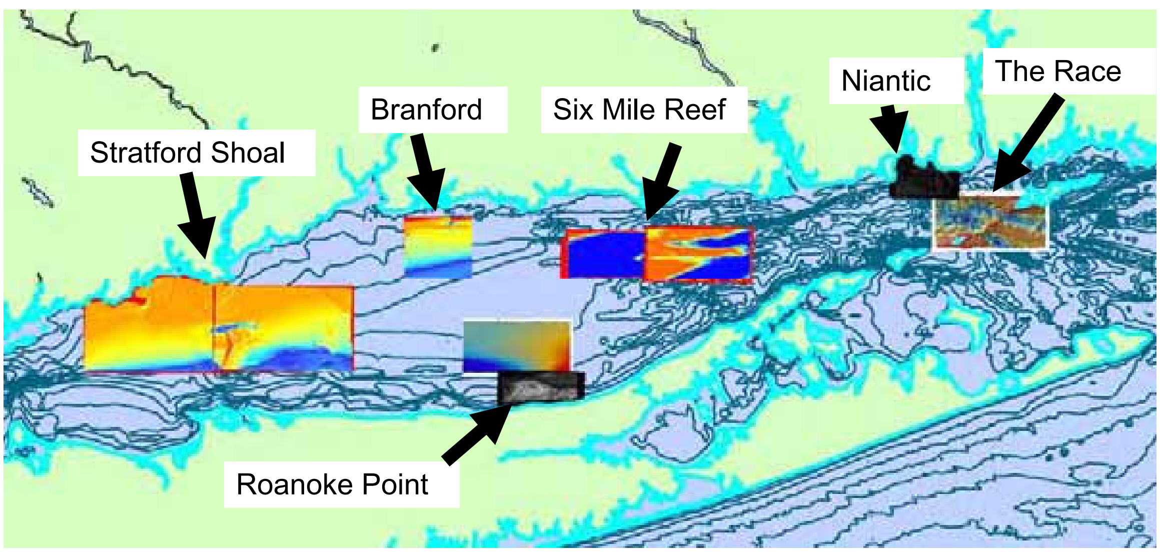


Figure 2.1. Location of multibeam and sidescan sonar maps used for evaluation of habitat classification schemes.

Individual point locations of sediment grab samples collected within each site were used to describe detailed physical and biological data at various levels of each classification scheme. The "Thiessen tool" in ArcGIS was used to convert point data to a continuous coverage of adjacent polygons. Thiessen polygons have the unique property that each polygon contains only one input point, and any location within a polygon is closer to its associated point than to the point of any other polygon. This interpolation method was used to create a topology coverage for each level of each classification scheme, with the exception of those levels that called for classification by slope. Slope was classified by values assigned to pixels on a digital elevation map (DEM). This DEM was an interpolation of the 1 m bathymetric contours.

Evaluation of Greene et al. 1999

Data sources used to characterize the multiple levels of classification, the attributes of seafloor habitats identified by the user survey as they correspond to those levels of classification, and the geospatial data needs as revealed from evaluating the scheme are summarized in Table 2.1. The first level of the scheme is defined as a marine benthic system and did not require classification at individual points. The second level of the scheme calls for characterization by depth, and 1 m bathymetry data was used to classify this subsystem (mega- and mesohabitats). Major geomorphic features present on side scan sonar (SSS) and / or multibeam records were used to characterize meso- or macrohabitats (Class; 3rd level). Macro- and microhabitats at the subclass level were characterized by substrate (based on distribution of surface sediments) and slope (based on the digital elevation map).

Fine scale modifiers such as bottom morphology and bottom texture were classified based on SSS and multibeam records. Bottom deposition was characterized by the type of sedimentary environment present at each sampling location. Chemical processes were characterized based on the concentration of Total Organic Carbon (TOC). Biological processes were characterized by dominant species and dominant species groups, but could include community type, key species, key managed species, or habitat forming species. Physical processes could not be identified based on Greene et al.'s (1999) definition (i.e. wave activity, upwelling, currents, *etc*.) because datasets are not available in a geospatial coverage. The same is true for anthropogenic processes. Such information may be available in primary literature sources, and could easily be converted to a geospatial dataset or used directly for characterization of these processes.

Evaluation of Valentine et al. 2005

As in the previous evaluation, data sources, habitat attributes and data needs are summarized in Table 2.2. Under Theme 1, Class 1 (topographical setting), subclass (depth) is defined by the presence or absence of macrophytes, and for this purpose was inferred by bathymetric contours. The subsequent category (major physiographic features) was classified based on multibeam records for each site. Attributes such as angle of seabed slope were characterized by the digital elevation map.

Under Theme 2, Class 2 (seabed dynamics and currents), subclass (mobile and immobile substrate) was classified based on sedimentary environment. The category (types of currents) and attributes (strength and frequency of currents) could not be classified based on available geospatial coverage but could be inferred from published data on currents and tides of LIS.

Under Theme 3, Class 3 (seabed texture, hardness and layering), subclass was classified fine-, coarse-, or mixed-grained sediment or rock and category was characterized by sediment type based on the distribution of surface sediments at each point. The percent of seabed cover (attribute) could not be determined accurately with only point data. Percent cover can be estimated from interpolated points, but may not be accurate.

Under Theme 4, Class 4 (seabed grain size), subclass was defined as the general sediment description and classified based on Phi values (Reid et al. 1979) or sedimentary environment for the corresponding sample. Category was characterized using the distribution of surface sediments for samples with a Phi value and for samples without a Phi value, category could not be determined. For samples with a Phi value, attributes were classified based on weight percent of that Phi value. For samples without a Phi value, attributes were classified based on the distribution of surface sediments.

Under Theme 5, Class 5 (seabed roughness), large and small scale geomorphic features (subclass and category) were defined based on multibeam and SSS records. Percent coverage of these features (attribute) could not be classified based on point data, but could be interpolated by the user.

Under Theme 6, Class 6 (faunal and floral species or groups), subclasses were identified based on method of data collection, i.e., grab samples. Fauna data could be taken from Pellegrino and Hubbard (1983) or Reid et al. (1979) data sets (currently available in geospatial coverage) or from independent data sets (i.e. photos of the seafloor, ROV dives, etc.). Categories were based on dominant species and dominant species groups, while attributes (presence/absence or percent cover) were left to be interpreted by the user, i.e. either estimate the percent cover of each based on interpolation techniques or identify each member as present/absent for each point.

Data were unavailable to proceed with classifying themes 7 (habitat usage) and 8 (habitat recovery from disturbance), which require geospatial coverage of use patterns related to associations with shelter or spawning grounds, fishing disturbance, and time to community recovery after impacts.

Evaluation of EUNIS (European Nature Information System)

The on-line expandable hierarchy was used as a guide to characterize all levels in the EUNIS classification scheme. Data sources, habitat attributes and data needs are summarized in Table 3. Level 1 is defined within EUNIS to distinguish the marine environment from terrestrial and freshwater habitats, therefore Long Island Sound and all sites within its bounds are characterized as "marine" by definition. Level 2 details broad habitat divisions and was classified as sublittoral, infralittoral, or circalittoral based on depth, i.e. 1 m bathymetric contours. Level 3 describes the habitat complex (sediment type) and was characterized based on the distribution of surface sediments. Level 4 details the biotope complex, or groups of biotopes with similar overall biologic and physical character. Biotope complexes were characterized based on the categories provided by the expandable hierarchy, which were appeared to be a more detailed description of the habitat complex. For example, a habitat complex characterized as sublittoral sediment might be further classified as circalittoral sandy mud at the biotope complex level. Level 5 is defined as the biotope level to differentiate among dominant species or dominant species groups. Characterization of biotopes was based on dominant species and dominant species groups in the Reid et al. (1979) and Pellegrino and Hubbard (1983) datasets. The sub-biotope (Level 6) is defined on the basis of less obvious species. In examination of the expandable hierarchy, sub-biotope levels were not often characterized though less obvious or rare species are often present within an area.

Sub-biotopes are not mapped for the purpose of illustrating a caveat in application of the EUNIS classification scheme. Sub-biotopes could easily be classified as other species present in the grab sample, i.e. those that were least abundant numerically.

Comparative Results

The fundamental approach to classifying seafloor habitat in all three classification schemes is to use seafloor topography and substrate type as primary habitat attributes. The diversity of habitats recognized and classified in the test sites (Figures 2.2-2.7) were dependent upon the physical and biological heterogeneity of the seafloor, as well as the organization and definition of the levels within each scheme. Similar information for classifying habitat was often used at multiple levels across the three classification schemes. For example, Green et al. (1999) classified depth of the habitat at the broad-scale 2nd level (subsystem, Figures 2.2 and 2.5), while Valentine et al. (2005) classified depth at the broad-scale 1st level under Theme 1, Class 1: Topographical Setting (subclass, Figures 2.3 and 2.6), and the EUNIS system indirectly classifies depth at either levels 3 or 4 by requiring the user to distinguish between intertidal and subtidal habitats (habitat and biotope complexes; Figures 2.4 and 2.7).

The same sites are classified differently across schemes based on the definitions of habitat descriptors. For example, Greene et al. (1999) define Branford as a shallow subtidal habitat based on the 0 – 30 m water shallow subtidal definition (Figure 2.2). Valentine et al. (2005) define Branford as deep aphotic based on the absence of macrophytic algae (Figure 2.3). The EUNIS system also defines Branford as a “deep circalittoral” habitat, or one that lies below the mean low water mark (Figure 2.4).

In addition to the discrepancy among definitions of habitat descriptors, some schemes incorporate the capacity to characterize habitat attributes that others do not. For example, Greene et al. (1999) contains modifiers to describe chemical processes, while Valentine et al. (2005) and EUNIS do not characterize any attributes related to chemical processes, whether naturally occurring or from anthropogenic impacts. Likewise, Greene et al. (1999) and Valentine et al. (2005) incorporate anthropogenic processes and impacts, while EUNIS ignores such effects on seafloor habitats.

Data sets such as Reid et al. (1979) and Pellegrino and Hubbard (1983) allowed us to test the sensitivity of classification approaches by correlating the distribution of habitat types with biological characteristics such as community composition, benthic species diversity, taxon specific distributions, and physical characteristics such as sedimentary environment, sediment types, and grain size distribution. Most biological data sets were spatially limited within test sites. As a result, such tests could not be conducted for all levels at every site. For example, Phi values were not available for the data points from Pellegrino and Hubbard (1983) that fell within the bounds of the Branford site. In an attempt to characterize seabed grain size under Theme 4, a general sediment description was used in place of the Phi values. Despite this caveat, results gave us an indication of the utility of each scheme.

The Greene et al. (1999) scheme was the most effective in providing a clear hierarchy for organizing and displaying both large- and fine-scale habitat classes, but lacked sufficient detail in bottom texture attributes at the finer scale. If adopted, this scheme would need to be modified to encompass the detail required to differentiate habitats at relevant levels.

The Valentine et al. (2005) scheme is the most complex, with a relatively large number and variety of independent themes. Some of the levels across themes are duplicative and provide more than one way to classify the available data. For example, general sediment descriptions and grain sizes were used for characterizing seabed texture, hardness, and layering in Theme 3, and seabed grain size analysis in Theme 4. This makes the scheme relatively complicated in application such that use of different survey approaches are used across themes at multiple levels, allowing for incomplete themes and levels when survey information is limited. In contrast to Green et al. (1999) that classifies biological attributes in a top down manner (i.e., entering the hierarchy at the system level), Valentine et al. (2005) employs what can be considered as a bottom-up approach whereby the biological data are first described in a distinct theme and results are placed in a broader context of major seabed features.

The EUNIS scheme places a great deal of emphasis on sediment type and little on large-scale features. This approach is complex and is not inclusive of all habitats that are found in LIS and at particular levels, does not include any habitats that are in LIS. Such caveats result in multiple levels within the hierarchy being classified in the same exact way, i.e. Level 2 (broad habitat type) and Level 3 (habitat complex) are both classified as sublittoral sediment (Figure 2.4). While the scheme does provide some level of detail for biological communities, it reflects those from the Northeastern Atlantic to the Mediterranean and not the Northwest Atlantic. If adopted this scheme would need to be altered to represent the LIS region. As it is designed, it is not easily adaptable for application outside of the current region of use and ignores other processes that have been identified as relevant to classification by users.

Table 2.1. Results from testing the scheme developed by Greene et al. 1999.

	System	Subsystem	Class	Subclass		Modifiers						
				Substrate	Slope	Bottom Morphology	Bottom Deposition	Bottom Texture	Physical Processes	Chemical Processes	Biological Processes	Anthro-pogenic Processes
Data Used to Test the Scheme	Marine Benthic by definition	1m Bathymetry	SSS; Multibeam	Distribution of Surface Sediments	1m Bathymetry ; Multibeam	SSS; Multibeam;	Sedimentary Environment	SSS; Multibeam; TRI	N/A	Total Organic Carbon; Metals	Reid et al. 1979; Pellegrino and Hubbard; Trawl Survey; Shellfish areas; Franz samples; McCall samples; Sanders samples; Clostridium data; Benthic foram data	N/A
Attributes of Seafloor Habitats Identified by User Survey		Depth Zone	Geo-morphic Feature (Large Scale)	Sediment Type		Geomorphic Feature (Small Scale)	Disturbance Regime		Disturbance Regime	Organic Carbon	Biologic Features; Habitat-forming Species, Dominant Species, Dominant Species Groups, Community Types, Key Species, Key managed Species	

Data Needs Revealed from Protocol Testing									Physiographic data describing wave activity (whether it be storm or tidal)			Presence absence of structures such as artificial reefs, sediment caps, “ghost” fishing gear; SSS records of past/current trawl or dredge marks, and lobster pots

Table 2.2. Results from testing the scheme developed by Valentine et al. 2005.

