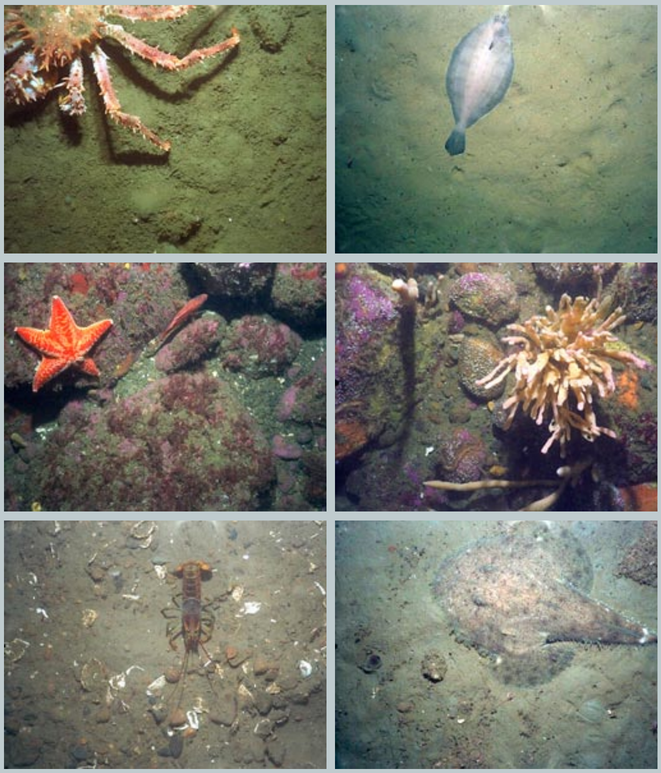
HABITAT CLASSIFICATION
IN THE
GULF OF MAINE



A Review of Schemes and a Discussion of Related Regional Issues

By P. T. McDougall with Marianne Janowicz
and Rachael Franks Taylor

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Habitat Conservation Subcommittee
of the Gulf of Maine Council on the Marine Environment
Marianne Janowicz, co-chair *New Brunswick Dept. of Environment and Local Government*
Kate Killerlain-Morrison, co-chair *The Nature Conservancy*
Christopher Boelke *NOAA/NMFS*
Priscilla Brooks *Conservation Law Foundation*
Maria-Ines Buzeta *Fisheries and Oceans Canada*
Susan Faraday *The Ocean Conservancy*
Susan Farquharson *Southwest New Brunswick Marine Resources Management Initiative*
Kathleen Leyden *Maine Coastal Program*
Art MacKay *St. Croix Estuary Project*
Laurie Murison *Grand Manan Whale and Seabird Research Station*
Patti Reilly *Ducks Unlimited*
Peter Taylor *Waterview Consulting*
Rachael Franks Taylor *The Nature Conservancy*
Anthony Wilbur *Massachusetts Office of Coastal Zone Management*

Scientific Advisory Panel
Peter Auster *University of Connecticut/National Undersea Research Center*
Robert Buchsbaum *Mass Audubon*
David Burdick *University of New Hampshire*
Maria-Ines Buzeta *Fisheries and Oceans Canada*
Larry Harris *University of New Hampshire*
Michael Johnson *NOAA/NMFS*
Rob Robertson *University of New Hampshire*
Page Valentine *U.S. Geological Survey*
Herb Vandermeulen *Bedford Institute of Oceanography*

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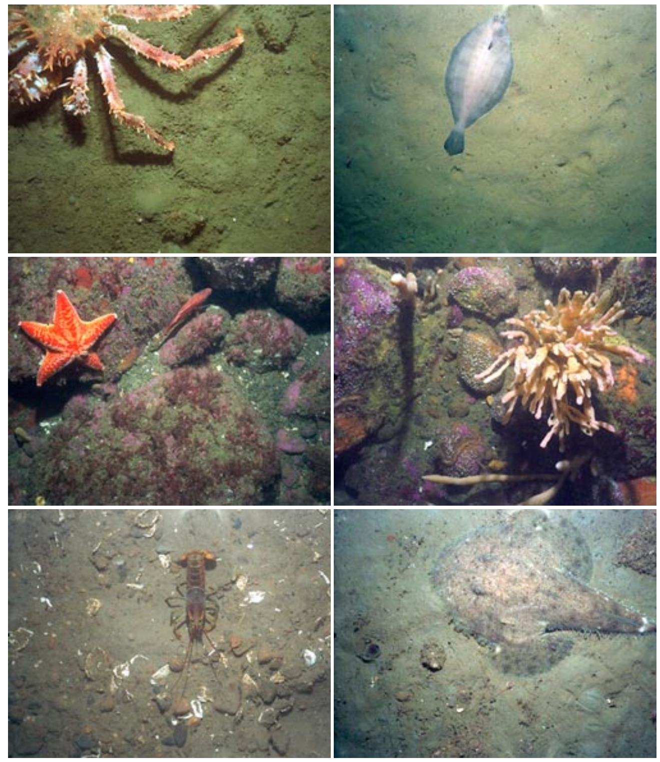
1.0 Executive Summary



Life on the seafloor in the Gulf of Maine. Clockwise from top left: spider crab; flounder; finger sponge; goosefish; lobster; sea star and redfish.

The goal of habitat classification is to provide a language through which data and information regarding habitats can be communicated and managed. This report provides background information on marine habitat classification, as well as information on current research efforts. By doing so, we hope it will facilitate a discussion on marine habitat classification in the Gulf of Maine region in which all stakeholders are able to participate.

Classification frameworks can be simple or complex, depending on the nature of the questions being asked. In general, a classification scheme covers a broad range of information and should be flexible and adaptable enough to evolve along with improvements in the science and understanding of habitats. Furthermore, a shift to ecosystem-based management requires a greater understanding of how habitats relate to each other and the environment around them. Classification schemes are important tools for studying these relationships.

There are a number of considerations and issues with classifying marine habitats in the Gulf of Maine region:

- The nature of the scheme chosen—whether developing a standard scheme for the region or selecting schemes on a case-by-case basis—can impact future conservation and management efforts.
- Habitat classification is scale dependent. Because of this, an appropriate scale should be selected, before starting the classification process, that addresses the relevant research or management questions. In the absence of a single appropriate scale, however, the scheme should be adaptable to various scales as needed.
- There is a shared responsibility between researchers and managers when it comes to communicating findings and research needs. This communication is important to ensure that a classification scheme meets both sets of needs.
- Classification and mapping efforts have the potential to greatly improve management decisions. These efforts can provide a better understanding of the cumulative effects and ecosystem impacts of seemingly isolated actions. But to increase the usefulness of such efforts, managers and researchers should communicate regarding what information is required to make effective management decisions.
- At their most basic level, classification schemes are rooted in either the physical or biological characteristics of the environment. Deciding on which type of approach to pursue will greatly affect the resulting structure and function of the classification scheme.

To help ensure that classification schemes can fulfill their potential, this report presents background information, methods, and current research—a primer of sorts—to serve as a foundation for an open, multi-stakeholder dialogue. Finally, some of the issues that could be addressed in such a dialogue are summarized as a starting point to the conversation.

2.0 Introduction and Goals of the Report

This report presents information about habitat classification relevant to management and conservation needs in both the nearshore and offshore regions of the Gulf of Maine. The report serves to inform discussions among stakeholders seeking to identify a classification scheme appropriate for the region. It is a continuation of the work of the Habitat Conservation Subcommittee of the Gulf of Maine Council on the Marine Environment and an activity identified in the *Gulf of Maine Council on the Marine Environment Action Plan 2007-2012* (see www.gulfofmaine.org/actionplan).