	Theme 1: **Topographical Setting**	**Theme 2:** **Seabed Dynamics and Currents**	**Theme 3:** **Seabed Texture, Hardness, and Layering in Upper 5-10 cm**	**Theme 4:** **Seabed Grain Size Analysis**	**Theme 5:** **Seabed Roughness**	**Theme 6:** **Faunal Group**	**Theme 7:** **Habitat Association and Usage**	**Theme 8:** **Habitat Recovery from Disturbance**
	Subclass: **Shallow/Deep Aphotic Zone**	**Subclass:** **Mobile or Immobile Substrates**	**Subclass:** **Coarse, Fine, or Hard Seabed**	**Subclass:** **General Sediment Description, phi, or Wentworth size classes**	**Subclass:** **Bedforms / Physical Structures**	**Subclass:** **Based on Method of Observation**	**Subclass:** **Faunal Habitat Association or Human Usage**	**Subclass:** **Fishing / Natural Disturbance**
Data Used to Test the Scheme	Presence/absence of macroalgae – can be inferred from depth (bathymetry) or taken from eelgrass surveys	Sedimentary Environment	Distribution of Surface Sediments	Taken from Reid et al. 1979 for corresponding point	Multibeam and SSS	Metadata (see methods: grab sample, video, etc.) from Reid et al. 1979, Pellegrino and Hubbard, Trawl Data, etc.	Unknown / not available for many data points tested. An example would be EFH designation.	Not available.

Attributes of Seafloor Habitats Identified by User Survey	Depth Zone	Sediment Type	Sediment Type	Sediment Type	Geomorphic Structure (Small Scale)	Biologic Features; Community Types; Habitat-forming Species	Biologic Features	Disturbance Regime
Data Needs Revealed from Protocol Testing							Scientific literature, designation by regulatory agencies	Type of disturbance – natural or anthropogenic (from physiographic data; SSS records of human disturbance; visual observations)
	Category: **Major Physiographic Features**	**Category:** **Currents Causing Sediment Mobility**	**Category:** **Descriptive Sediment**	**Category:** **Grain Size Distribution**	**Category:** **Bedform Types**	**Category:** **Taxonomic Group or Species**	**Category:** **Species**	**Category:** **Recovery of Physical and Biological Structures**
Data Used to Test the Scheme	Multibeam data/location	Data not available but can hypothesize tidal and storm waves from general knowledge	Distribution of Surface Sediments	Distribution of Surface Sediments	Multibeam and SSS	To be determined by user from data mentioned above.	From data if available.	Not available.
Attributes of Seafloor Habitats Identified by User Survey	Geomorphic features (Large Scale)	Disturbance Regime	Sediment Type	Sediment Type	Geomorphic Structure (Small Scale)	Dominant Species; Dominant Species Groups; Key Species; Key Managed Species	Habitat-forming Species; Community Type; Dominant Species; Dominant Species Groups; Key Species; Key Managed Species	

Data Needs Revealed from Protocol Testing		Physiographic Data of wave activity						Recovery of bedforms, attached epifauna, fish burrows, etc. most likely found in past studies, primary scientific literature, and reports.
	Attributes: **Angle of Seabed Slope & Types of Seabed Features**	**Attributes:** **Strength of Currents/Frequency of Events**	**Attributes:** **Percent of Seabed Covered by Sediment Type**	**Attributes:** **Degree of Sorting**	**Attributes:** **Percent of Seabed Covered by Bedform Type**	**Attributes:** **Presence/Absence or Percentage**	**Attributes:** **Type of association.**	**Attributes:** **Time Required for Recovery**
Data Used to Test the Scheme	Bathymetry; Multibeam	Data not available. If tidal, we know it is semidiurnal.	This is interpreted by the user. Here we are testing points rather than continuous coverage.	Taken from Reid et al. 1979 for corresponding point.	This is interpreted by the user. Here we are testing points rather than continuous data.	This is interpreted by the user from the available data.	Not available. An example would be spawning grounds.	Not available.
Attributes of Seafloor Habitats Identified by User Survey	Geomorphic Features (Small Scale)	Disturbance Regime				Visual observations and or samples from videos / photos		
Data Needs Revealed from Protocol Testing		Magnitude and temporal variability in wave activity.				Visual observations and/or samples from videos / photos	Visual observations and/or samples from videos / photos	Time required for recovery from primary scientific literature, reports, etc.

Table 2.3. Results from testing the EUNIS Classification System.

	Level 1: Environment	**Level 2: Broad Habitat Type**	**Level 3: Habitat Complexes**	**Level 4: Biotope Complexes**	**Level 5: Biotopes**	**Level 6: Sub-biotopes**
Data Used to Test the Scheme	As dictated by EUNIS – Marine or Coastal depending on how one views LIS (as a body of water separate or included in the Atlantic Ocean)	As dictated by EUNIS and confirmed by bathymetry data	Distribution of Surface Sediments	As dictated by EUNIS	From any faunal/floral data set: Reid et al. 1979, Eelgrass surveys, LIS Trawl Survey Data	From faunal/floral data sets.
Attributes of Seafloor Habitats Identified by User Survey		Depth Zone; Geomorphic Feature	Sediment Type	Biologic Features on Sediment Type; Habitat-forming Species	Community Type; Dominant Species Groups; Dominant Species; Key Species; Key Managed Species	
Data Needs Revealed from Protocol Testing						

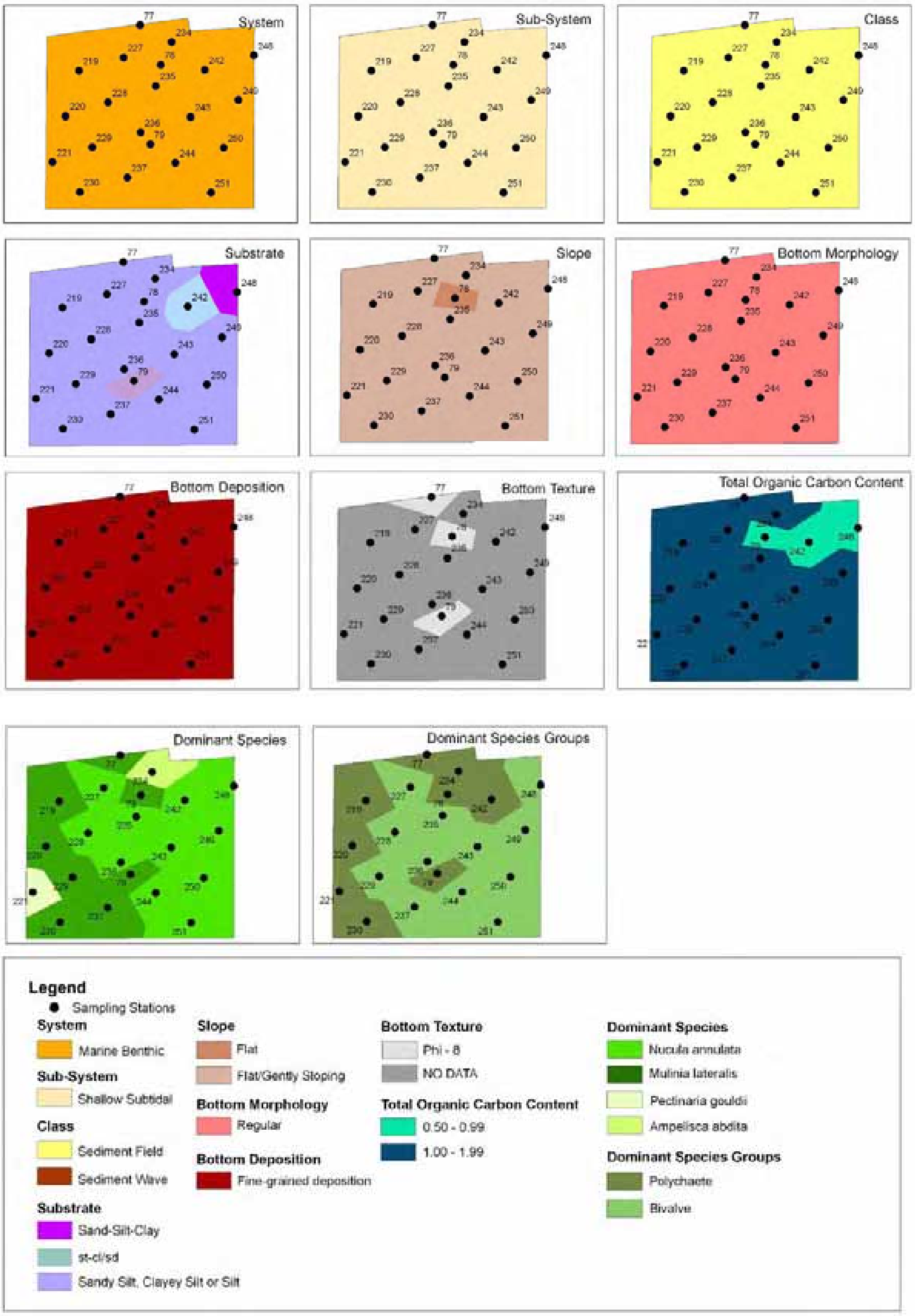
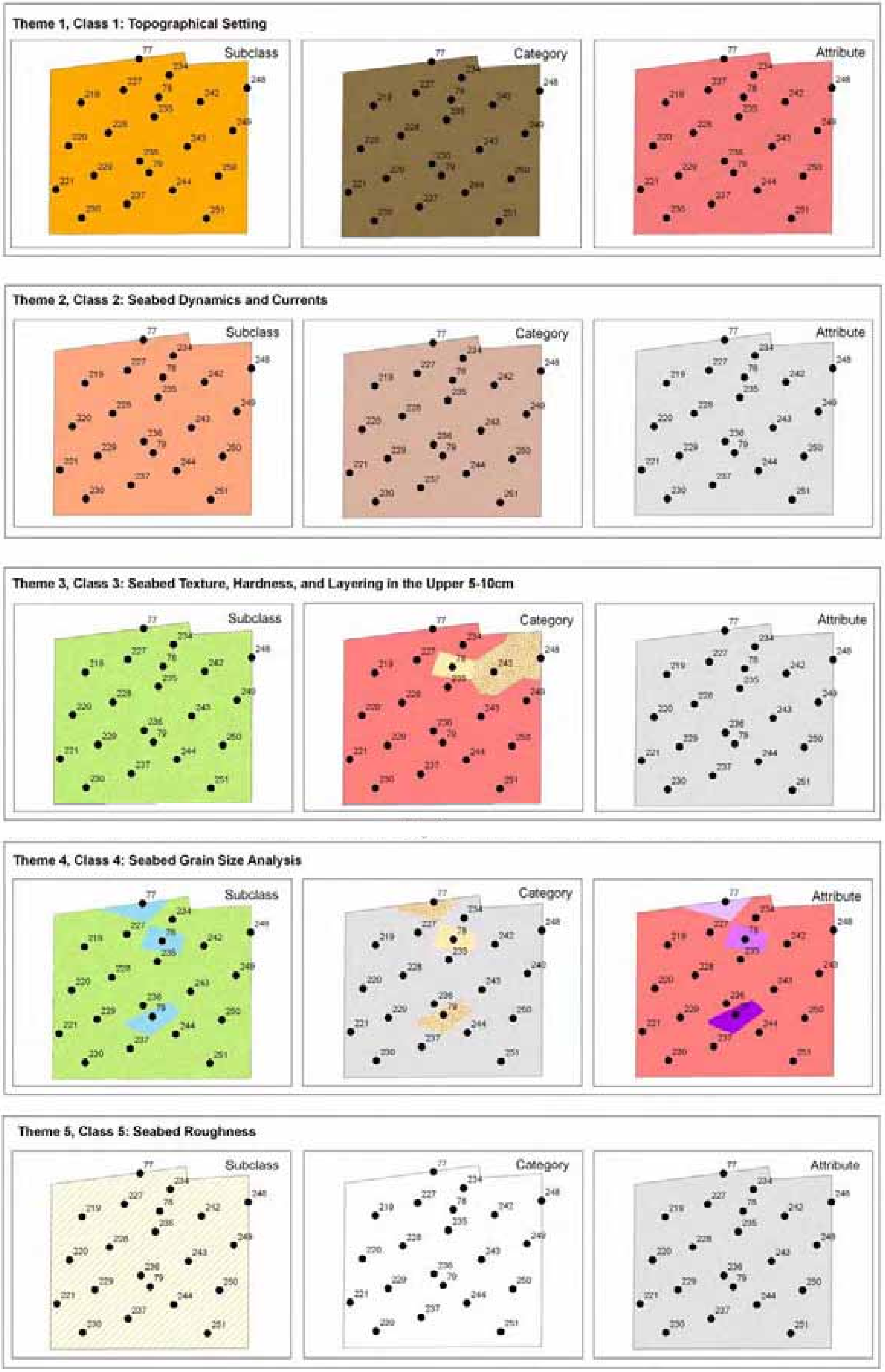


Figure 2.2. Branford site based on Greene et al. classification.


Theme 1, Class 1: Topographical Setting
Subclass
Category
Attribute
Theme 2, Class 2: Seabed Dynamics and Currents
Subclass
Category
Attribute
Theme 3, Class 3: Seabed Texture, Hardness, and Layering in the Upper 5-10cm
Subclass
Category
Attribute
Theme 4, Class 4: Seabed Grain Size Analysis
Subclass
Category
Attribute
Theme 5, Class 5: Seabed Roughness
Subclass
Category
Attribute

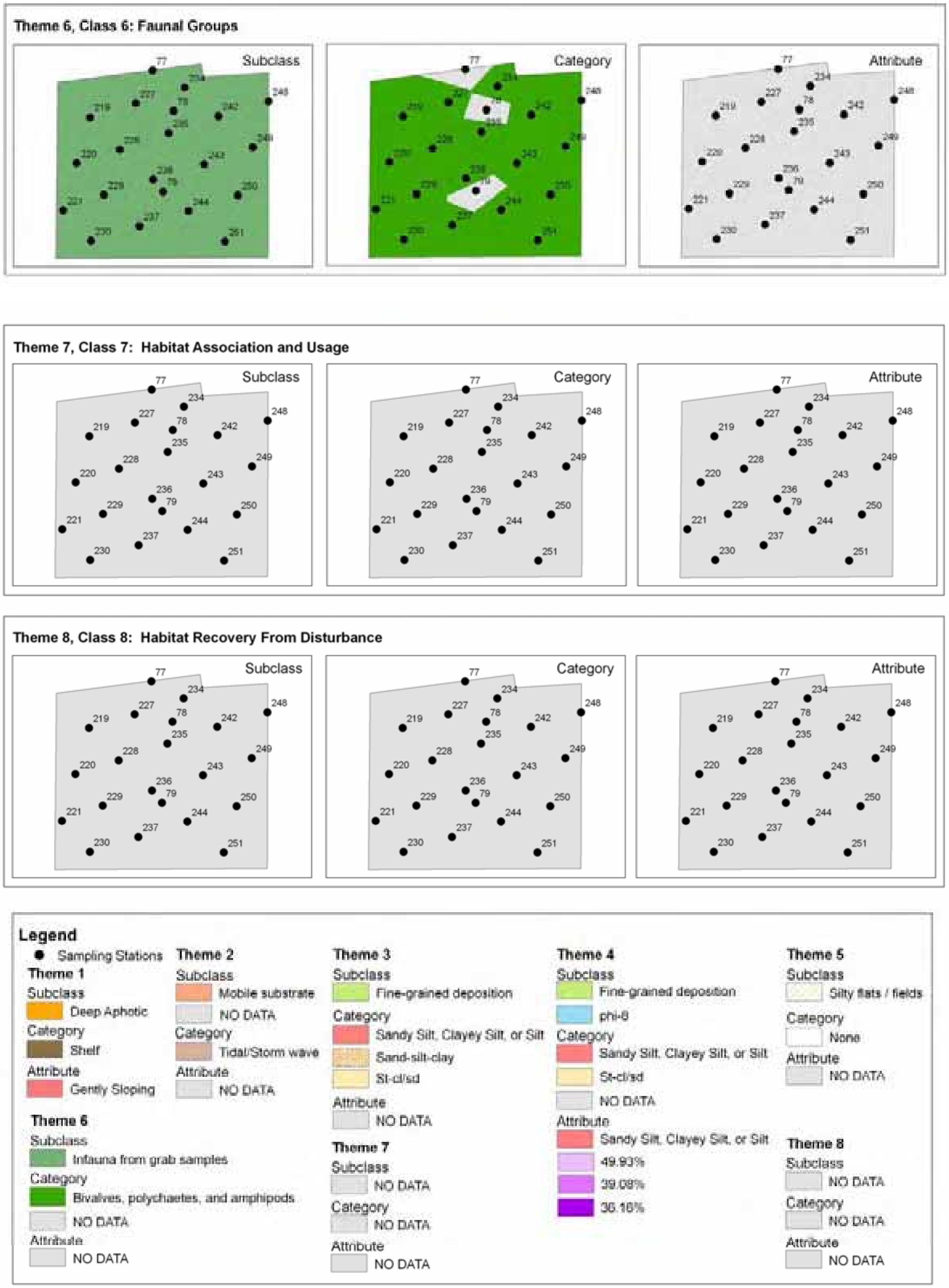


Figure 2.3. Branford site based on Valentine classification.

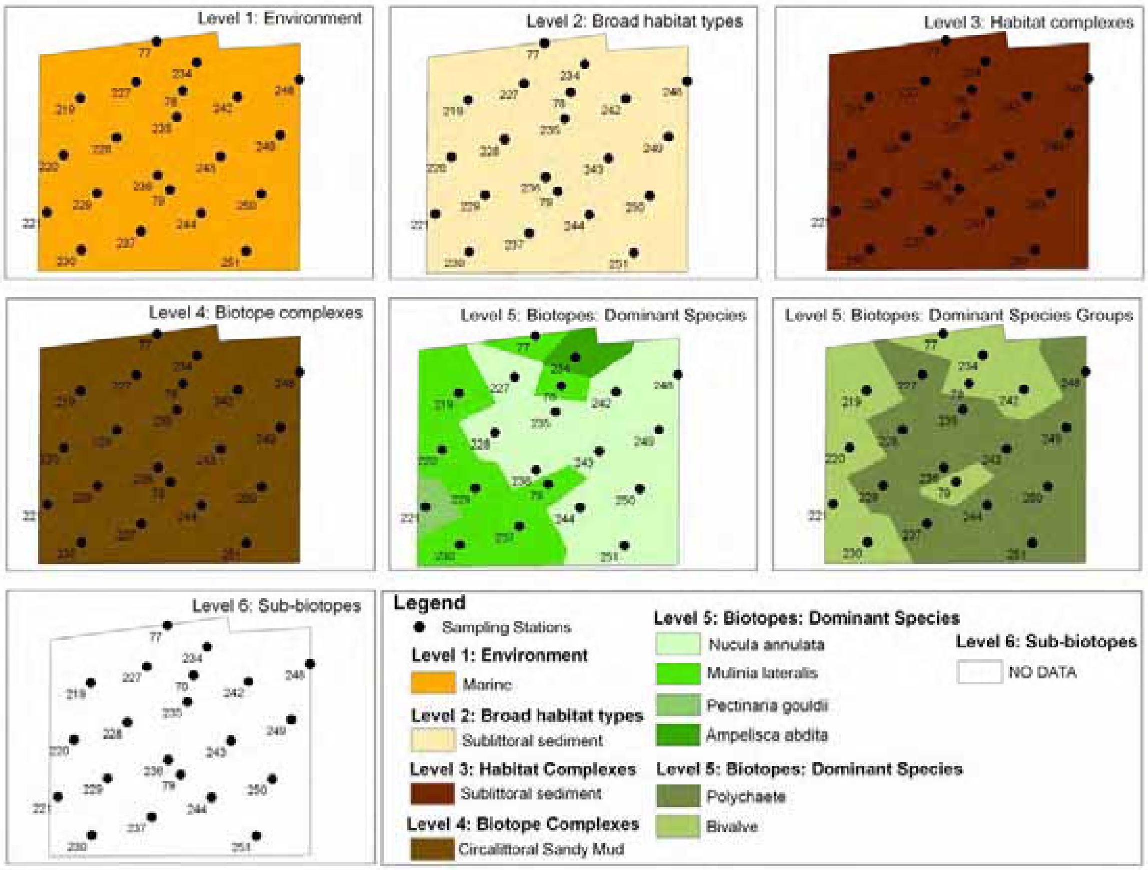


Figure 2.4. Branford site based on EUNIS classification.

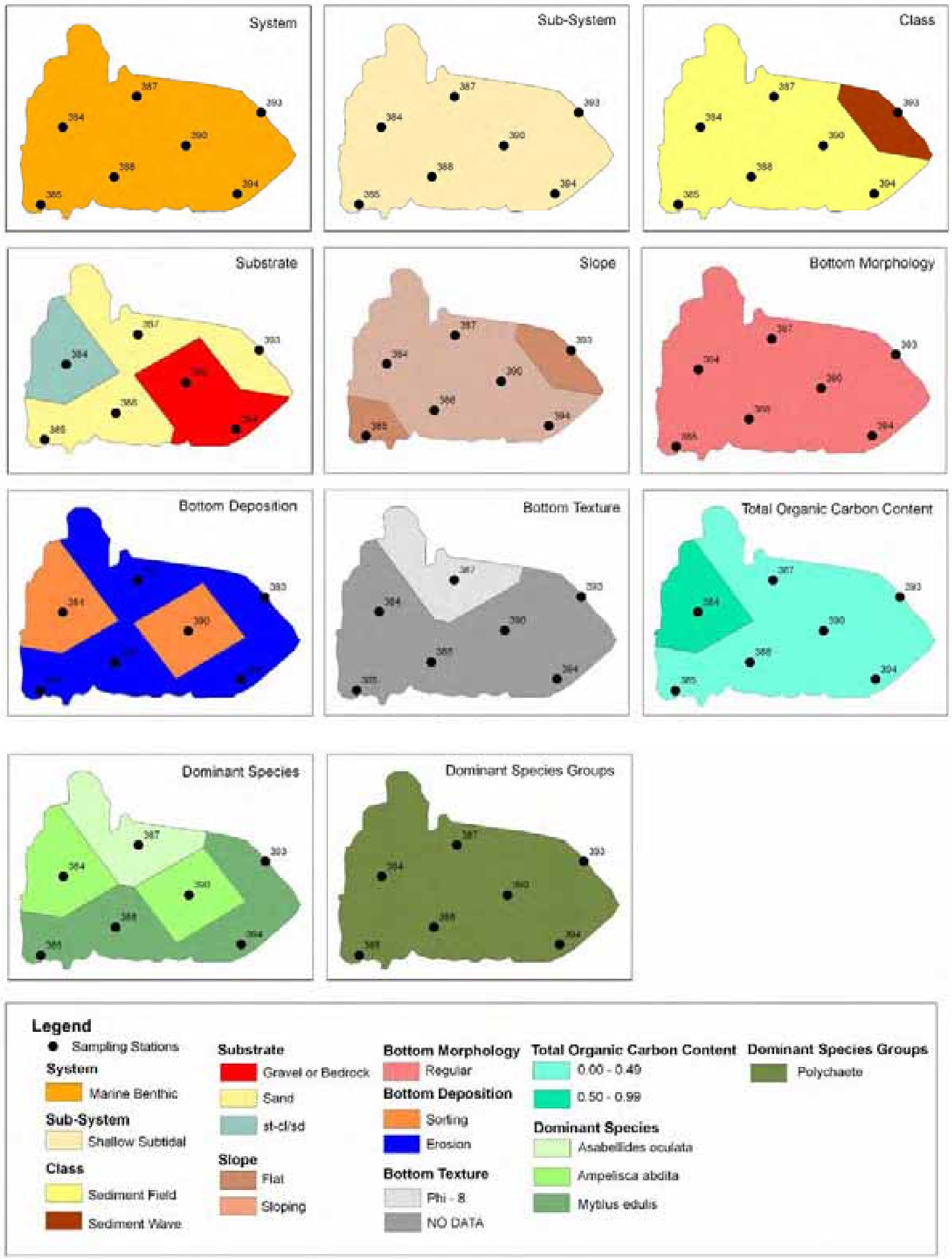
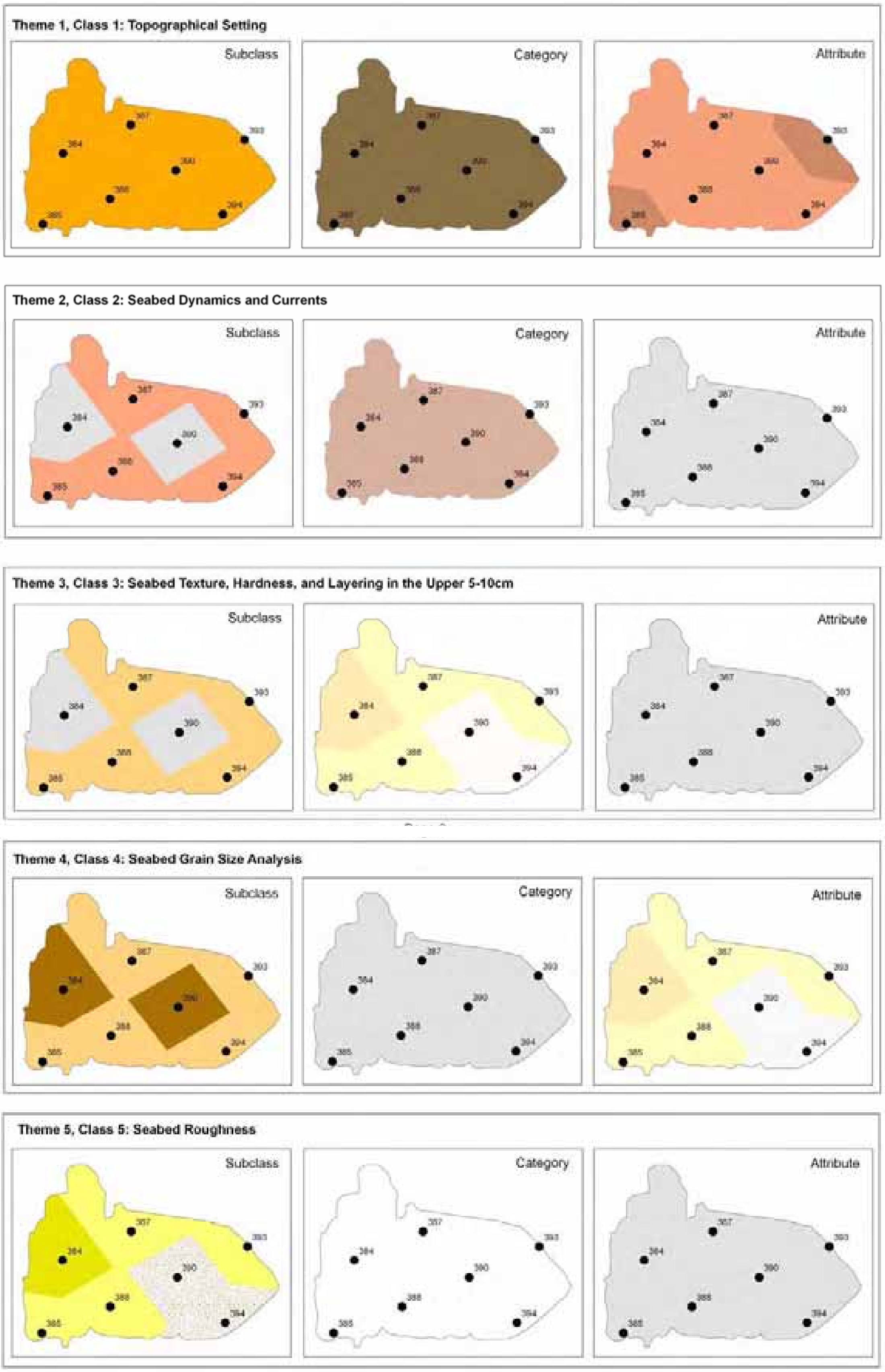