This report is meant to provide a basic understanding of marine habitat classification so that stakeholders can participate equally in the discussion. The report includes definitions, an explanation of why habitat classification is important for conservation and management, and an overview of some common research methods. The report also reviews some current marine classification schemes intended for application at the regional level within the Gulf of Maine region, in an adjacent region, or on a national scale. This review includes research that has yet to be published in peer-reviewed literature.

The report does not review schemes in depth, but it provides a clear, concise, and accessible description, so they can be understood and compared. Also, this report does not seek to endorse one scheme over another. Each system was designed for a specific purpose and therefore involves a unique set of strengths and weaknesses. The report does, however, make recommendations on various issues in an effort to provide direction and framing to the conversation on marine habitat classification in the Gulf of Maine.

The information included in this report is derived from a combination of research papers and interviews with researchers. Additionally, a December 2006 draft copy of the Massachusetts Office of Coastal Zone Management's *Feasibility Study on Habitat Classification* by Katie R. Lund and Anthony R. Wilbur provided useful insight into various schemes.

3.0 Researching Marine Habitat Classification

3.1 Marine Habitat Classification Defined

Habitat is loosely defined as any area that provides the conditions and resources that a species needs to survive. Following this definition, 'marine habitat' is any such area in the marine environment, including but not limited to the sea bottom, water column, intertidal areas, deep seafloor, estuaries, and so on. Differentiating among these various marine habitats is the basic task of marine habitat classification and the basis for this report.

Marine habitat classification is an area of research that describes discrete habitat types within a defined spatial scale. The descriptions are based on various geological and biological characteristics such as depth, substrate type, and the organisms associated with a particular area. Many different classification schemes exist to differentiate these habitats from one another, reflecting the difficulty of dividing natural continuity into a set of artificially distinct categories.

Classification approaches are used to organize items in a variety of contexts—from grocery stores to living organisms. While using a classification scheme to ensure that all dairy products are kept together seems rather straightforward, designing a taxonomic scheme to organize all known living organisms on the planet is a much greater challenge. The latter provides a much better comparison for what researchers are attempting to do with marine habitats.

The incredible diversity of organisms present in the world mirrors a similarly diverse range of habitat types. In both cases, there are limitations in whether certain characteristics can or cannot be associated with one another. For example, organisms with gills rarely have fur. Similarly, the deep ocean floor (referred to as the abyssal plain) does not support seagrass communities. In some ways, however, designing a classification scheme for habitats is more difficult than designing one for biological organisms. Because organisms are a product of their genetics, many characteristics simply cannot coexist based on their respective evolutionary paths. The same is not always true of the physical, chemical, geological, and biological characteristics at play in habitats, which makes habitat classification more difficult and ultimately more subjective.

3.2 Classification Versus Mapping

When discussing habitats, people often use the terms classification and mapping interchangeably.[1] While both are important when converting continuous

[1] "Characterization" and "description" are two more terms sometimes used instead of "classification" and "mapping." In general, habitat descriptions are qualitative narratives that define different habitats. Habitat characterization, on the other hand, refers to the gathering of data that characterize a specific habitat; this information often can be helpful in habitat classification efforts.

habitat into discrete categories, they are different processes. Habitat classification refers to the use of characteristics such as salinity, sediment type, or species to define a given habitat type. Habitat mapping involves spatially illustrating habitat distributions.

Although classification and mapping are two very different processes, the two are most useful when applied together; therefore, the distinctions between them are less critical for the current discussion. A classification scheme without a spatial component is only a tool for habitat taxonomy. It is important to know not only the habitat types but the locations of the habitat types. Hence the importance of habitat mapping. For example, while knowing that a habitat characterized by "rocky, immobile substrate with high rugosity[2] and low biogenic structure[3]" exists is valuable, managers also need to know where that habitat exists, how common it is, and what habitats surround it.

The schemes covered in this report differ in that some are aimed primarily at generating maps, while others are designed with maps as a secondary tool. Understanding the context of different schemes is critical when discussing how they may address management and conservation needs.

3.3 Why Is Marine Habitat Classification Important to Managers and Conservationists?

Habitat classification allows people to communicate more effectively about the environment around them. Lessons learned in one region need to be available to other regions that are facing similar issues. Classification allows some level of transferability of this kind of information, especially when determining which environmental factors are important as indicators for system health. Without this transferability, conservationists and managers have to perpetually reinvent the wheel.

Lessons learned are widely shared among terrestrial managers, partly because habitats are already classified and mapped at many levels of resolution. Terrestrial managers also enjoy the luxury of directly seeing and experiencing the results of long-term adaptive strategies. The marine environment lags behind its terrestrial cousin in that we still do not have a sufficiently standard marine classification system, nor do we have the benefit of actually seeing in real time the impacts of management decisions. By using a standard framework to consistently describe specific habitats, managers and researchers can help to ensure that communication among agencies, jurisdictions, regions, and studies is efficient and effective.

Long-term resource tracking becomes more efficient when managers identify habitats in the same way from year to year. Furthermore, changes in the patterns of resource use become easier to identify when many sites can pool their data to permit regional analyses. If local and regional managers know the types and locations of marine habitats in their jurisdictions, they are better equipped to address human impacts that affect particular habitat types.

Knowing what habitats are present in a given area allows for better management of the marine resources and the potential uses (e.g., fisheries, mineral extraction, tourism) that are associated with those habitats. It is difficult to understand the effects of one sector on another without an understanding of where they intersect, which often relates to habitat type. This applies for all scales of management from local to regional.

3.4 Data Collection Methods

Ocean mapping has greatly improved from the days of attaching a lead weight to the end of a line and lowering it from the side of a ship. A number of technologies are currently available to map both shallow and deep habitats. They provide data at different resolutions and in different forms, but they all combine to provide a fuller understanding of the habitats targeted for mapping. The majority of the technologies and methods described below involve indirect or remote sampling. For these indirect methods, it is critical to ensure that adequate direct sampling takes place to "ground truth" the habitat patterns and classifications generated from the remotely collected data.

The following list is not meant to be comprehensive. It merely serves the purpose of informing a broad audience about the range and nature of technologies that are in practice today.