Figure 2.5. Niantic site based on Greene et al classification.


Theme 1, Class 1: Topographical Setting
Subclass
Category
Attribute
Theme 2, Class 2: Seabed Dynamics and Currents
Subclass
Category
Attribute
Theme 3, Class 3: Seabed Texture, Hardness, and Layering in the Upper 5-10cm
Subclass
Attribute
Theme 4, Class 4: Seabed Grain Size Analysis
Subclass
Category
Attribute
Theme 5, Class 5: Seabed Roughness
Subclass
Category
Attribute

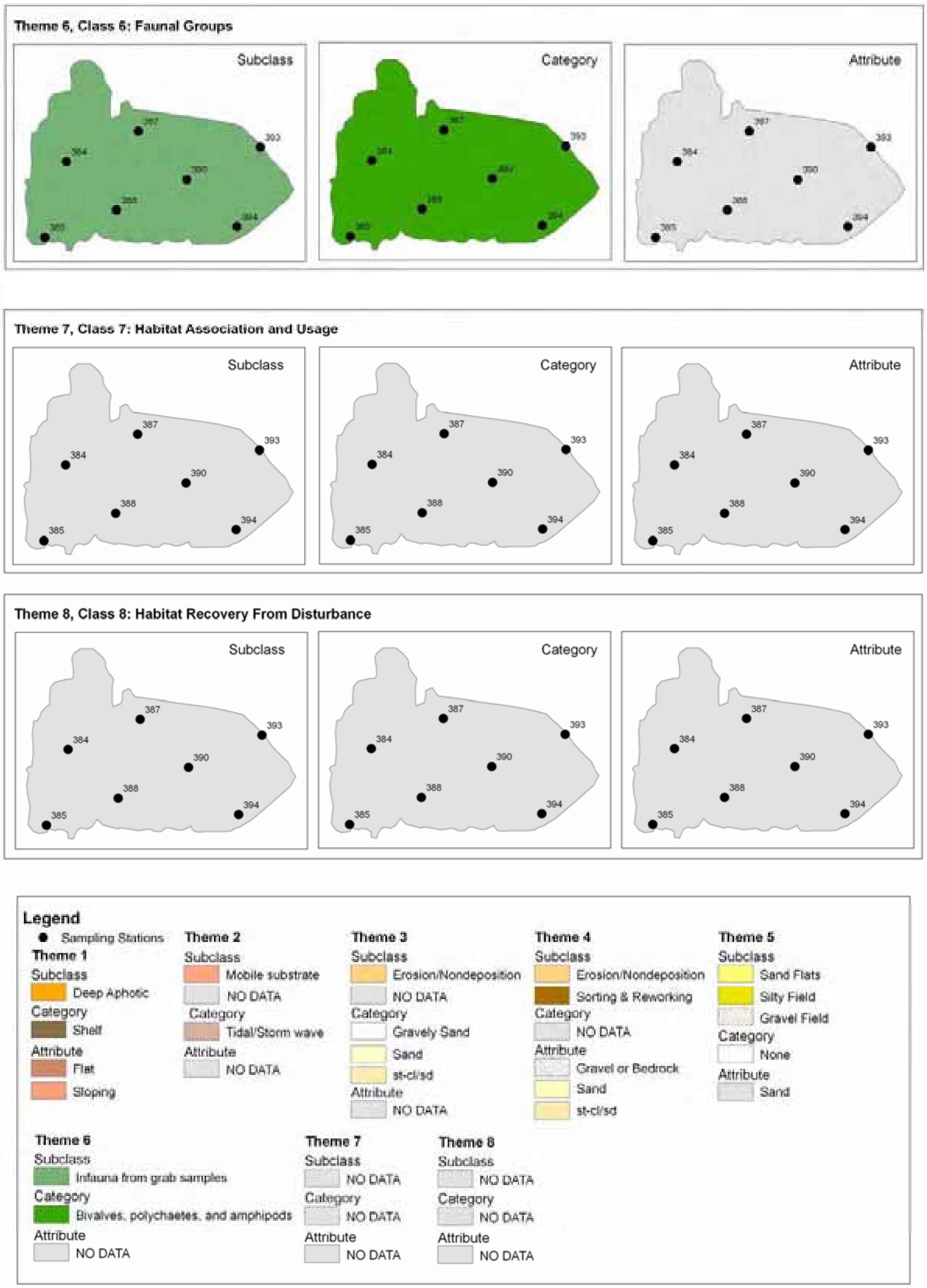


Figure 2.6. Niantic site using Valentine et al. classification.

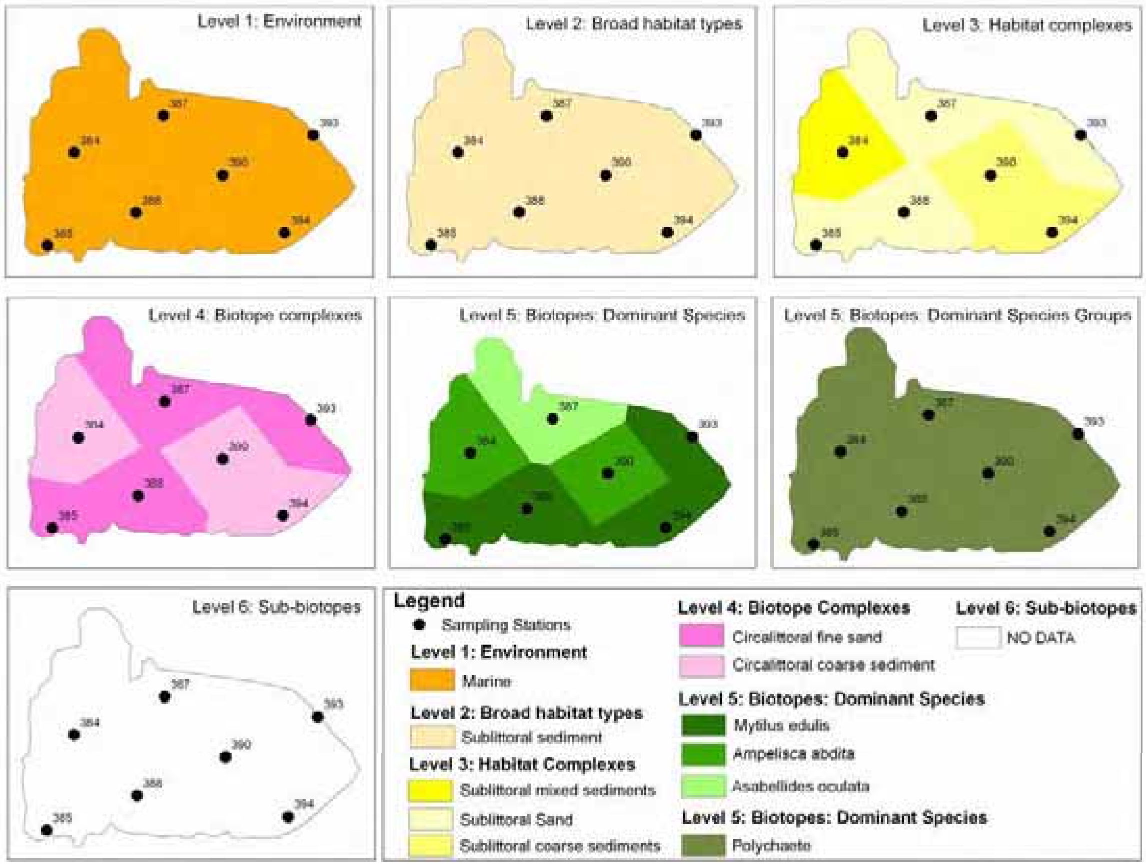


Figure 2.7. Niantic site based on EUNIS classification.

Appendix 3. Long Island Sound Seascapes

Defining the spatial boundaries in which matrices of "habitats" are nested, requires the delineation of regional or seascape boundaries. Seascapes are spatially bounded regions or subregions in which habitat patches are embedded and have similar conditions within a seascape unit but demonstrably different conditions between seascape units. (In the following section on existing classification schemes, seascapes could be considered as "system", "topographic setting" or "environment" level attributes of a classification scheme.) Delineation of seascapes can be based on bathymetry (e.g., boundaries between basins), sedimentary environments (e.g., based on depositional or erosional processes), and threshold values for oceanographic conditions along east-west estuarine gradients (e.g., areas with consistently steep salinity or productivity gradients) that can produce significant shifts in community composition or patterns of species dominance. Identifying the geospatial boundaries where such shifts occur can define environmental landscape units within which habitats can be considered unique and classified accordingly. For example, if seascape units are classified at the scale of the major basins of Long Island Sound (Figure 3.1), then boulder reefs within eastern, central and western basins would each be considered unique habitats. That is, while the habitat "class" is the same, the environmental landscape in which reefs occur uniquely mediate community composition in ways that would make such reefs across the Sound region unequal. Monitoring programs could take such patterns into account when designing projects or analyzing data and gain new insights into pattern and process. Further, the permitting processes could take rarity or abundance of particular habitats within particular seascapes into account when assessing environmental effects of regulated activities. In order to determine seascape boundaries for LIS, we reviewed multiple published studies of invertebrate communities (e.g., Reid et al. 1979, Thomas et al. 2000, Zajac et al. 2000 and selected references therein), published data sets on invertebrate distribution (i.e., from Zajac 1998 that are based on Pellegrino and Hubbard 1983), and conducted additional analyses of unpublished data on fishes to determine if there were logical geospatial boundaries to divide Long Island Sound into multiple seascape units based on distributional responses of biological communities.