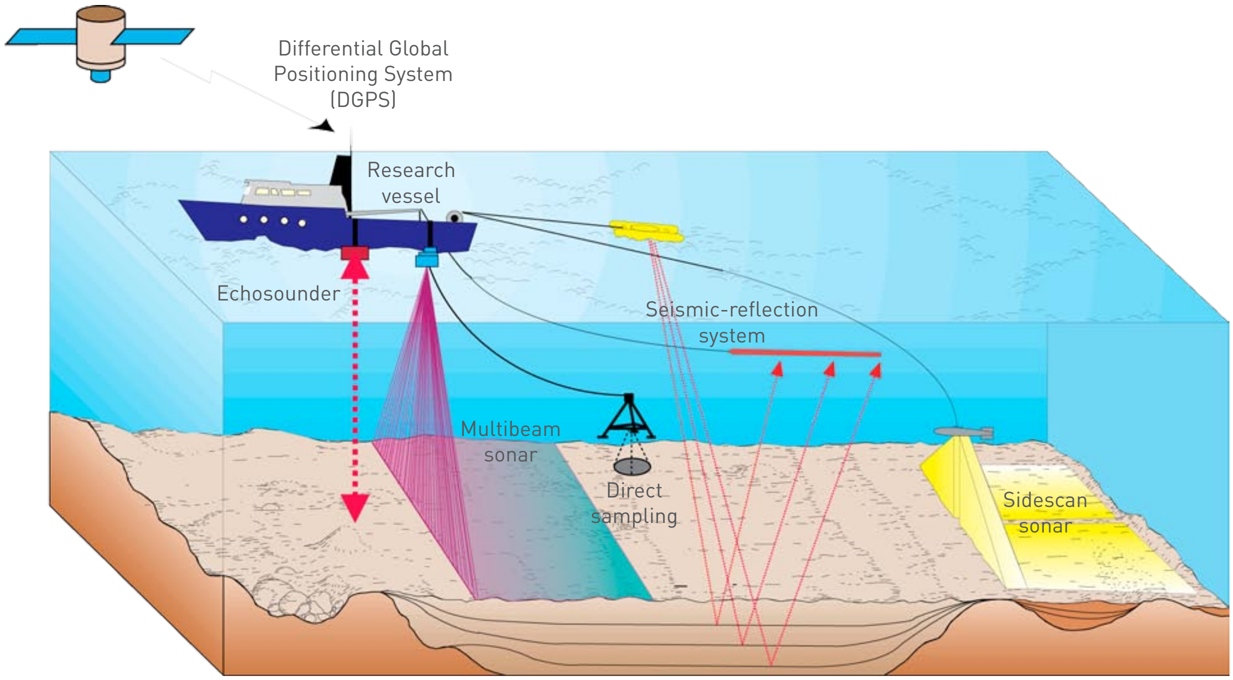
3.4.1 Satellite Data

Since 1997, satellite altimetry[4] has made information available for many of the world's oceans. This information is not generally of a sufficient resolution to be useful for direct mapping purposes, but it does provide a base level of water-depth information

[2] Rugosity is a measure of surface roughness or complexity, frequently defined as a ratio of the surface area of a region to its planar area.

[3] Biogenic structure is a term for physical formations—such as kelp forests, coral reefs, and shellfish beds—that are created by organisms.

[4] Altimetry is the measurement of altitude. In satellite altimetry of the ocean, satellites measure the small changes in sea-surface elevation that reveal the presence of seafloor topographical features.



Examples of methods used to collect information about the seabed for habitat classification.

for offshore areas. A more recent generation of commercial satellite systems called QuickBird was launched in 2001. QuickBird provides multi-spectral photography of intertidal bottom conditions.

Satellites also provide information on sea-surface temperatures and currents. Measurements of sea-surface salinity will be possible with the launch of a new European satellite in 2007.

3.4.2 Multibeam and Single-beam Sonar

Multibeam sonar uses sound waves to provide high-resolution, three-dimensional data on ocean depths and seafloor topography. It is especially useful in areas of deep water. The sound waves are generated from an array attached on a ship hull or in some cases on a pole attached to the side of a boat. The array consists of a number of transducers[5]—some that transmit and some that receive—arranged in a specific pattern on a set of perpendicular bars. The transmitting portion of the array sends out a pulse of sound waves in a broad swath below the boat. The swath is wide to either side of the ship but narrow from front to back. The sound waves reflect off the substrate and return to the receiving portion of the array at specific angles.

The time it takes for the sound waves to return to the array provides depth measurements for various points along the swath. The number of depth measurements (and therefore the resolution) is dependent upon how many transducers are in the array, the specific shape of the array, and the depth of the water. In general, the width of the imaged swath is twice as wide as the water is deep. In this way, very large stretches of ocean can be mapped quickly when in deeper water. As the water gets shallower, however, the swath gets smaller. Therefore, a greater number of "passes" are required in order to cover a given area. This makes multibeam sonar less efficient for measuring bathymetry in shallow waters. It is generally used in deep, offshore waters.

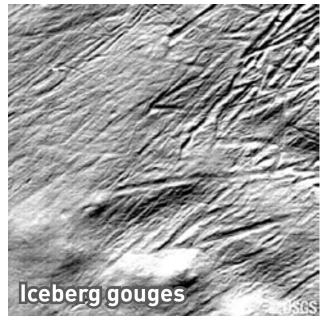
Single-beam sonar works similarly to multibeam sonar, except that only a very small footprint directly under the array is measured with a single pulse of sound. Because the footprint is so small, single-beam is not useful for measuring depths across a large area, but it can generate very accurate bathymetric contours for the route traveled by the research vessel. Single-beam sonar is effective in shallower waters (depths less than 4 meters), however, so it can be used in conjunction with multibeam sonar, which is most effective in depths greater than 10 meters.

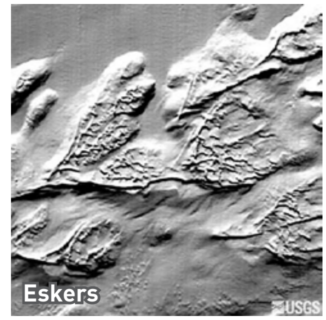
In addition to providing depth information, the returning sound waves also provide information about the properties of the surficial substrate. Substrates reflect sound waves differently according to their specific properties—the harder the substrate, as with bedrock or shell fragments, the stronger the returning signal or "backscatter." The image generated from the backscatter appears in shades of white, grey, and black. White represents a very strong returning signal, and black indicates no returned signal (also referred to as a void).

With multibeam sonar, backscatter also provides a shaded view of the seafloor topography. Three-dimensional features such as pinnacles and boulders

[5] Transducers are small devices that convert electrical impulses into sound waves and vice versa.

show up with the side facing the sonar array appearing bright white. The side facing away appears black because it is in the "shadow" of the sound waves.





Sonar backscatter images reveal seafloor features in the Gulf of Maine.

3.4.3 Sidescan Sonar

Sidescan sonar can be used in shallow waters, and it detects features of the substrate such as sand waves and shipwrecks. Sidescan sonar operates similarly to multibeam sonar in that it uses a swath of sound waves reflecting off the seafloor. However, a sidescan sonar array is streamlined and is towed at some distance behind and below the operating vessel. The sidescan sonar array resembles a finned torpedo and is often called a fish-tow because of its shape. Because the fish-tow is much lower in the water, the sound waves strike the seafloor at a shallower angle, providing a greater overall footprint for imaging and highlighting three-dimensional objects from a greater angle. Sidescan sonar systems, however, tend to be more expensive than hull- or pole-mounted multibeam systems.

3.4.4 LiDAR

Often referred to as laser imaging, Light Detection and Ranging (LiDAR) uses light waves in the place of sound waves to measure heights of nearshore benthic formations. Depth and water conditions (e.g., turbidity) limit the effectiveness of LiDAR. Generally, it is used along the coastline to create three-dimensional images of intertidal areas and above the high-tide mark. Typically the LiDAR array is mounted on a low-flying aircraft, but it can be ground-based, depending on the characteristics of the coastal topography. LiDAR produces very high-resolution measurements. Light waves have a shorter wavelength than sound waves, so LiDAR can measure smaller objects than sonar. An added benefit of LiDAR is that the habitat-characterization data can be matched with a high-resolution photograph of the targeted area.

3.4.5 Direct Sampling

The previous methods all involve indirect, or remote, sampling. Sound waves measure depth after taking into account angles and interference patterns between multiple transducers. Backscatter provides information about the substrate, but only after a great deal of processing. Only by directly sampling the substrate—its depth, composition, or other characteristics—can one be certain of the validity of indirect measurements. For this reason, direct sampling, also referred to as ground-truthing, is an important step in habitat classification. Direct sampling is usually required to measure or confirm the biological characteristics used in habitat classification.

Direct sampling provides the highest-resolution information, but it is also the most labor intensive. Consequently, direct sampling generally is used in conjunction with indirect methods. For example, direct sampling is used to ground-truth the data produced by multibeam and sidescan sonar.