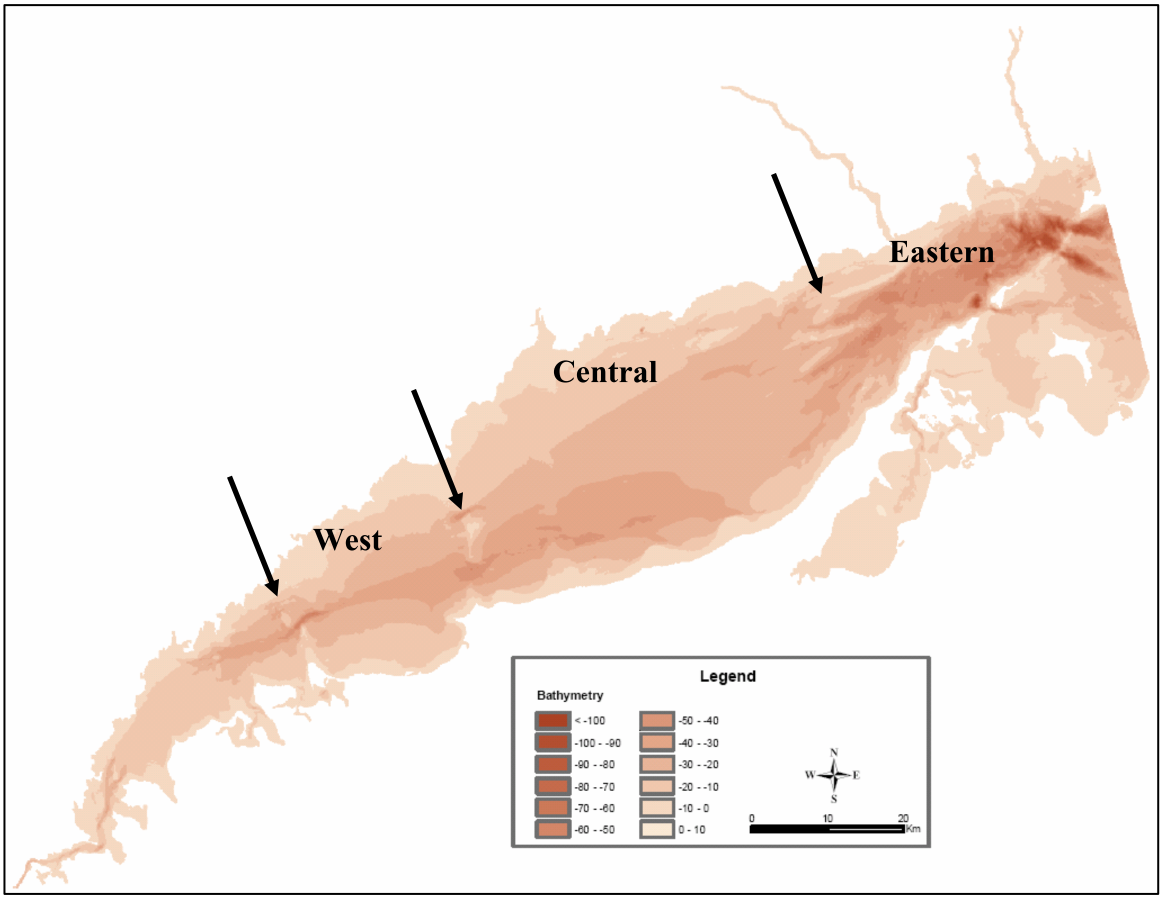


Figure 3.1. Bathymetry of Long Island Sound. Arrows indicate location of shoals and sills that delineate boundaries of west, central and eastern basins. There is also a topographic rise from the eastern basin into Fishers Island Sound.

Overall we found the responses of seafloor communities to the gradient of environmental variables across the east-west axis of LIS do not correspond consistently to specific geologic features (e.g., basins) that would indicate definitive seascape boundaries. For example, the distribution and boundaries of benthic invertebrate assemblages (i.e., amphipod, bivalve, polychaete, and the overall multi-species community) varied both across depth (i.e., north-south) as well as across the nominal east-west environmental gradient (Figure 3.2). Community groupings were associated with sediment type and environmental features at multiple scales (Zajac 1998, Zajac et al. 2000). While some communities were tightly bounded geographically within a specific region of LIS, other community types were more widely distributed.

The distribution of distinct fish assemblages within LIS exhibit patterns similar to the benthic fauna (Figure 3.3). Hierarchical clustering of fish community composition from spring and fall trawl survey data collected by the Connecticut Department of Environmental Protection from 1992 through 2002 yielded three distinct clusters in each season (P. Auster and D. Simpson, unpublished). While one assemblage group is generally associated with the central LIS region, the other groups are more widely distributed, indicating a high level of connectivity across the Sound.

East, central and western "basins" are generally delineated by topographic barriers (i.e., broad north-south shoals and sills; from west to east Hempstead Sill, Stratford Shoal Complex, Mattituck Sill respectively; Figure 3.4). However, connectivity of water masses between basins occurs at relatively deep depths (i.e., basins are not fully isolated) precluding significant barriers to dispersal and movement of many organisms (Figure 3.5).

While a search of distribution patterns of individual taxa revealed spatial concordance with geologic features, the lack of spatial correlation between major assemblage types and basin features leads to the conclusion that use of seascape units in which to nest habitat types within LIS is not a useful approach for classification or mapping. While strong east-west gradients in multiple attributes of the environment and biological communities clearly occur, we conclude there are no definitive east-west seascape boundaries that can be defined by physiographic features and that comport with broad and consistent discontinuities in the distribution of communities.
However, planning and management needs alone may provide the rationale for designating seascapes based solely on geomorphology (i.e., basins), allowing for a generalized spatial concordance with east-west environmental gradients. Figure 3.4 depicts spatial boundaries from The Narrows to the Eastern Basin and a bathymetric profile down the central axis of the Sound (based on Welsh 1993). The profile illustrates the general character of the major barriers between basins and may serve to designate generalized boundaries.

While there is little evidence to suggest that major geomorphic features limit the distribution of (at least) dominant organisms in LIS, there may be some utility in delineating seascapes based on large scale geomorphic features such as major basins. The major basins in LIS have a long history of use in developing and discussing management options and in predictive modeling for attributes such as water quality. While linear boundaries across the topographic highs between basins may have little meaning in an ecological sense, delineating transition zones between basins can incorporate the high level of environmental variability between basins that may be considered relatively homogeneous within. Figures 3.6 – 3.9 illustrate transition zones between major basins and features (e.g. Fisher's Island Sound) based on abrupt transitions in depth.

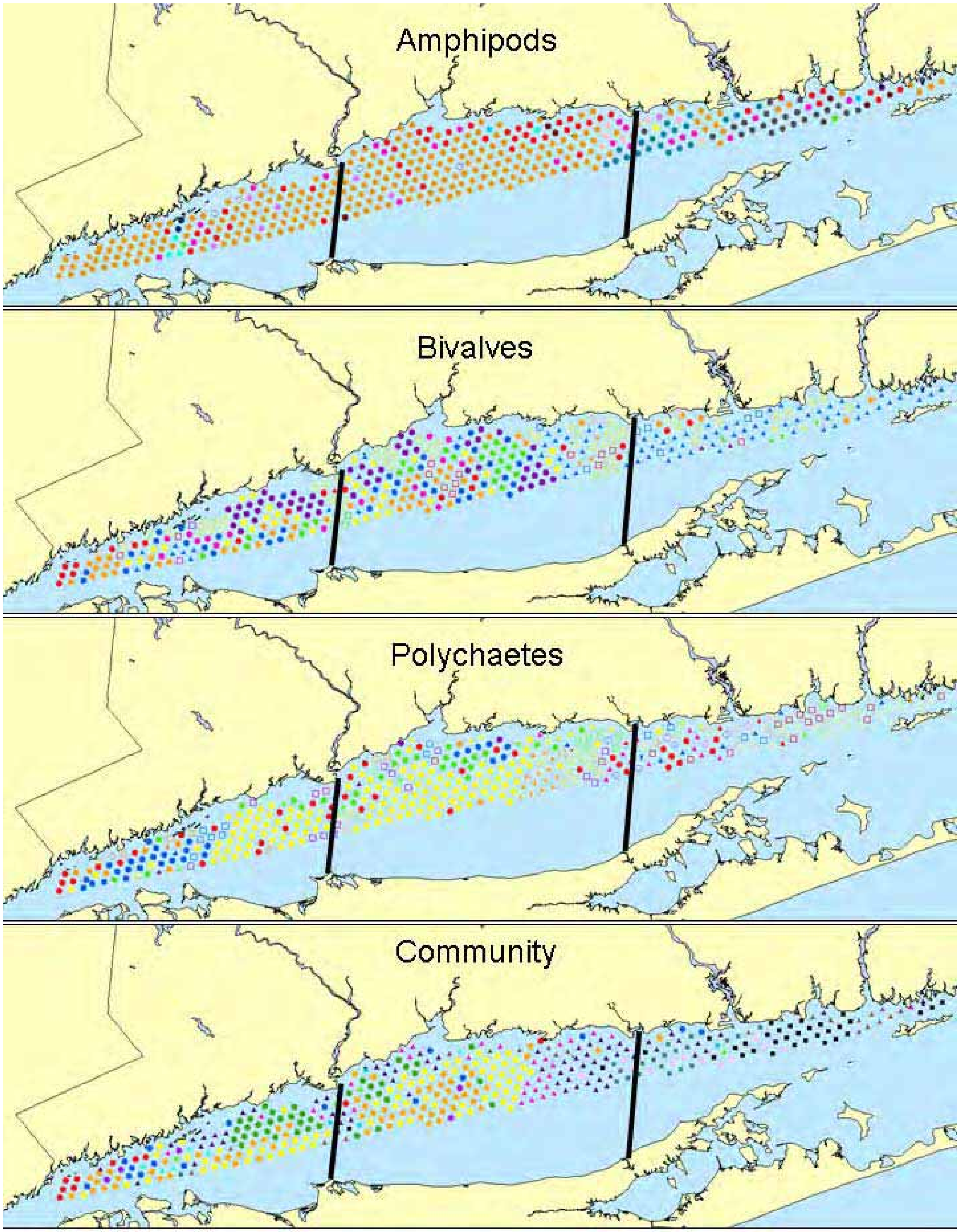


Figure 3.2. The spatial distribution of community types based on amphipod, bivalve, and polychaete faunas as well as distribution of the benthic community across all taxa (after Zajac 1998). The maps here simply illustrate the spatial variation in community types. Symbols within each map correspond to unique community compositions derived from cluster analysis (see Zajac 1998 for details of analysis and results).

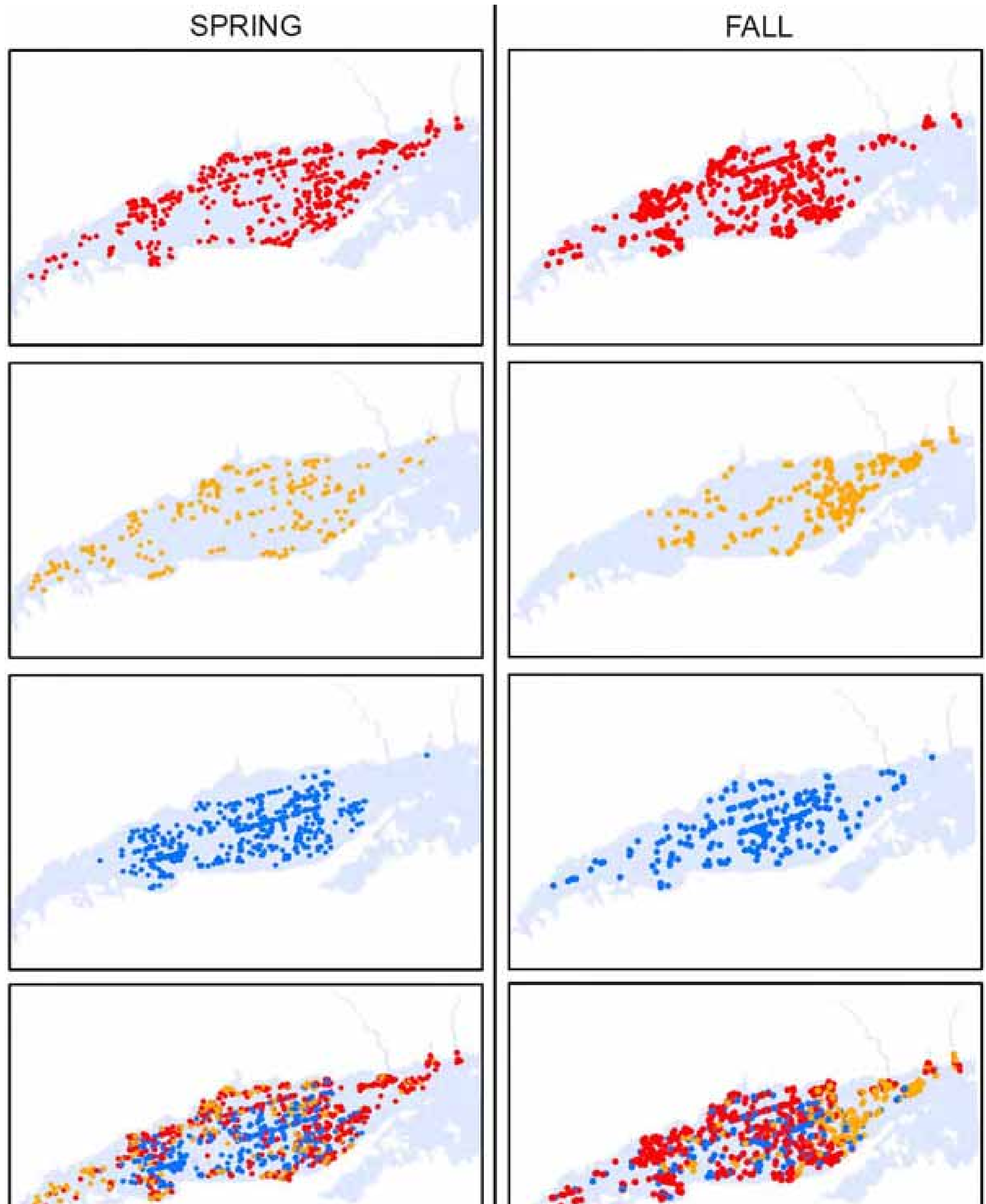


Figure 3.3. Distribution of fish assemblages in LIS based on hierarchical clustering of annual (1992-2002) spring and fall trawl survey samples. The top three panels illustrate distribution of each of three cluster groups by season. Bottom panel illustrate distribution of cluster groups combined.

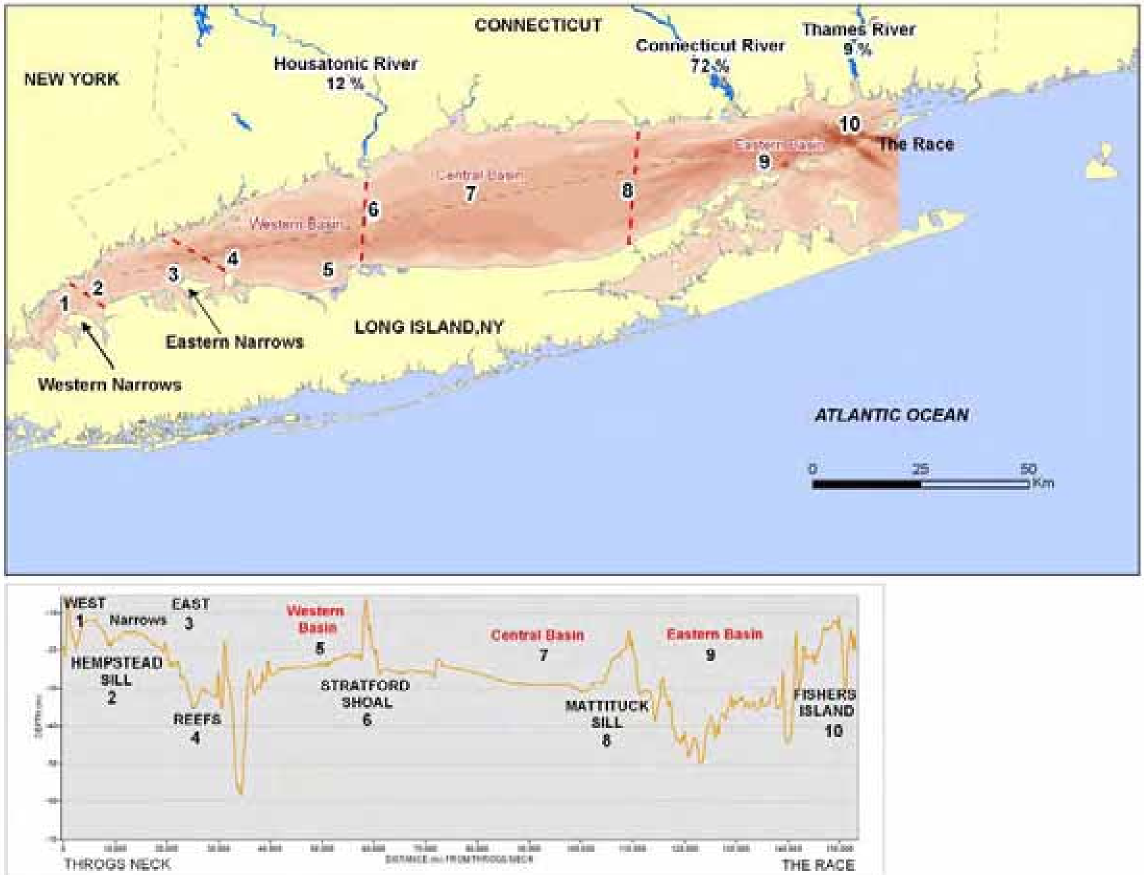


Figure 3.4. (Top) Generalized regions based on locations of geomorphic features in LIS. Major river inputs to LIS are also indicated. Numbers correspond to features in bottom panel. (Bottom) Depth profile through geomorphic features along the central west-east axis of Long Island Sound. (After Welsh 1993)

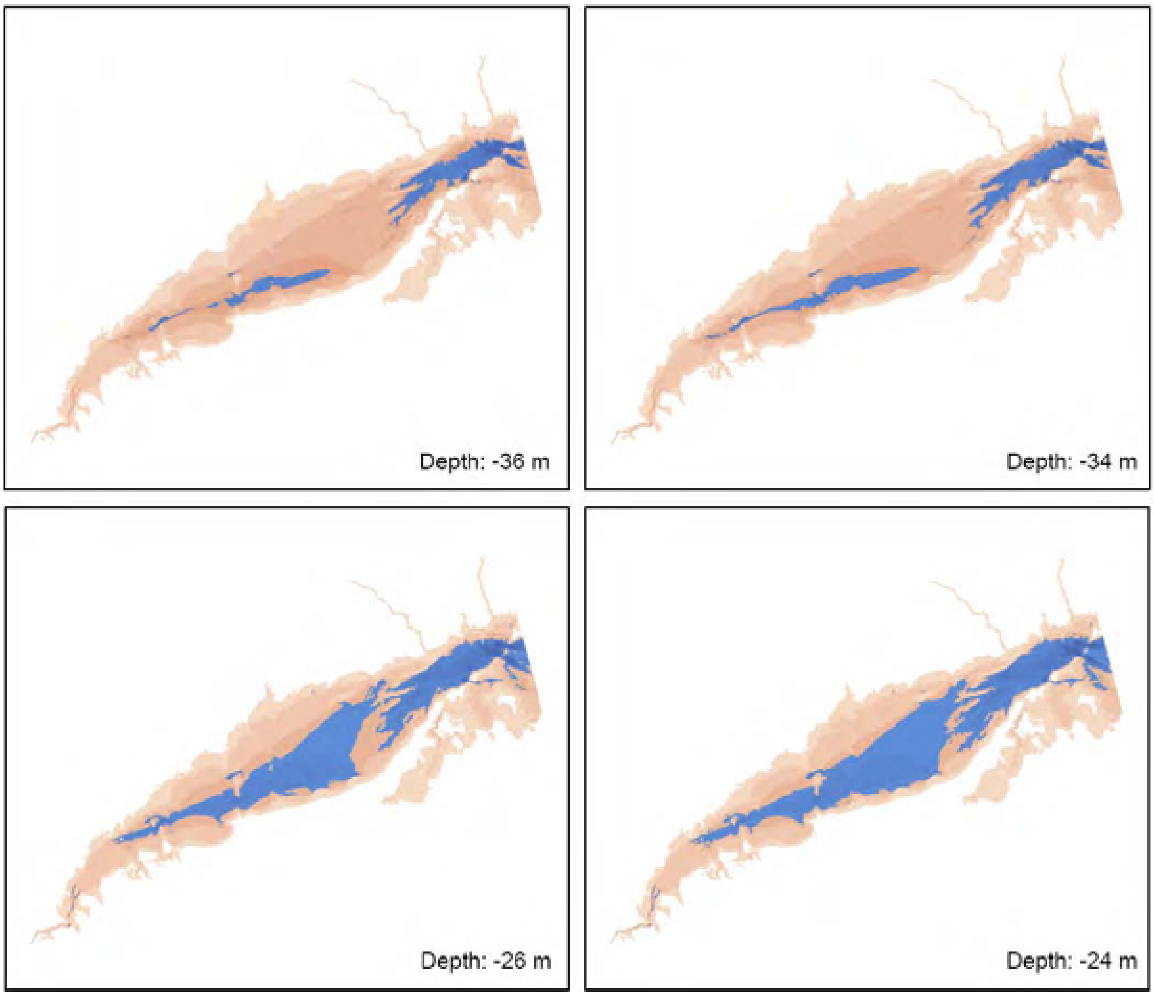


Figure 3.5. Maps that illustrate the spatial distribution of water filling the LIS basin. These were produced to illustrate the deepest depths at which water is exchanged between basins as a gross indicator of connectivity of organisms across the LIS region (depth below mean low water). The deepest depth at which water is exchanged between western and central basins is between 36 m and 34 m (top two panels) while the deepest depth for exchange of water between west-central and eastern basins is between 26 m and 24 m (bottom).

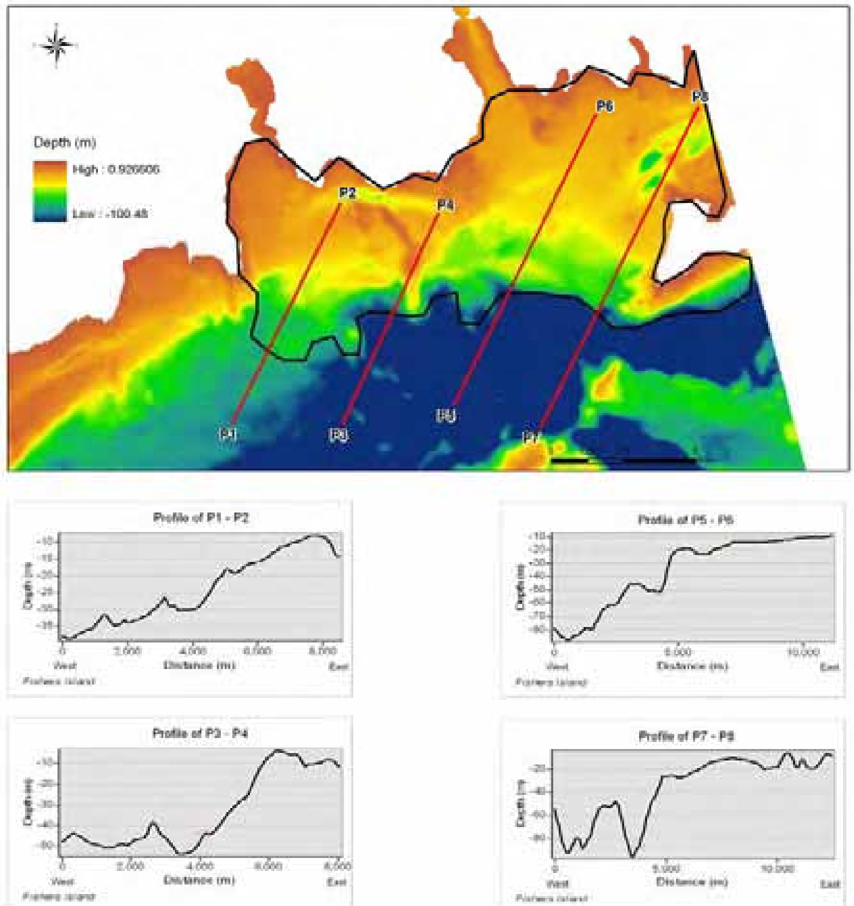


Figure 3.6. Transition zone (black line) between eastern basin and Fishers Island Sound based on rapid changes in bathymetry.

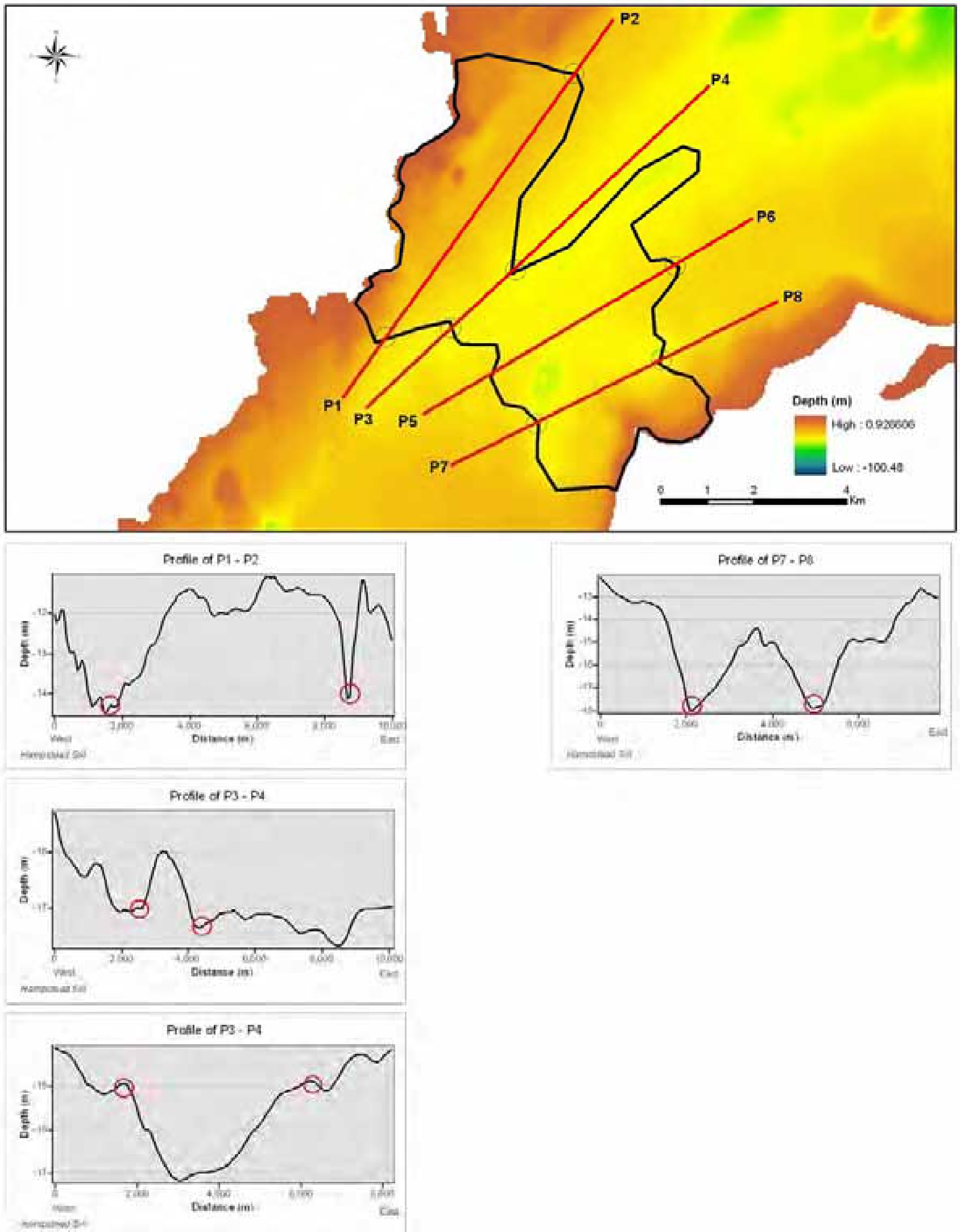


Figure 3.7. Transition zone over Hempstead Sill (black line) based on rapid changes in bathymetry.