Direct sampling can take many forms. Visual sampling (both video and still) can be performed by remotely operated vehicles (ROVs), manned submersibles, dropped and towed cameras, and divers with appropriate gear. The appropriate method depends on the depth and characteristics of the habitats in question. ROVs and manned submersibles generally are used for deeper, offshore waters. Physical sampling involves the collection of geological and biological samples with grabs, cores, and other gear, which may be deployed from a boat or ship. Just as with visual sampling, the appropriate method depends on the depth, habitat type, and the type of data being sought.

The data-collection methods described above require processing time and analysis, and indirect methods also require ground-truthing. As a result, time and funding typically are major factors that limit the resolution of habitat data.[6]

[6] For a more detailed discussion of information- and data-gathering for identifying habitat characteristics and the use of various methods, see Valentine et al. (2005).

4.0 Habitat Classification Schemes

4.1 General Overview

In most cases, classification schemes are designed to address specific research questions. For instance, studying the geographic distribution of habitats requires first classifying the habitat types. Therefore, when comparing many different schemes, it is important to understand the intended use or application of each scheme and the research context.

Most schemes involve different levels of information based on some scale or metric. This means that most schemes are, to some degree, organized in a hierarchy of characteristics. Some schemes target one specific region or type of substrate, whereas others extend to all underwater habitats (i.e., intertidal to the deep seafloor, and everywhere between). In almost all cases, classification schemes have an associated code that facilitates statistical analysis and mapping using Geographic Information Systems (GIS).[7] The codes range in complexity and in the amount of information they convey, but they generally are a series of numbers and letters that have specific meanings within the classification system. A few examples of codes are provided in the next section. No classification scheme is right or wrong, because each has been designed to address a unique set of questions.

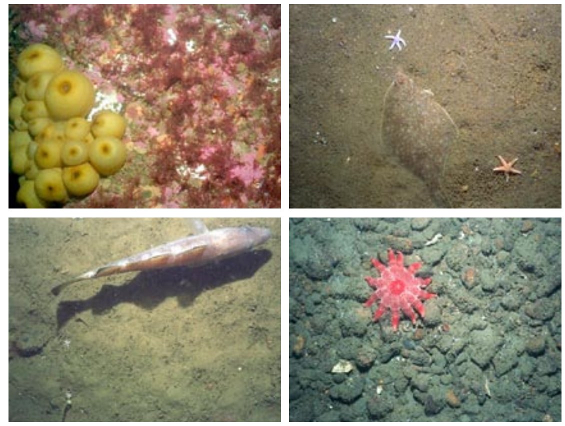
The following section summarizes a number of schemes that are prominent in the Gulf of Maine region, and a few that have received national attention as well. The goal of each summary is to provide an understanding of the function, context, form, and usefulness of each scheme in addressing the classification needs of the Gulf of Maine Council on the Marine Environment and its partners. The summaries do not provide in-depth description; greater detail is available from the original published or in-press papers.

4.2 Some Current Habitat Classification Schemes and Related Research

4.2.1 Madden et al. (2005) Coastal and Marine Ecological Classification Standards (CMECS)

The Madden et al. (2005) framework is the most detailed ecosystem- or ecology-based scheme reviewed in this report. Its function is to provide a system to classify all coastal and marine habitats in the United States. The collaboration between NatureServe and NOAA, among others, leading to CMECS originated from a national workshop in 2003.

The scheme is based on spatial scales of less than one square meter to thousands of square kilometers. Each of the six levels identifies a subset or defining component of the previous level:



Clockwise from top left: anemones; sea stars and flounder; sea star; cod. Next page (left to right): rocky habitat; sea star; sand dollars.

Level 1/Regime: differentiated by a combination of salinity, geomorphology and depth.
Level 2/Formation: large physical structures formed by either water or solid substrate within systems.
Level 3/Zone: water column, littoral, or sea bottom.
Level 4/Macrohabitat: large physical structures that contain multiple habitats.
Level 5/Habitat: a specific combination of physical and energy characteristics that creates a suitable place for colonization or use by biota.
Level 6/Biotope: the characteristic biology associated with a specific habitat.

CMECS also includes a number of formal terms called descriptors and classifiers. The descriptors are a set of attributes that help explain the habitat and how it functions. Descriptors cover a wide range of habitat characteristics, including temperature, energy intensity, and substrate type. Some of these descriptors are referred to as classifiers (such as salinity or oxygen regimes), which are the specific descriptors that the classification scheme depends on to differentiate between habitats. For instance, classifying a given regime as estuarine, freshwater influenced, nearshore marine, neritic[8], or oceanic requires a combination of salinity, geomorphology, and depth classifiers.

The CMECS code[9] is based on each level of the classification holding a specific position in the code. Some levels are represented by letter codes, others by numbers. For example, the code **A.01.B.a.04** represents an estuarine (**A**) lagoon (**01**) bottom (**B**) oyster (**a**) shell midden habitat (**04**). This example has no biotope component.

[7] The process of using GIS to produce a finished map from spatial information is beyond the scope of this report.
[8] Neritic refers to marine waters between 30 and 200 m deep.
[9] For information on CMECS, go to www.natureserve.org/getData/CMECS/app/classification/tree/pivot/browse

4.2.2 Greene et al. (in press) Standardized Marine Benthic Habitat Mapping

Building on previously published work (Greene et al. 1999), Greene et al. (in press) present an updated version of the scheme, complete with a new coding system. The updated scheme focuses on the marine benthic system, which it defines based on salinity and proximity to the seafloor.

The scheme has proven adaptable. It has been applied successfully in mapping marine benthic habitats in many different regions, including southeastern Alaska and southern California. Furthermore, Greene et al. (in press) has been amended for mapping estuarine habitats. Adaptations for intertidal habitats are planned.

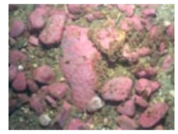
The Greene et al. scheme divides a given region into four hierarchical scales:

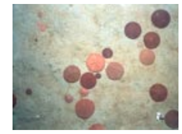
1. Megahabitat is measured on the scale of kilometers to tens of kilometers, such as a lava field on the continental shelf.
2. Mesohabitat is measured on a scale of tens of meters to kilometers, such as a pinnacle within the lava field.
3. Macrohabitat is measured on a scale of 1–10 meters, such as a boulder field at the base of the pinnacle.
4. Microhabitat is measured on a scale of centimeters to a meter, such as anemones at the tip of the pinnacle.

With those four scales providing a framework, Greene et al. developed a two-part code that enables easy and flexible classifications based on a mix of remote sensing and ground-truthing data. The code is a series of characters that represent specific characteristics of the habitat. If data are scarce, certain characteristics can be absent from the code without compromising the classification. Additionally, a great deal of flexibility and adaptability is present in the coding framework. New habitat features can be incorporated into the coding system by defining new characters and/or adding additional letters or numbers to existing characters.

There are seven possible primary characters representing data from indirect sampling (i.e., satellite or multibeam bathymetry) and four possible secondary characters representing data collected directly (i.e., physical or video sampling). For primary characters, the numbers and letters that make up the code indicate:

Definitions of Scale
The term "scale" has two different uses related to classification and mapping schemes. One use relates to physical space such that "large scale" refers to a large object or large geographic area. The other use involves the ratio for scaling objects on a map. In the mapping sense, a small object would need a large scale (e.g., 1:10) when represented on a map. A large region such the Gulf of Maine would require a small scale (e.g.,1:100,000) when represented on a map. Greene et al. define and use "scale" in the mapping sense of the term. For the sake of consistency with the other research reviewed in this report, their work will be translated into the physical-space sense of the term.





1. Megahabitat (e.g., lava field)
2. Bottom hardness
3. Presence of a particular feature (e.g., canyon)
4. Texture of the substrate sediment
5. Slope
6. Rugosity
7. Geologic age and origin of the sediment

As mentioned, some of these characteristics are optional and can be omitted from the code if they do not apply (such as the presence of a feature) or are unknown (such as the geologic age and origin of the sediment). This allows for greater flexibility in the classification process for environments where incomplete data sets exist. While other schemes allow for incomplete data, most other codes lose specificity and resolution with any loss of data.

The secondary characters describe smaller-scale characteristics whose measurements require actual observations or sampling. This scale of classification is important in identifying the patchiness and heterogeneity of macrohabitats and microhabitats. The secondary characteristics describe geological coverage (e.g., gravel, mud, sand, cobble) and biological coverage (e.g., sponges, detritus, corals, algae).

When a substrate is especially patchy, researchers can string multiple characters together to represent decreasing percentages of overall coverage. For instance, substrate that is dominated by mud but also has sand and cobble could be represented as (m/s/c). The same approach applies for biological coverage in the case of sponges, corals, and algae, which could be represented as [s/c/a].

The secondary characteristics also describe the small-scale measure of slope (different from the primary characteristic listed as #5 above) and the small-scale measure of rugosity (taken as a linear measure).

As an example, the code **Ssc_u1B*(s/c)[d]** represents a habitat patch of sand, cobble (**s/c**), and detritus **[d]** within a larger area distinguished as flat (**1**), low-rugosity (**B**), unconsolidated sediment (**u**), in a submarine canyon (**sc**), on the continental shelf (**S**).

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

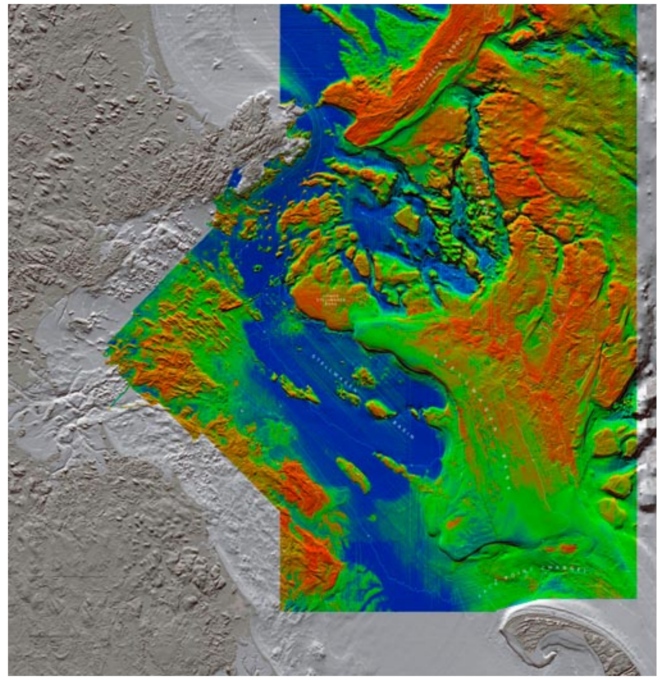
In their 2005 paper, Valentine et al. outline a scheme to define marine sublittoral habitats in terms of geological, biological, and oceanographic attributes and the natural and anthropogenic processes that affect the habitats. The scheme recognizes eight seabed themes that serve as the major elements of the classification and that emphasize the geological characteristics of habitats. This framework differs from the other schemes presented in this report in that it is only partly hierarchical.

The Valentine et al. system involves 24 classes of measurements such as topography, substrate texture, faunal groups, and human usage. In addition to these classes, there are other levels of information that include subclass, category, and attribute.

To organize the classes, Valentine et al. grouped them into the eight themes:

1. Topographical setting describes the slope and features of the seabed, including anthropogenic structures.
2. Seabed dynamics and currents indicates whether the ocean currents move the substrate, based on strength and frequency of the currents.
3. Seabed texture describes how hard the substrate is and what the sediment feels like.
4. Grain size analysis involves particle description such as shape, skewness, and kurtosis.
5. Seabed roughness describes the three-dimensional characteristics of the substrate.
6. Fauna and flora indicates the dominant and typical biological elements that define the habitat, such as anemones and sponges.
7. Habitat association and usage describes not only how humans use the habitat but how organisms use it (e.g., spawning or migration).
8. Habitat recovery from disturbance describes the amount of time it takes for the habitat to recover from human or natural disturbances.

The Valentine et al. coding system is different from other approaches presented here in that it limits the information expressed in the code to just 3 components. At a minimum the code indicates only the seabed type (e.g., mud), which involves measurements within the seabed texture theme. At its most informative, however, the code provides information on the seabed type, a measure of its mobility (seabed dynamics theme), and a measure of complexity for the physical and biological structures. Valentine et al. propose the use of only 3 components because a code, by definition, can only provide a limited description of a habitat. They claim that developing a deeper understanding of the nature of a habitat requires considering how the biological and physical components interact. They consider this degree of resolution prohibitive for inclusion in the code beyond a simple measure of the overall complexity.

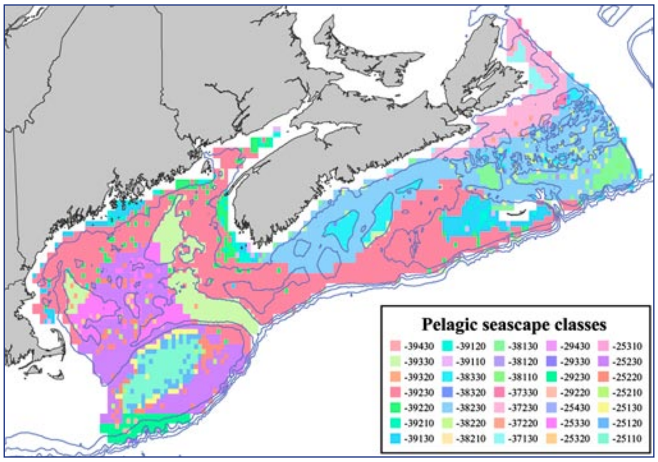


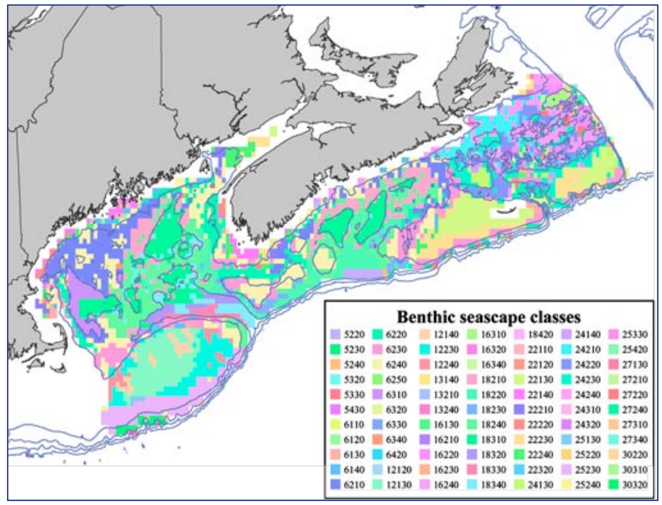
Backscatter intensity draped over seafloor topography in a shaded-relief view of Stellwagen Bank and environs. The tip of Cape Cod is visible in the lower right corner of the image.

For example, the code **I_M_ps5–10L_bs<1VVL** describes an immobile (**I**), mud (**M**) habitat with low physical structural complexity (**ps5-10L**), and very, very low biological structural complexity (**bs<1VVL**). The two parts of the code that describe physical and biological structure convey information about both the coverage (5–10% coverage of the substrate by physical structures and less than 1% coverage by biological structures in this example) and the complexity (low for physical structures and very, very low for biological structures).