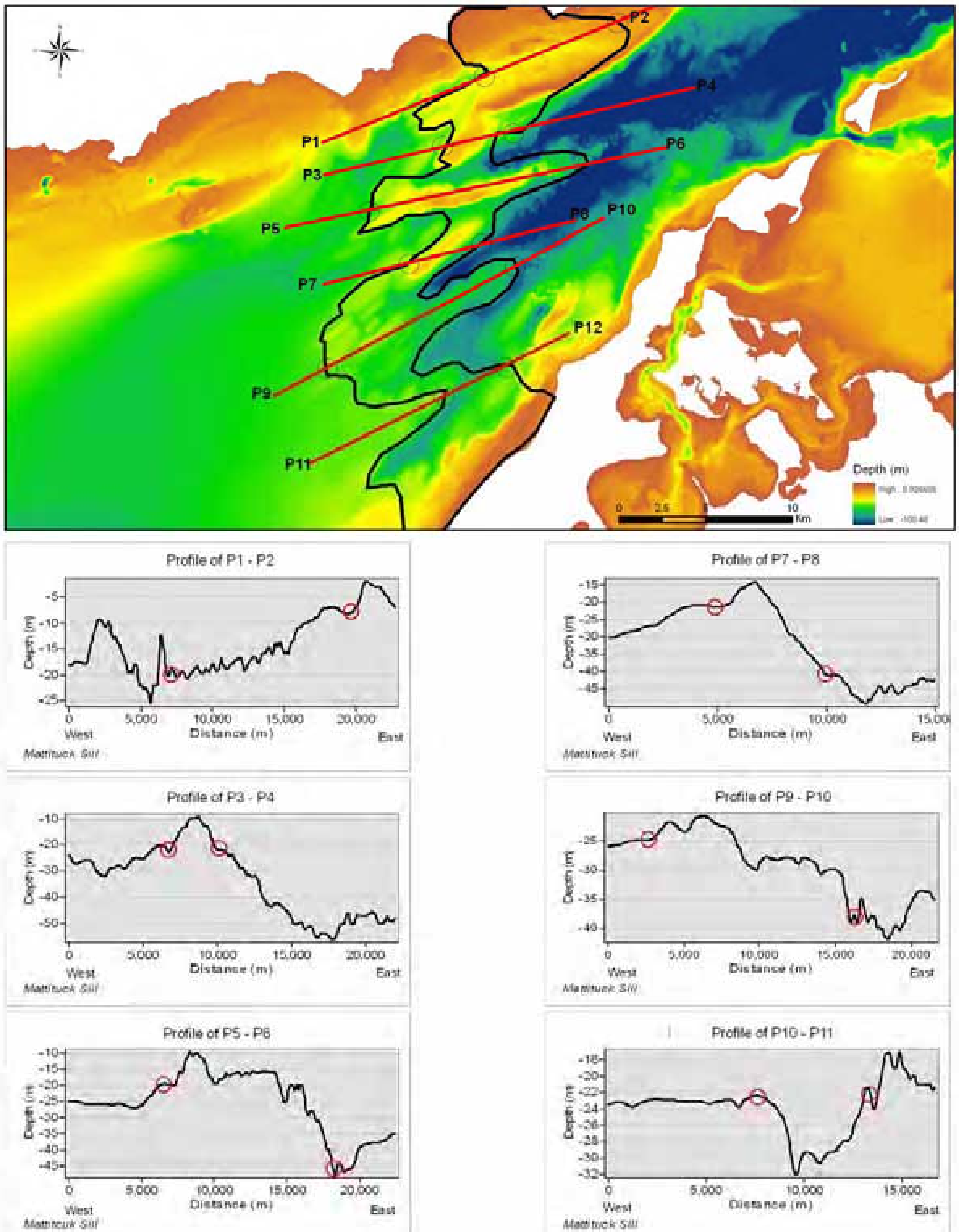


Figure 3.8. Transition zone over Mattituck Sill.

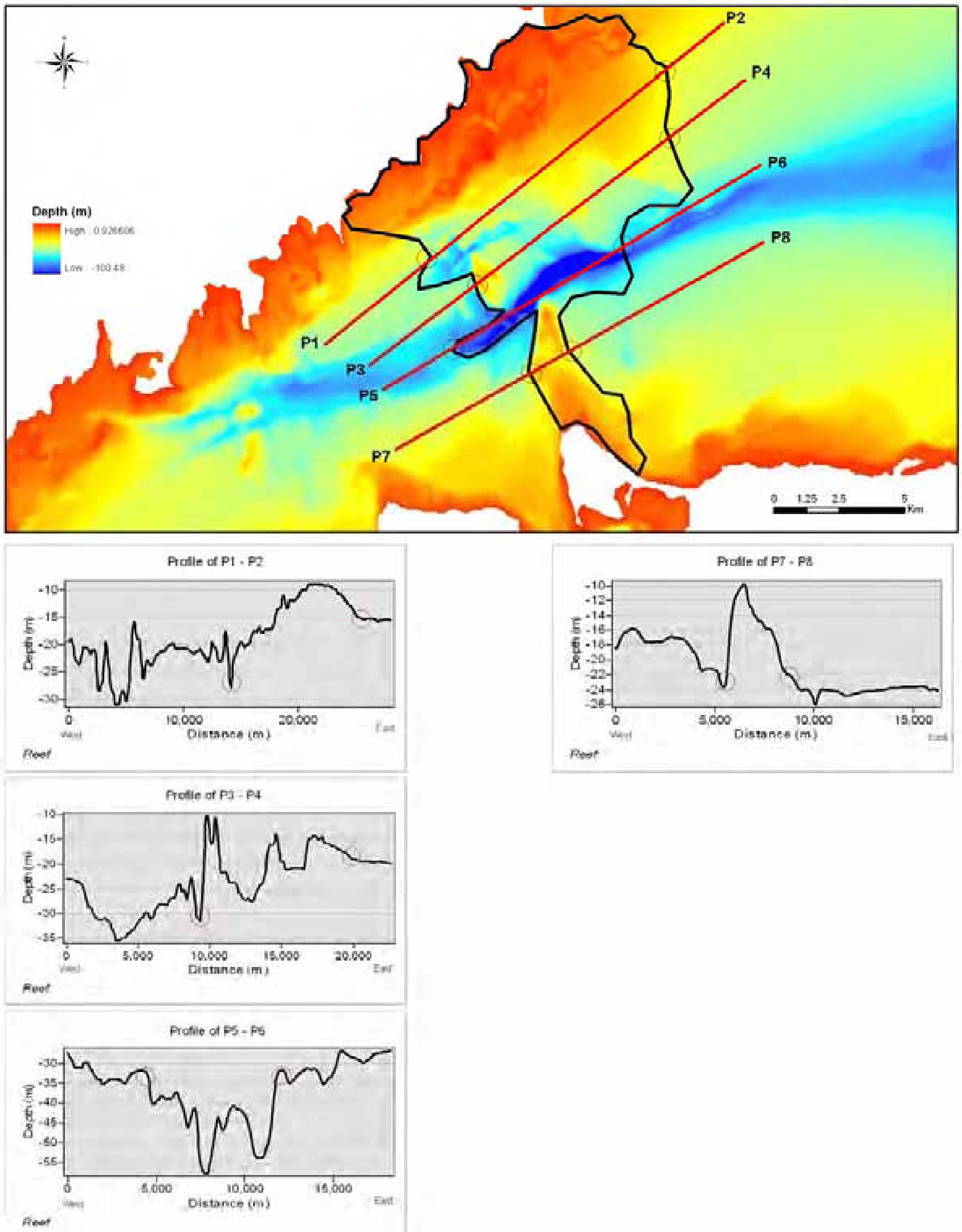


Figure 3.9. Transition zone over Reef region.

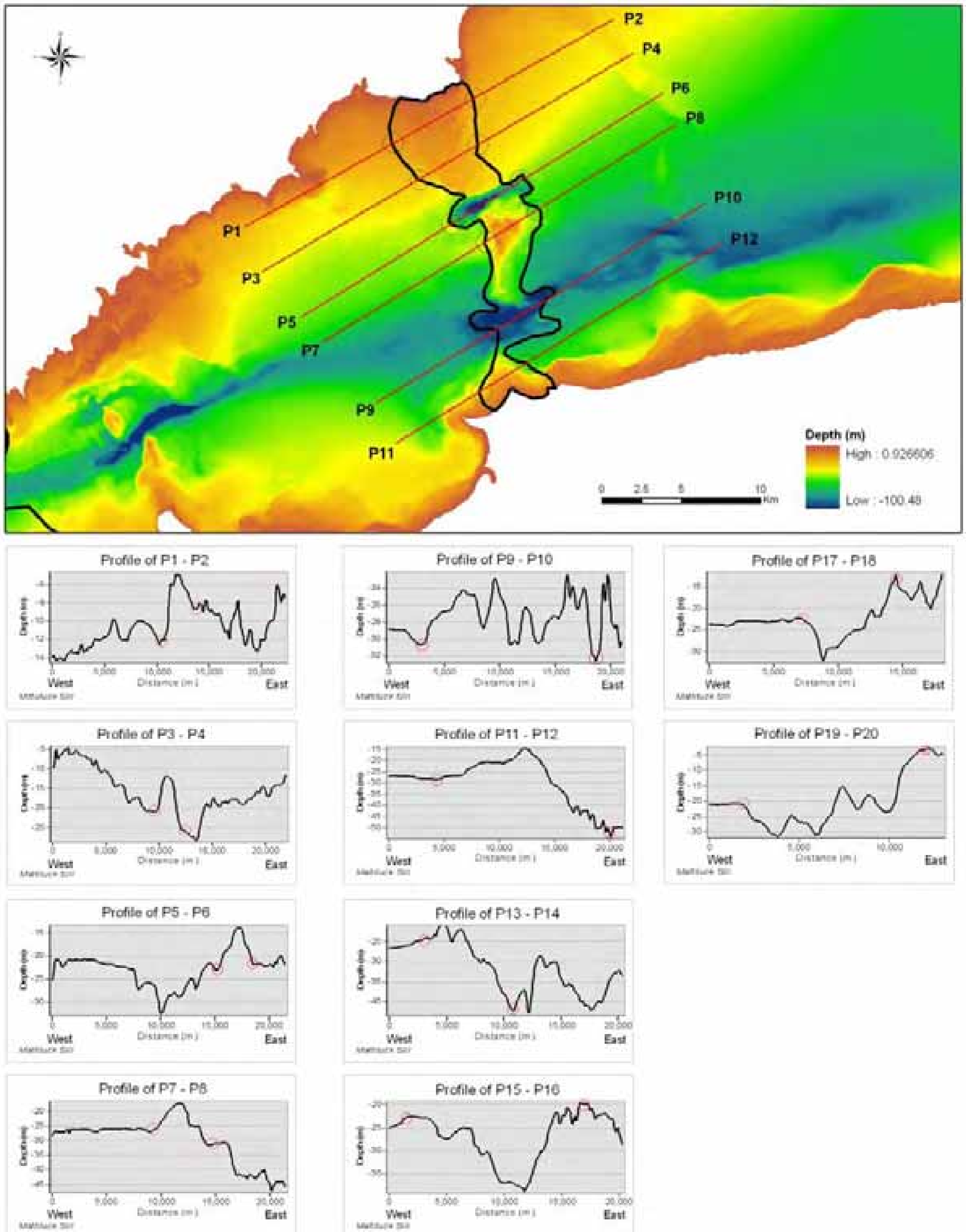


Figure 3.10. Transition zone over Stratford Shoal.

Appendix 4. Derived Products

A Terrain Roughness Index as a Proxy to Identify Rare Habitats

Terrain roughness index (TRI) maps were produced from LIS 1 m bathymetry to locate areas of high relief and associated communities. TRI is a measure of the deviation in depth of 8 adjacent cells or pixels for each cell or point. TRI values were expanded across grey scale values such that high TRI values are white while low values are black. Values were then classified by quintile. Preliminary analysis indicates top two quintiles correlate with spatially "rare" and sensitive habitat types. For example, habitat features identified through use of theTRI as a proxy include boulder reefs along the crest of Stratford Shoal, dense shell habitat at the base of Roanoke Point Shoal. Preliminary results from an ongoing analysis suggests there is potential for use of TRI maps as a decision-support tool for managers (e.g., to focus survey attention to assess status and distribution of resources within such areas, to stratify sampling effort during natural resource surveys, to avoid impacts to habitat features and communities that are spatially rare by implementing precaution when other information is absent).

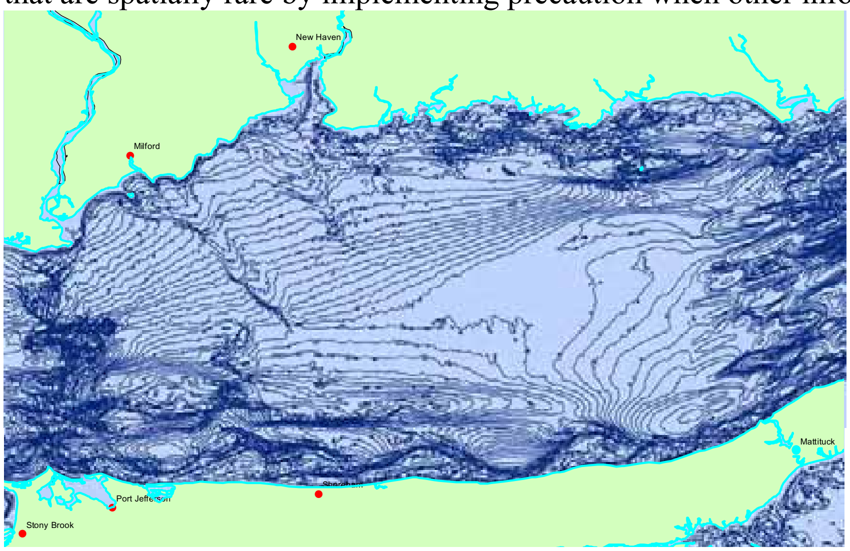


Figure 4.1. One meter bathymetric resolution

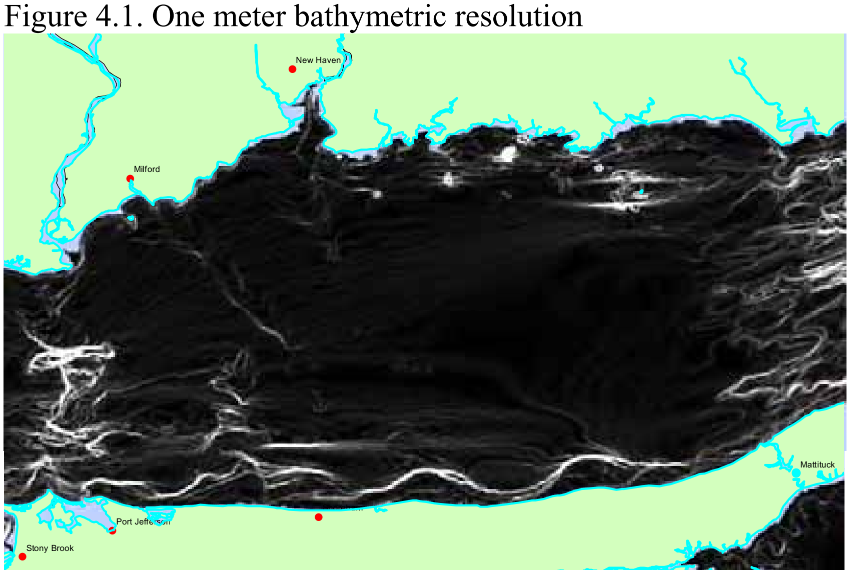


Figure 4.2. TRI map with gray scale range (original values 0 – 6.901; grey scale range 0-255)

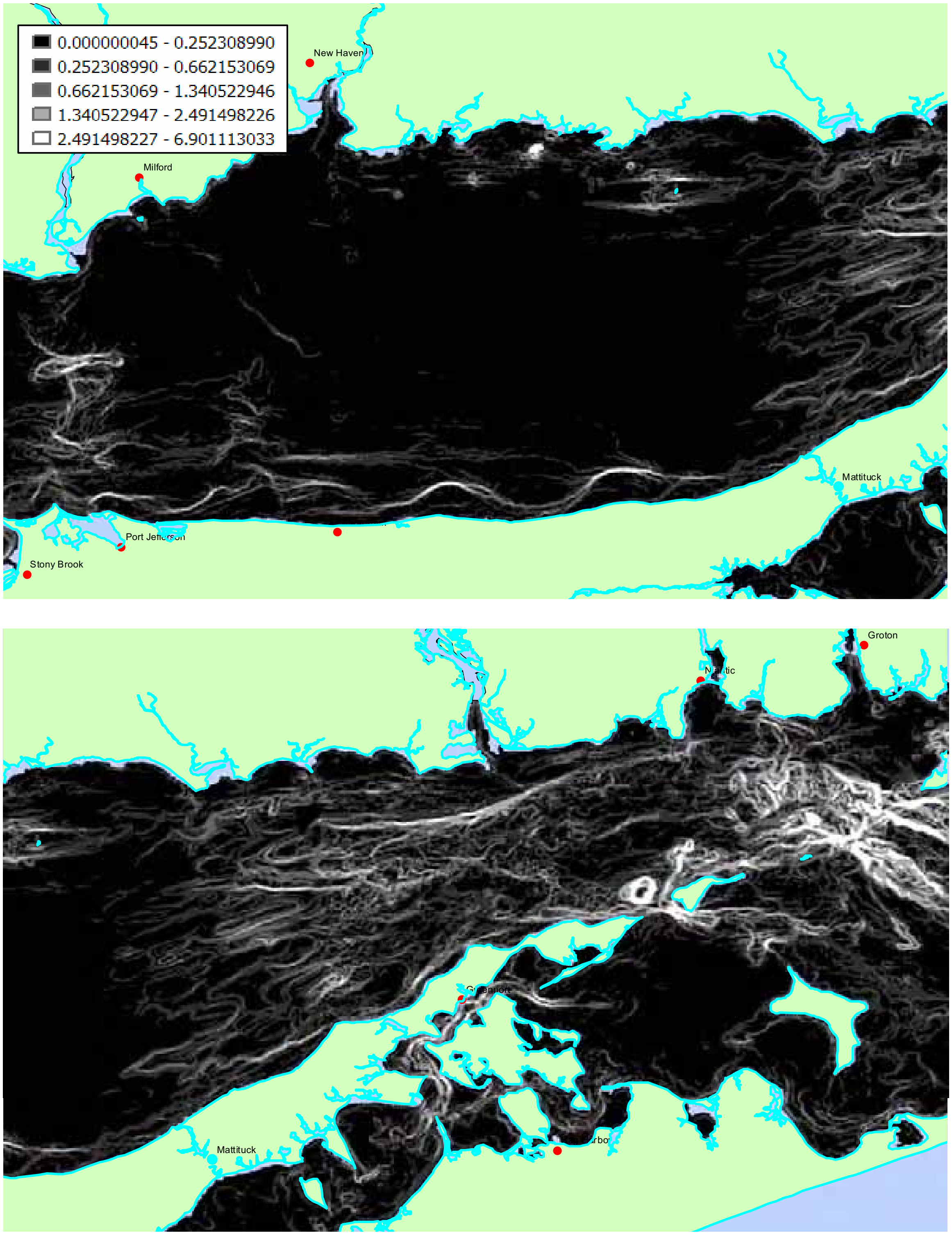


Figure 4.3. TRI values as five classes based on natural breaks (Jenks). Central LIS region (top) and eastern region (bottom).

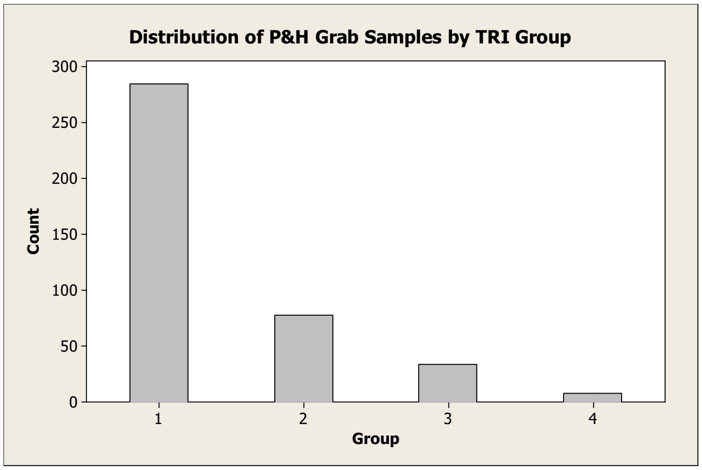


Figure 4.4. Distribution of samples from Pelligrino and Hubbard in TRI groupings based on quintile (i.e., 1-5). Note reduction of sampling effort in areas of increased topographic complexity.

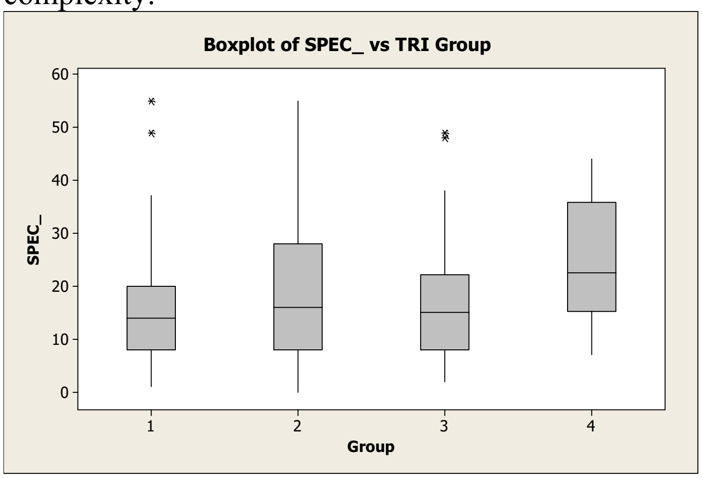


Figure 4.5. Boxplot of infauna species richness based on TRI group. There was a significant increase in diversity as complexity increased (i.e., $1 < 2 < 3 < 4$).

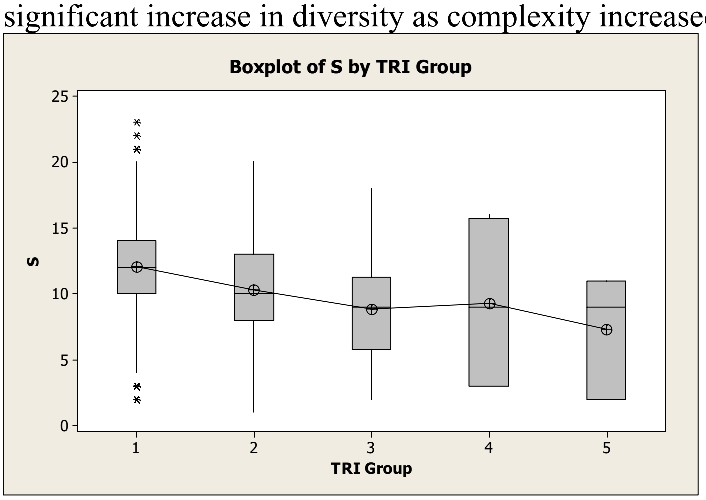


Figure 4.6. Boxplot of fish species richness (spring DEP trawl survey) based on TRI group. Richness declined with increased complexity.


A
B
C
D
E
F
4059N9241?07249W1059
19:38:28 Q0S00 0.0
G
4059N9273?07249W1060
19:37:52 Q0S00 0.0
H

Figure 4.7. Underwater images of habitats and communities observed in areas of high TRI values (top two quintiles). A. Dense sponge and coral habitat on boulder reef at crest of Stratford Shoal. B. Coral dominated boulder at same location as A. C. Shell habitat at on lower slope of Roanoke Point Shoal. D. Young-of-the-year scup (right) and black sea bass (bottom center) using razor clam valve as shelter. E. Kelp dominated habitat at Black Ledge. F. Boulder reef habitat (piled boulders) with deep crevices used by species such as tautog for shelter. G. Steep features also produce topographically enhanced currents and flow refuges. Species may not necessarily be associated with proximate seafloor features but with oceanographic characteristics associated with such features. Here Atlantic silversides were observed in patchy distributions at base of Herod Point Shoal. H. Prey associated with features described in G attracted predators such as striped bass.