While much of the preliminary classification can be prepared using indirect methods, direct sampling through video imaging and/or physical sampling is critical for the latter stages of the process. A recent pilot program successfully used this scheme to classify a portion of the substrate on Stellwagen Bank. The result was a set of six high-resolution maps that are useful for important management concerns. Generating the maps—which show seabed dynamics, seabed habitats, ruggedness, seabed disturbance, seabed substrates, and fine- or coarse-grained substrate distributions—was an integral part of the classification process.

The scheme was designed to classify seafloor habitat of northeastern North America. Nevertheless, with the addition of new classes, the authors feel that the framework could be applied to other regions.





Maps of habitats classified with the Roff et al. (2003) method by the Conservation Law Foundation and WWF-Canada (Crawford and Smith 2006). Benthic seascapes (above) were defined by depth, substrate, and benthic temperature-salinity zones. Pelagic seascapes (above left) were defined by stratification, depth, and pelagic temperature-salinity zones. Maps reproduced from Crawford and Smith (2006) with permission.

4.2.4 Roff et al. (2003) Abiotic Characteristics of the Water and Seafloor for Classifying Seascapes in the Northwest Atlantic Shelf Region

Roff et al. (2003) view their work as a logical approach to habitat classification, rather than as a new classification scheme. The approach focuses on predicting the distribution of marine organisms based on the distribution of physical habitat types. Crawford and Smith (2006) illustrate this approach to classifying seascapes at a coarse scale. The same approach could be applied at finer scales.

For pelagic habitats, the measurements are limited to key physical properties of seawater—temperature, salinity, depth, currents, and water-density values, which indicate whether the water is well mixed or stratified. For benthic habitats, substrate type is included. The resulting map of habitats can inform management decisions and research.

Pelagic habitat types are differentiated based on the following properties, in order of importance:

1. Stratification classes (or amount of mixing) include well-mixed, frontal, and stratified. The classes are defined by the difference in seawater density between the surface and at 100-meter depth.
2. Temperature-salinity (T-S) zones are differentiated based on a multi-variate cluster analysis. The data used in the analysis covered a 12-month time series, so the zones represent groupings of similar regimes of temperature and salinity, not just snapshots at a given time of year.
3. Depth measurements are the average of all available depth soundings within a given 5-minute[10] grid square.

Benthic zones are based on a similar set of physical properties—depth, stratification class, and substrate type (i.e., clays and silts; muddy sand; sand; gravel and till; and bedrock). The code is created by assigning a specific numeric code to different classes within the three physical properties used in the classification. Each code was listed at different orders of magnitude in order to permit collapsing the three physical properties of the classification together.

For example, the pelagic code **–25110** (composed of three numeric codes: -25000, -100, and -10) represents a 5-minute square with a pelagic T-S zone of **25000** (a total of five possible zone numbers were listed for the region), a depth class (**100**) corresponding to 0-60m (the euphotic zone), and water column that is well mixed (**10**).

The benthic code **-5230** (composed of three numeric codes: -5000, -200, and -30) represents a 5-minute square with a benthic T-S zone of **5000** (a total of 11 possible zone numbers were listed for the region), a depth class (**200**) corresponding to the epipelagic zone of 60-200m depths, and a substrate sediment class of sand (**30**).

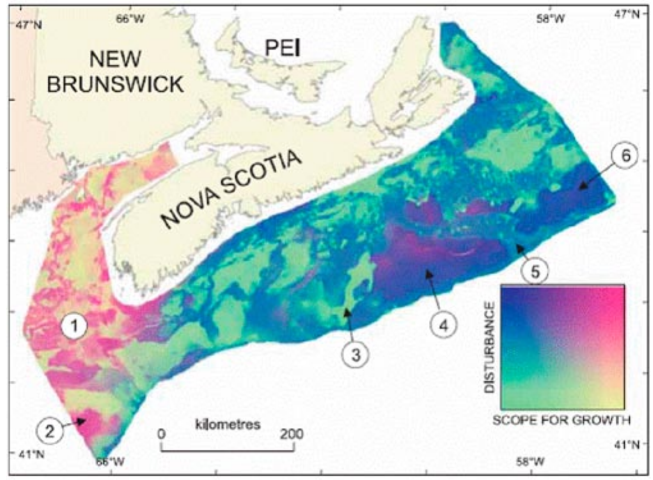
The maps generated from this information are at a coarse scale and are geared primarily towards offshore environments, but the principles of the approach can apply at finer resolutions as well. The maps can be useful to managers and researchers seeking to target their efforts on particular habitat types.

[10] Degrees of longitude and latitude are divided into minutes. Sixty minutes equal one degree. Oceanographers frequently divide large geographic areas into a grid, using measurements of minutes, to facilitate analysis.

4.2.5 Kostylev et al. (2005) Framework for Classification and Characterization of Scotia-Fundy Benthic Habitats

Kostylev et al. (2005) offer a classification scheme that considers interaction between physical characteristics of the environment and the life history traits and strategies of various benthic communities. The framework is structured around two axes:

1. Disturbance considers the frequency and extent of natural disturbances such as the action of waves and currents on the substrate. Areas that naturally experience a high level of disturbance generally host species that are less vulnerable to disturbance.
2. Scope for growth considers the conditions of the environment such as how much energy in an organism's overall budget is available for growth, reflecting harsh or favorable conditions. Areas that have a high scope for growth are generally associated with faster recovery.



Kostylev and Hannah (2007)

Level of disturbance and scope for growth in seabed habitats of the Scotian Shelf, Gulf of Maine, and Bay of Fundy, as measured with the Kostylev et al. (2005) method.

Plotting the two axes in a table with disturbance (stable versus disturbed) in the left column and scope for growth (benign versus adverse) across the top provides four categories in which to characterize habitats: stable-benign, stable-productive, disturbed-benign, and disturbed-productive.

This classification framework is more complex than some others reported here in that the values for disturbance and scope for growth involve calculations and assumptions, rather than relying strictly on direct and indirect measurements. In the case of disturbance, factors used to characterize the substrate as "disturbed" or "stable" include the physical properties of the particles in the substrate and the strength of the currents and waves above that substrate. By plotting a ratio of the frictional velocity and the critical current, a spectrum of disturbance can be generated such that low values (0) are relatively stable and high values (1) are disturbed.

- Frictional velocity is an estimate of how fast the water moves in a particular area based on high-resolution bathymetry, historical estimates of wave heights, grain analysis, and estimates of near-bottom tidal currents.
- Critical current is a value indicating how fast the water needs to be moving in order to shift the type of particles in the substrate. It is based on an estimate of grain size taken from a database of the region and use of an analysis referred to as the Hjulstrom diagram.

To estimate scope for growth, indices were calculated for five environmental factors known to influence growth (food availability, annual bottom temperature, seasonal and interannual temperature variability, and oxygen saturation). Each factor was weighted equally and combined to calculate an overall ratio from 0 to 1 for growth potential. Low values represent low scope for growth, and high values represent high scope for growth.

When mapped across the region, the two spectra of disturbance and growth overlap to provide a characterization of Scotia-Fundy benthic habitats based on their vulnerability to disturbance and their recoverability from disturbances. The map purposely involves gradients rather than distinct lines since distinct, clean lines do not divide habitats in nature. Nevertheless, there are regions of the benthos that are clearly highlighted as susceptible to anthropogenic disturbance (low growth-low disturbance, which translates to low recovery-highly vulnerable) and those that should prove relatively resilient to anthropogenic impacts (high growth-high disturbance, which translates to high recovery-low vulnerability).

This framework provides an interesting template for characterizing habitats based on specific management needs. The generated map identifies regions of concern where management efforts should be focused, although the approach as it stands relates primarily to offshore habitats. The authors raise a number of concerns relating to the temporal component of the indices and the quality of the data. These concerns, however, could apply to all classification schemes.

4.2.6 Buzeta et al. (in progress) Benthic Biodiversity in Southwest New Brunswick, Bay of Fundy: Examination of Relationships Between Factors and Species

The research of Buzeta et al. (in progress), while not geared towards developing a new classification scheme, can inform the current discussion by increasing the understanding of seafloor ecology. The research shows that patterns of species assemblages[11] and richness can be statistically linked to habitat characteristics.

Using both existing and new data, the study looked at how physical and hydrological factors correlated with species assemblages and richness. This work permitted the identification of physical characteristics that acted as indicators for biological community types. These indicators can be used in management decisions that are part of a larger-scale conservation and management framework or plan.

So far, the results have linked species assemblages to habitats of different temperature and salinity characteristics, geology, and geomorphology. Species richness has been linked to a similar set of characteristics. Ultimately, the most important characteristics can be identified, acting as proxies for the other characteristics, which would streamline the classification process in the future.

The ability to predict characteristics of the biological community from physical factors can greatly benefit conservation and management efforts. Knowing how habitats and communities are linked is just as important for conservation and management efforts as knowing where those habitats are located. The research of Buzeta et al., when considered in conjunction with a standard habitat classification scheme for the entire Gulf of Maine region, could prove to be useful in the effort to protect biodiversity and other ecosystem elements.

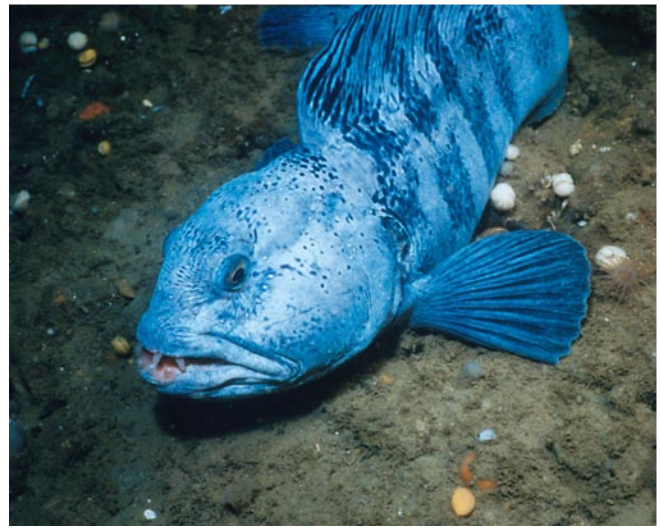
4.2.7 Auster et al. (in progress) Long Island Sound Mapping Effort

In an earlier paper, Auster et al. (2005) used a habitat classification approach to study fish assemblages. The scheme they developed was designed to address the questions in their specific research project and was adapted from elements of preexisting schemes.

This approach reflects how most habitat classification research has been performed to date. It also illustrates how future research efforts could benefit from a regional classification scheme. While it is critical to answer the research questions at the core of a project, the data collected during that single project could have much greater value if integrated into a more universal scheme from which others could benefit.

[11] A species assemblage is the collection of species in a given area or habitat that make up a community.





Peter Auster and Paul Donaldson / National Undersea Research Center, University of Connecticut

The wolf fish (*Anarhichas lupus*) usually is found hiding among rocks. The fish uses a bony plate in its upper mouth to crush its prey—crustacean, shellfish, and echinoderms.

Based on his extensive work on linking classification schemes with management questions—fisheries questions in particular—Auster is now leading an effort in the Long Island Sound region to adapt components of preexisting schemes to address management needs at all levels for local, state, and federal managers.

To date, the project has involved polling managers to determine what questions are most relevant to their needs. The results of the poll are still being compiled, but they indicate a broad range of information needs that cover multiple spatial scales and include habitats from the intertidal to the deep seafloor.

Preliminary consideration by Auster et al. of a number of different schemes, including most of those discussed in this report, has found potential to pursue a combination of the Madden et al. (2005) and Greene et al. (1999) schemes for large- and small-scale classifications, respectively. Given the similarities between the efforts underway in the Long Island Sound region and the habitat classification discussions ongoing in the Gulf of Maine region, close communication between the two groups is encouraged.

5.0 The Issues

5.1 Is a Standard Scheme Needed?

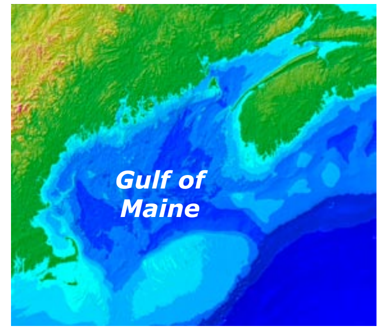
It is necessary to ask whether establishing a standard, one-size-fits-all classification scheme is worthwhile, as opposed to continuing the ad hoc approach currently reflected by the diversity of habitat classification schemes. The complexity and diversity of marine habitats may make it difficult to support a classification scheme that would apply everywhere within a region.

Because one of the biggest obstacles to marine habitat conservation and management is the low availability of data, a standard scheme might allow researchers and managers to collect data using specific guidelines, thereby allowing the development of a common database representing information over a large geographic area. The costs associated with marine habitat research are high; improving researchers' abilities to build from other studies could therefore streamline the advances in our understanding of the marine environment. By improving the comparability between studies, we would, by extension, enhance our management of marine resources. In the end, improved management leads to a more effective balance between use and conservation.

Whether a single scheme could be equally effective for offshore and nearshore habitats has yet to be determined. While a standard approach may be desirable and appropriate for the region, it is possible that the best solution would be two or more complementary schemes that together adequately represent different regimes (i.e., nearshore, offshore, intertidal).

5.2 What Spatial Scale Is Appropriate for the Desired Application?

It is critical that researchers and managers understand the scale of the questions they are asking and of the information that they need. Scale is a dominant issue in the habitat classification structure. How and what information is gathered for habitat classification depends largely on the scale of the question being asked. Some classification schemes are best suited for particular spatial scales. A system that classifies habitats at a resolution suitable for Gulf-scale issues such as harmful algal blooms (HABs) and climate change may not provide adequate information for localized questions about dredging or the siting of a proposed pier. Understanding patterns of Gulf-scale3 currents is critical for managing HABs and planning for the impacts of climate change. Understanding tidal currents at the scale of an estuary, however, can be key for reducing the impacts of dredging a new channel or deciding where to site a new pier.



The classification approach ultimately chosen for the Gulf of Maine—whether standard or otherwise—must be flexible enough to incorporate many different scales. Even without attempts to compare the Gulf of Maine region with other regions, it is essential that studies within the Gulf itself are comparable. Lack of comparability hinders the development of regional conservation and management plans.

5.3 Are Geology and Geomorphology an Appropriate Base for Habitat Classification?

Greene et al. (in press) present this question as a difference between bottom-up classification (i.e., based on geology) and top-down classification (i.e., based on biology).

Nearshore areas such as eelgrass beds and certain intertidal areas tend to be classified primarily based on the biological communities that they support. Offshore communities are commonly classified first by their geological features; then biological characteristics are taken into account.

Greene et al. make the argument that flora and fauna may change significantly as the focus moves offshore and that these elements can be transient compared to the permanency of the geological features in the region. They argue that because geomorphology is much more continuous and permanent it should be the basis of any marine classification scheme. On the other hand, biological components of shallow-water communities are easy to measure, which likely explains why they feature prominently in related classification approaches. Geological features are easier to measure remotely in the marine environment, so they might provide the most suitable foundation for a marine classification framework of offshore areas. In the case of nearshore areas, geological features may provide a foundation for a species assemblage, but other factors (e.g., temperature, salinity, currents) may prove more important in determining the type of habitat and therefore the classification.

Regardless of the choice of primary factors, geology and biology both form integral parts of any habitat definition. Any geology-based classification scheme must include levels of information that incorporate how organisms influence and are influenced by the processes involved in the system. With the growing interest in an ecosystem-approach to management, biological components of ecosystem processes are gaining more prominence in conservation and management plans. Ecosystem functioning relies on the interaction of both physical and biological components for the delivery of ecosystem services. The chosen classification system (or systems) must suitably reflect this interaction.

5.4 What Are the Current and Future Management and Conservation Needs?

Management questions cover a broad spectrum of geographic scales from local to regional to global. Some existing management efforts at the federal level already require habitat information such as essential fish habitat in U.S. fisheries management plans and the ecosystem-based management approach under Canada's Oceans Act. State and provincial managers, along with municipal managers, may also be mandated by existing regulations to have a basic understanding of habitats existing within their jurisdictions.

As ocean zoning and spatial management become increasingly important in marine resource management, habitat mapping stands out as a significant blind spot for managers. It is difficult to adequately plan a resource management and conservation strategy without knowing where the habitats—and resources—are located.

Pressure is increasing to find alternative sources of energy and seafood, while developing existing sources of both. The intersection of existing and future sectors will inevitably result in conflicts over resources as well as space. Balancing competing uses with adequate conservation efforts requires a greater level of information about the habitats in the Gulf of Maine than what is already known.

Ultimately, we need a better understanding of not only where habitats are located but also how they interact as part of an ecosystem and how susceptible specific habitats are to anthropogenic disturbance. The ongoing shift in management towards considering ecosystems as a whole makes this type of information increasingly important.

5.5 What Level or Scale of Information Is Needed by Managers?

A habitat classification effort often results in an extensive database of spatially explicit habitat descriptions. The volume of information available depends largely on the classification scheme used and the scale of the data collected. Such databases often contain more detailed information than an individual manager needs for a specific question or issue. Because of this, information typically is presented for management purposes in the form of a distribution map.

The preliminary polling results of Auster et al. in the Long Island Sound region demonstrated that managers require information at spatial scales from local to regional. Yet the term scale can also refer to the degree of detail in the information generated by classification schemes. While all geographic scales are potentially valuable for conservation and management efforts, the degree of detail provided—or needed—varies according to the intended application.

Is it sufficient to provide end products only to meet management requests, or is there a responsibility to provide greater depth and context in order to better inform management decisions? Answering this question requires an ongoing dialogue, which in turn requires improved communication between researchers and managers, as well as the general public.

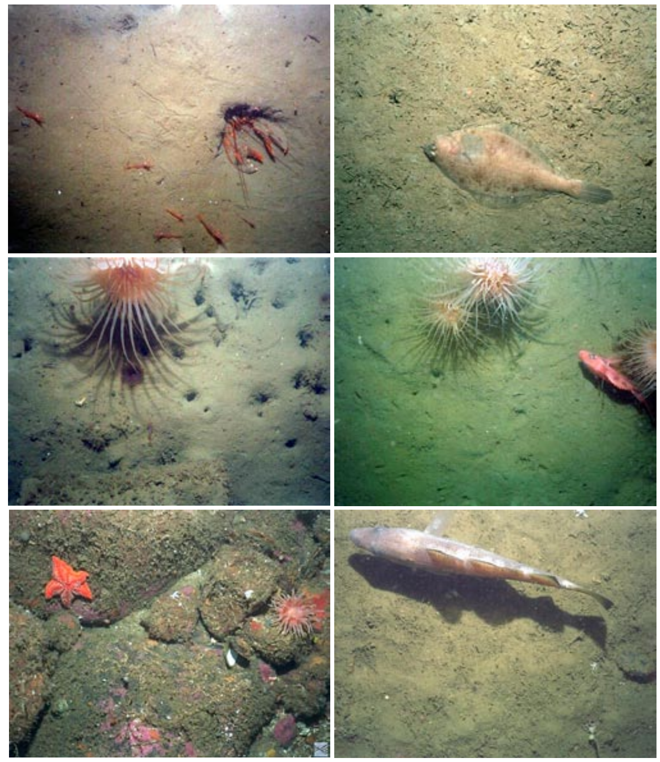
5.6 Should Researchers Tailor Research to Better Inform Managers? If So, How?

It is not surprising that researchers and managers pursue habitat classification for different reasons. Reconciling different goals in order to improve future progress becomes a very important effort towards enhancing the usefulness of habitat classification. Researchers act as purveyors of scientific information on which managers rely, whereas managers act as translators of that information into policies and decisions. Both are important roles in the management and conservation of the ocean ecosystem. Strengthening the links and ongoing communication is essential for good decision-making and for implementing ecosystem-based management.

Managers rely on research to provide answers to management questions. Research does not have the luxury of operating in a vacuum. Yet research questions cannot be restricted to current management issues alone. The nature of science is to pursue lines of questioning that lead to unknown and unforeseen areas of ideas. To check this process could seriously hinder future management efforts that may someday rely on these new ideas.

How can we balance the push and pull of scientific freedom with immediate needs of management? Improved communication is part of the answer, but the question remains an important one for everyone involved in marine habitat classification.

6.0 Recommendations



Clockwise from top left: lobster; flounder; anemones and redfish; cod; sea star and anemone; anemone and burrows.

1. **There are advantages to using a standard classification scheme** for the entire Gulf of Maine region rather than continuing with a number of ad hoc schemes. A regional system that allows flexibility and comparability within the Gulf of Maine region also should have connections with other geographic regions so that comparisons can be made.

2. **It is essential that the chosen approach have the capacity to classify nearshore, offshore, intertidal, seafloor, and pelagic habitats** to be useful for ecosystem-based management. Furthermore, the links among marine habitats and between terrestrial and marine ecosystems are becoming increasingly important to consider. Ensuring that habitats are classified using compatible measures and schemes at the outset will avoid potential problems with integration after data have been collected.

3. **Habitat classification codes should be designed, as much as possible, to facilitate management needs and research needs alike.** Codes are necessary to allow for statistical analysis and to avoid ambiguous descriptions of similar habitats. Generally, a coding system that allows flexibility in how much information is included is preferable to one that needs large amounts of information, which may not be available or necessary for the application.

4. **To facilitate management, a habitat classification scheme should allow for the spatial representation of key ecological characteristics such as resilience and disturbance regimes**. Resilience of habitats to anthropogenic impacts such as fishing, dredging, runoff, and coastal development is of major interest to managers. Resilience should be defined for the geological characteristics (e.g., substrate type) and biological characteristics (e.g., life cycle and sensitivity of organisms) of a given habitat.

5. **Using a standard classification scheme could allow the creation of a common database representing information over a large geographic area.** One of the biggest obstacles to marine habitat conservation and management is the scarcity of data, which is due in part to the high costs of studying marine habitats. Enabling scientists and managers to integrate data from different habitat studies would be helpful to advance understanding of the marine environment. Improving the integration among studies would, by extension, enhance people's capacity to manage marine resources.

6. **The issues raised in this report should be discussed in a venue that allows interaction across multiple sectors and stakeholders.** Identifying common goals for classifying and mapping the Gulf of Maine can mitigate the inevitable questions and issues that will arise during habitat classification efforts.

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